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Where are the Cyborgs in Cybernetics?

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ABSTRACT Cyborgs – cybernetic organisms, hybrids of humans and machines – have pervaded everyday life, the military, popular culture, and the academic world since the advent of cyborg studies in the mid 1980s. They have been a recurrent theme in STS in recent decades, but there are surprisingly few cyborgs referred to in the early history of cybernetics in the USA and Britain. In this paper, I analyze the work of the early cyberneticians who researched and built cyborgs. I then use that history of cyborgs as a basis for reinterpreting the history of cybernetics by critiquing cyborg studies that give a teleological account of cybernetics, and histories of cybernetics that view it as a unitary discipline. I argue that cyborgs were a minor research area in cybernetics, usually classified under the heading of 'medical cybernetics', in the USA and Britain from the publication of Wiener's *Cybernetics* in 1948 to the decline of cybernetics among mainstream scientists in the 1960s. During that period, cyberneticians held multiple interpretations of their field. Most of the research on cybernetics focused on the analogy between humans and machines – the main research method of cybernetics – not the fusion of humans and machines, the domain of cyborgs. Although many cyberneticians in the USA and Britain viewed cybernetics as a 'universal discipline', they created contested, area-specific interpretations of their field under the metadiscourse of cybernetics.

Keywords bionics, cold war, cybernetics, cyborgs, Norbert Wiener, scientific discourse

Where are the Cyborgs in Cybernetics?

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Cyborgs – cybernetic organisms, hybrids of humans and machines – are all around us, pervading everyday life, the military, popular culture, and, since the advent of cyborg studies in the mid 1980s, academic literature (Haraway, 1985, 1997, 2000; Gray et al., 1995). Yet, when researching the history of cybernetics, I was surprised to find few cyborgs in a material or a metaphorical sense in the scientific discipline that gave them their name. Cyborgs are largely absent in the writings of Norbert Wiener, the MIT mathematician who did much to establish the field of cybernetics in the late 1940s and early 1950s, in the discussions at the cybernetics conferences sponsored by the Josiah Macy Jr Foundation from 1946 to 1953, and in the research of physical and social scientists in the USA and Britain who worked in cybernetics from about 1945 to 1970.

The genealogy of the word 'cyborg' is well known (Gray et al., 1995). In 1960, during the height of the Cold War space race, Manfred Clynes,

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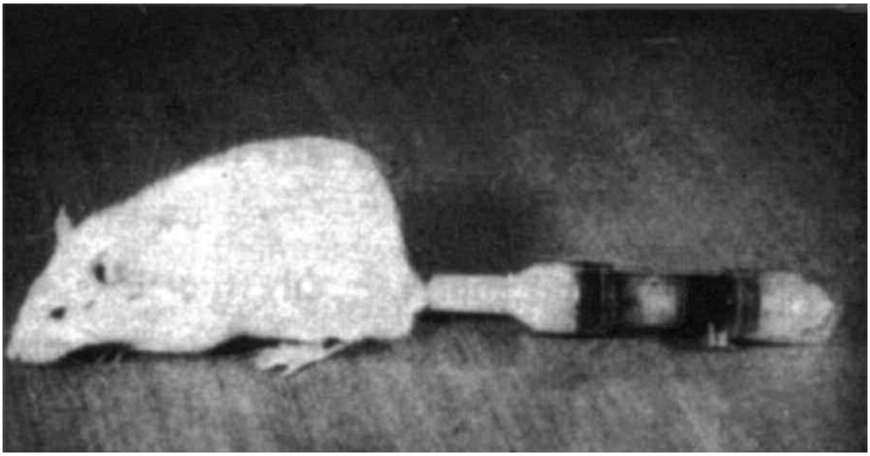
FIGURE 1
Cyborg Mouse with Implanted Osmotic Pump, from Clynes and Kline (1960: 27)



chief research scientist at the Rockland State psychiatric hospital in New York, introduced the term in a paper presented at a military conference on space medicine that he co-authored with Nathan S. Kline, director of research at Rockland and a specialist in therapeutic drugs. 'For the artificially extended homeostatic control system functioning unconsciously, one of us (Manfred Clynes) has coined the term Cyborg. The Cyborg deliberately incorporates exogenous components extending the self-regulatory control function of the organism in order to adapt it to new environments' (Kline & Clynes, 1961: 347–48).[1] Clynes and Kline created the cyborg technique as a means to alter the bodies of astronauts so they could survive the harsh environment of outer space, an alternative to providing an earth-like environment for space travel.

Clynes and Kline introduced the term as an abbreviation for 'cybernetic organism'. They used 'cybernetic' in the sense defined by Wiener, as an adjective denoting the 'entire field of control and communication theory, whether in the machine or in the animal' (Wiener, 1948: 19). At first thought, 'cybernetic organism' seems like a misnomer because all organisms are cybernetic in that they interact with the world through information and feedback control, the key concepts in cybernetics.[2] The usage by Clynes and Kline becomes clearer when we consider the laboratory mouse that they implanted with an osmotic pump (Fig. 1). Drugs are injected into the mouse at a biological rate controlled by feedback. The researcher monitors and sets the rate of the pump (Kline & Clynes, 1961). The mouse and implanted pump is thus a *cybernetically extended organism* – an organism extended by means of cybernetic technology – what they called a cyborg.

In the first part of the essay, I use the terms 'cyborg' and 'cybernetics' in this general manner, while also acknowledging metaphorical uses of the terms, to answer the question: Where are the cyborgs in cybernetics? I focus on the work of early cyberneticians who researched and built cyborgs to explain why cyborgs had a relatively minor place in the early years of cybernetics. In the second part of the essay, I employ that analysis of the cyborg to lay a basis for reinterpreting the history of cybernetics in the USA and Britain. I critique cyborg studies that give a teleological account of cybernetics, and histories of cybernetics that view it as a unitary discipline.

Several studies have reduced the complex history of cybernetics to the science of cyborgs by reading the early years of cybernetics through the lens of cyborg studies, ironically something that Haraway does not do herself.[3] We see this tendency in the review of 'cyborgology' by Gray et al. (1995); in Edwards (1996), who interprets cybernetics and information theory as the basis for a 'cyborg discourse' that supported the 'closed-world discourse' of the computerized Cold War in the USA; in Hayles (1999), especially in her account of the first-wave of cybernetics; and in the *International Encyclopedia of the Social and Behavioral Sciences* (Smelser & Baltes, 2001).[4] The second edition of this classic reference work, published in 1968, has an entry on cybernetics that recounts the wide variety of research performed under that flexible and contested rubric (Maron, 1968). The third edition of the encyclopedia, published in 2001, replaced the entry on cybernetics with one on cyborgs. It describes how the cyborg grew out of Cold War research in cybernetics, the proliferation of cyborgs in science fiction and fact, and how scholars have followed Haraway to embrace the cyborg as an ironic myth for political action (Law & Moser, 2001).

In contrast, Galison's history of the origins of cybernetics in Wiener's wartime research on an anti-aircraft system (Galison, 1994) criticizes Haraway for her attempt to base a postmodern methodology on the cyborg metaphor, for thinking that a cybernetic creature could shed its patriarchal military origins. But his argument that a 'cybernetic vision' of the world, based on the ontology of the enemy pilot, extends from World War II to the present, flattens the history of cybernetics. It reduces its many interpretations to a single, decontextualized Manichean vision that replicates itself expansively during the turbulent course of the Cold War. Kay (2000: chap. 3) and Bowker (1993; 2005: chap. 2) also ignore multiple interpretations of cybernetics and analyze it as a uniform discourse.[5] Kay treats cybernetics as the vehicle to create and popularize an 'information discourse' in post-war molecular biology, and Bowker treats it as a 'universal discipline' or metascience that claimed to subsume all sciences. Despite their differing methodologies, all of these authors describe a uniform, successful, and (for Bowker) a rather atemporal scientific discourse.[6]

I argue, instead, that cyborgs were a minor research area in cybernetics, usually classified under the heading of 'medical cybernetics', in the USA and Britain from the publication of Wiener's *Cybernetics* in 1948, to the decline of cybernetics among mainstream scientists in the 1960s, and that cyberneticians held multiple interpretations of their field. Most of the research on cybernetics focused on the analogy between humans and machines – the main research method of cybernetics – not the fusion of humans and machines – the domain of cyborgs. Most researchers created models of human behavior, rather than enhancing human capabilities through cyborg engineering. Although many cyberneticians in the USA and Britain viewed cybernetics as a 'universal discipline', they created contested, area-specific interpretations of their field under the metadiscourse of cybernetics.

Creating Cyborgs from Cybernetics: A Critique of Hayles

Katherine Hayles's influential book, *How We Became Posthuman*, provides one answer to my question (Where are the cyborgs in cybernetics?) by explaining how cyborgs grew out of cybernetics. Three interrelated themes run through the book: 'how *information lost its body*', 'how *the cyborg was created as a technological artifact and cultural icon*' after World War II, and 'how a historically specific construction called *the human is giving way to a different construction called the posthuman*' (Hayles, 1999: 2, her emphasis). By 'posthuman', Hayles refers to the loss of human subjectivity characteristic of the Enlightenment, not a reconstruction of the body through cyborg engineering.

The construction of the cyborg is tied to her history of cybernetics, which she represents by three overlapping waves: homeostasis (ca. 1945 to 1960); self-organization (ca. 1960–1985); and virtuality (ca. 1985 to the present). Cybernetics 'was formulated as a discipline' in the first wave, reformulated as the radical epistemology 'second-order cybernetics' in the second wave, and is now central to 'contemporary debates swirling around an emerging discipline known as "artificial life"' (Hayles, 1999: 6, 16). The anthropological concept of the skeuomorph – old design elements existing in new designs – explains the morphing from one wave to the next. Hayles admits that her book 'is not meant to be a history of cybernetics'. It leaves out important figures in order to show '*the complex interplays between embodied forms of subjectivity and arguments for disembodiment throughout the cybernetic tradition*' (Hayles, 1999: 6, 7, her emphasis). The skeuomorphs thus mark one trajectory of development in the history of cybernetics.

How are cyborgs created? Although Hayles distinguishes between 'cyborgs in the technical sense' (for example, a human with a pacemaker) and 'metaphoric cyborgs' (for example, a human playing video games), she follows Haraway in viewing the cyborg 'as both technological object and discursive formation' (Hayles, 1999: 115). Hayles argues that Wiener's book, *Cybernetics*, illustrates 'how discourse collaborates with technology to create cyborgs'. For example, a cybernetician proposes an 'electronic or mathematical model' to analyze a physiological tremor. 'Sometimes the model is used to construct a cybernetic mechanism that can be tested experimentally.' The researcher claims discursively that the unknown 'human mechanism' is similar to this homeostatic model. Then,

> cybernetics can be used not only to correct dysfunctions but also to improve normal functioning. As a result, the cyborg signifies something more than a retrofitted human. It points toward an improved hybrid species that has the capacity to be humanity's evolutionary successor. (Hayles, 1999: 118, 119)

TABLE 1
Areas of research and practice in Cybernetics, ca. 1940–1970 (United States and Britain)

	Representative workers
Automation and Control	Wiener, Diebold, Beer, Tsien
Automata and Computers	Ashby, Walter, Shannon, Bigelow
Information Theory	Wiener, Shannon, MacKay
Neurophysiology	McCulloch, Pitts, Lettvin, Walter, Rosenblueth
Biology	Quastler, George
Bioastronautics	Kline and Clynes
Bionics	McCulloch, Von Foerster
Prosthetics	Wiener
Philosophy of Science	Wiener, Rosenblueth, Northrop, MacKay
Psychiatry	Kubie, Bateson
Anthropology & Psychology	Bateson, Mead, Bavelas
Political Science and Politics	Deutsch, Beer
Technology Policy	Wiener, Dechert, Halacy
Management	Diebold, Beer
Music	Pask, Barrons

Sources: Ashby (1952); Bateson (1972); Bavelas (1952); Beer (1969); Dechert (1966); Deutsch (1963); Diebold (1952, 1958); Dunbar-Hester (2009); George (1965); Halacy (1965a, 1965b); Kline & Clynes (1961); Kubie (1953); MacKay (1969); McCulloch (1965); Mead (1951); Northrop (1948); Pask & McKinnon-Wood (1965); Quastler (1953); Rosenblueth et al. (1943, 1949); Shannon (1948, 1952); Tsien (1954); von Foerster (1960, 1963a); Walter (1950, 1951, 1969); Wiener (1948, 1950b, 1964).

What Hayles has done here, I would argue, is to read later concerns about cyborgs as the next step in evolution back into the early history of cybernetics. The move is made possible by a 'present-mindedness' that traces a line of development from the past to the present (Wilson & Ashplant, 1988), represented here as three overlapping waves that proceed in an orderly progression toward the shore of the present. The role of the founders of cybernetics is to set the cybernetic wave in motion, to disembody information so that it can travel across boundaries between the organic and mechanical, to create the material and metaphorical figure of the cyborg. The cyborg can then disrupt old notions about human autonomy, especially in the science fiction analyzed so well in the book.

We obtain a more contextualized answer to the question, Where are the cyborgs in cybernetics? – or to Hayles's question, How did cybernetics generate cyborgs? – if we look at the broader history of cybernetics. Several recent scholars have described an enormous range of research in, and interpretations of, the field of cybernetics in the USA, Europe, and the Soviet Union.[7] That range is evident in Table 1, which lists areas and representative workers in the USA and Britain from circa 1940 to 1970. These men – and almost all of these researchers were men, anthropologist Margaret Mead being a prominent exception as co-editor of the proceedings of the Macy conferences – identified their work as cybernetics, as an application of cybernetics, or as associated with cybernetics. The areas receiving the most attention in American popular media at the time were automation and automata (robots), not cyborgs.[8]

I include information theory as an area of cybernetics in Table 1 because most of my actors did so in the 1950s. In that first age of info-hype, sparked by the popularity of Wiener's *Cybernetics*, a large number of physical and social scientists applied information theory to their fields. These included the areas on my list for cybernetics, as well as physics, statistics, linguistics, economics, organizational sociology, communication studies, and library and information science. By 1960 the followers of Bell Laboratories mathematician Claude Shannon had drawn sharp boundaries around the highly mathematical discipline of information theory in order to protect it from enthusiastic researchers who were applying it non-mathematically to everything from photosynthesis to religion (Kline, 2004).

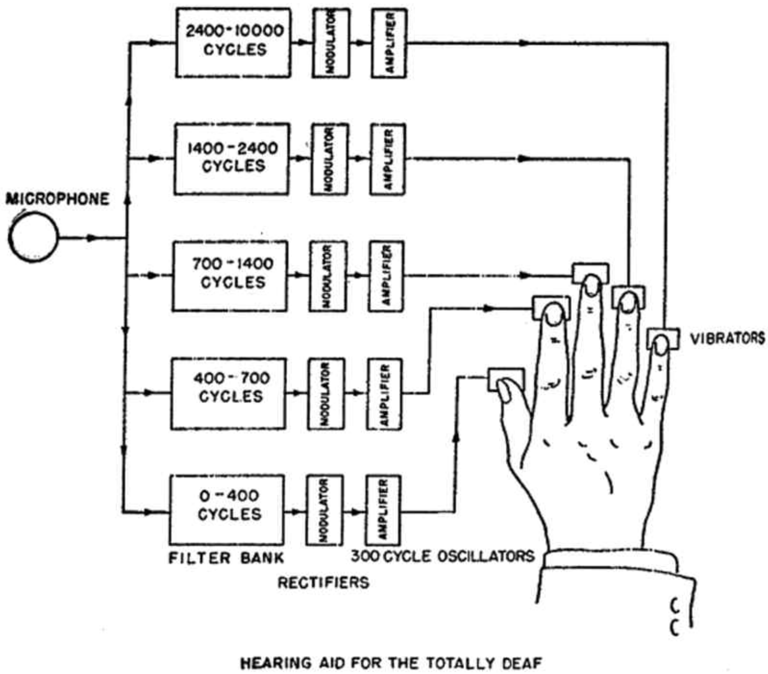
In contrast, the founders of cybernetics had defined themselves as transdisciplinary from the very beginning (Bowker, 1993). The members of the Macy conferences on cybernetics, chaired by Warren McCulloch, a neurophysiologist then at the University of Illinois Medical School, looked to mathematics, control and communication engineering, and the nascent field of computer design for models to apply to the neurological, social, and behavioral sciences (Heims, 1991). After the demise of the Macy conferences in 1953, cyberneticians created other organizations to promote their field: the International Association for Cybernetics, founded in Belgium in 1956; the American Society for Cybernetics, established in 1964; and the Institute of Electrical and Electronics Engineers Professional Group on Systems Science and Cybernetics, founded in 1965. These groups provided institutional support for cybernetics in the USA and Europe, and function to this day.[9]

We can find cyborgs in four areas of cybernetics: prosthetics, bioastronautics, bionics, and technology policy. Later, writers and film directors often blurred the boundaries between robots and cyborgs – in the first *Terminator* movie, for example, where the Cyberdyne System Model 101, identified as a cyborg in the movie, is a 'barely organic' cyborg, 'merely a human skin over a complete robot' (Gray et al., 1995: 2). Early robots in cybernetics included exemplars such as: Wiener's moth/bedbug (Wiener, 1950b: 191–95) and W. Grey Walter's tortoises (Walter, 1950, 1951), which moved toward or away from the light; W. Ross Ashby's homeostat, which simulated the random adaptation of an 'organism' to its 'environment' (Ashby, 1952), and Shannon's electromechanical mouse, which 'learned' to run mazes (Shannon, 1952). But these did not have an organic component and, consequently, would not fall under the (rather broad) scholarly usage of the term 'cyborg' (Gray et al., 1995; Lewis, 1997: 5–7). As noted by Hayles (1999: 141), these early robots were 'cybernetic mechanisms', not cyborgs.

Cyborgs in Cybernetics: Wiener and Prosthetics

Wiener's work on prosthetics was an early area in which a prominent cybernetician combined humans and machines into integrated information systems – what would later be called cyborgs. In February 1949, Wiener

FIGURE 2
MIT's "Felix" Hearing Aid, from Wiener (1950b: 202).



publicly announced that MIT was developing a hearing aid for the deaf (Anonymous, 1949a). The device – which was being developed at MIT's military-funded Research Laboratory of Electronics (RLE), where Wiener advised the communications group – converted spoken sounds into vibrations sensed by a person's fingertips (Fig. 2). In the mechanism, code named Project Felix, a microphone converted sound waves into electrical signals, which were broken up into signals representing five octaves. These were amplified and converted into mechanical vibrations applied to each finger.[10] Theoretically, a unique pattern of vibrations was generated for each phoneme. Once the bugs were worked out of the system, the laboratory, which had built a prototype based on Wiener's suggestions, intended to miniaturize it into a portable hearing glove. Deaf people could improve their speech by comparing the patterns of vibrations they created when speaking into the microphone with those created by non-deaf speakers. Presumably, the device would also act as a regular hearing aid to translate speech into sensory patterns (Wiener, 1950a).

Unfortunately, there were many bugs to be worked out in a device that Wiener had prematurely described in a public lecture and in academic journals (Wiener, 1949; Wiesner, Wiener & Levine, 1949). In December 1949, Wiener again touted the device, this time in a lecture on sensory prosthesis at the American Mathematical Society (Wiener, 1951a). The address drew more media coverage than the talk in February. The *New York Times* (Anonymous, 1949b), an Associated Press newspaper story,[11] and *Life* magazine (Anonymous, 1950: 17) heralded the new wonder coming from the lab of the famous founder of cybernetics.

The bugs lasted from the outset of the project to its demise. In the fall of 1949, the RLE reported that the five-channel system 'failed to differentiate the phonemes adequately', but that a seven-channel unit gave a 'unique pattern for each phoneme'. The project's group studied electrical stimulation of the skin and thought it would work better than mechanical vibrations (Wiesner & Levine, 1949: 55). In January 1950, the group addressed these problems by testing copper electrodes to electrically stimulate a subject's forearm on a seven-channel unit (Wiesner et al., 1950a). In the spring, they used a different type of microphone and added a random-noise generator to tune the device (Wiener et al., 1950b), all to no avail. The group reported that summer that 'Felix has operational shortcomings. Whenever the subject's ability to receive words varied substantially from one test to another, we could not ascertain to what degree this was the fault of the subject or of the equipment' (Wiesner et al., 1950c). Digitizing the amplitude of the signals did not help (Howland et al., 1951).

During this period, MIT and Wiener were kept busy explaining to impatient parents of deaf children, and also to an aged Helen Keller who tried out the device in the lab, that it was still in the experimental stage. Keller wrote Wiener, 'I can never be too grateful when I reflect that you have said the experiments you are trying out for the deaf are the first constructive application of cybernetics to human beings.'[12] Wiener stopped working on Project Felix around the time he severed relations with Jerome Wiesner, associate director of the RLE and the head researcher on the project, in 1951–1952,[13] and the project languished.[14] Wiener also stopped advising a project at the lab to design a photocell device, connected to earphones, as a navigational aid for the blind (Wiener, 1950a: 204–06).

The hearing glove is a good example of what Hayles calls technical cyborgs, although she does not mention the device. Information is extracted from sound waves in a disembodied form so it can travel across the boundary between the machine (the electrical filters) and the organism (the human hand). In fact, Wiener described the glove's operation in terms of 'amount of information', a key concept that he and Shannon had independently developed in information theory (Kline, 2004). Hayles (1999: chap. 3) rightly identifies the theory as the site for the scientific disembodiment of information, a prelude to creating electronic cyborgs. Wiener called the hearing aid an 'artificial external cortex' (Wiener, 1949: 261; 1950b: 201). This is the type of comment that inspired Marshall McLuhan (who admired Wiener[15]) a decade later to talk about telecommunications as the artificial nervous systems that humans wear outside of their bodies (McLuhan, 1964: 43–46, 57, 68).

At the same time he was working on the hearing glove, Wiener started thinking about another way to create cyborgs: artificial homeostasis, the external cybernetic control of a homeostatic physiological function in animals. In

1951 he described the recent invention of a 'mechanical anesthetist' at the Mayo Clinic that automatically regulated the administration of anesthesia to an animal or human based on feedback from an electroencephalogram (EEG). Wiener called it an 'artificial chain of homeostasis combining elements in the body and elements outside', and noted that the principle could be applied in other areas such as medicating the heart (Wiener, 1951b: 66). He later predicted that this form of 'artificial homeostasis' would be used to treat patients with diabetes with insulin (Wiener, 1953: 92–93).

Toward the end of his life (he died in 1964), Wiener worked a great deal in these areas, placing prosthetics and artificial homeostasis in the area of 'medical cybernetics' and the analysis of brain waves, for example, in the area of 'neurocybernetics' (Wiener & Schadé, 1963: 1). In 1965, Ronald Rothchild, a masters student in mechanical engineering at MIT, designed and built an artificial arm controlled by amplified electromyographic (EMG) signals from the amputated muscle. The resulting 'Boston Arm' was inspired by Wiener's ideas on the subject in the early 1960s (Mann, 1997: 402–05; Conway & Siegelman, 2005: 322–24). In 1963, Wiener proposed the idea of implanting a syringe into diabetes patients to give them automatic injections of insulin based on feedback monitoring, which Wiener again referred to as 'artificial homeostasis'.[16] He may have discussed this type of cyborg in conversations he had with a Lockheed scientist on applying cybernetics to space flight earlier in 1963, or with Manfred Clynes at a control-systems conference in Russia in the summer of 1960, when Clynes was in the midst of his research on cyborgs and bioastronautics.[17] What better way to describe the material cyborg, in fact, than an organism with artificial homeostasis?

Bioastronautics: The Cyborg Concept

The debt Manfred Clynes and Nathan Kline, the creators of the cyborg technique, owed to cybernetics is clear. In May 1960, shortly before they delivered their paper to a symposium on the psychophysiological aspects of space flight, held at the Air Force's School of Aviation Medicine in Texas, a reporter asked Kline how they came up with the cyborg concept.

> 'We were asked to present a paper on drugs for space flight', he said, 'and this naturally led to a question of how they would be administered. This would have to be done automatically, of course, and this led us to applications of cybernetics to the problem. From this we established a whole new approach based on adapting the man to the environment rather than keeping him in a sort of environment to which he was naturally adapted.' (Anonymous, 1960a)

Clynes and Kline proposed that humans could endure the rigors of long space flights, to Mars for example, by becoming cybernetically extended organisms. Like the cyborg mouse of Fig. 1, humans would be unconsciously injected with drugs to control their physiological functions – a form of artificial homeostasis – so they could explore the vastness of space without cumbersome space suits and other life-support equipment. Artificial organs would further reduce their physiological needs. Ironically, Clynes and Kline thought that becoming a cyborg in this manner would thus *free* humans from their machines, from all the equipment needed to create an earth-like environment in space. In a recent interview, Clynes said he did not think that joining humans to machines in this manner would change the nature of being human (Gray, 1995a), the concern of science-fiction writers, social scientists, and humanists since the 1960s.

The partner most familiar with cybernetics was Clynes. After receiving a bachelor's degree in physics from the University of Melbourne in 1945, Clynes, an accomplished pianist, took courses on physiological acoustics and psychomotor coordination at the Juilliard School of Music, where he obtained a master's degree in 1949; he then studied the psychology of music on a Fulbright Fellowship. He joined Rockland State Hospital in 1956 as Chief Research Scientist in charge of the Dynamic Simulation Laboratory. At Rockland, Clynes specialized in applying computer techniques and feedback theory to understanding homeostatic physiological functions, a field that was becoming known as 'biocybernetics'.[18] Soon after joining Rockland, he met Warren McCulloch, who had worked at the hospital in the 1930s (Heims, 1991: 129, 133). A major figure in the network of cybernetics following the Macy conferences, McCulloch was impressed with Clynes's research, giving his grant application to the National Science Foundation the highest rating and supporting his application for senior membership in the Institute of Radio Engineers.[19] McCulloch was also impressed with how Kline had put the Rockland hospital on the research map after the war.[20] By 1961, Clynes had published almost a dozen papers on the application of control-system theory to physiology (Clynes, 1961: 969), and Kline was well-known for his work on psychiatric drugs.

Theirs was a fruitful collaboration for creating the radical idea of the cyborg technique for space medicine, of implanting cybernetic devices into astronauts so they could endure long space flights and explore planets. Clynes and Kline called the optimistic enterprise 'participant evolution', and predicted that this human-controlled endeavor would drastically reduce the time it would take natural evolution to adapt humans to the environments of outer space. For them, 'The challenge of space travel to mankind is not only to his technological prowess, it is also a spiritual challenge to take an active part in his own biological evolution' (Kline & Clynes, 1961: 344, 345, 361).

The term 'cyborg' and representations of the space cyborg quickly entered popular culture. A few days before the Air Force symposium at which Clynes and Kline introduced the term in May 1960, the *New York Times* published a layperson's definition of the cyborg in an article about their paper, based on a press release and interviews with the authors. 'A cyborg is essentially a man-machine system in which the control mechanisms of the human portion are modified externally by drugs or regulatory devices so that the being can live in an environment different from the normal one' (Anonymous, 1960a). In July,

FIGURE 3
Vision of Cyborgs on the Moon, from LIFE Magazine (11 July 1960, pp. 77. Artwork by Fred Freeman).

an artist illustrated the futuristic vision of Clynes and Kline for a photo essay in *Life* magazine, nearly a year before the Russians launched the first human into space (Fig. 3). In the drawing, two cyborg astronauts, part-human, part-machine, explore the Moon's surface in skin-tight space suits. Their lips sealed, but their eyes open (probably to give them a more human appearance), the cyborgs 'breathe' by artificial lungs and communicate through radios activated by voice nerves. An array of tubes on their belts infuse chemicals to control homeostatically their blood pressure, pulse, body temperature, and radiation tolerance (Anonymous, 1960b).

The illustration seems to come straight out of a science-fiction novel. Indeed, it was more futuristic than most contemporary science fiction in the USA from the 1930s to the 1950s, which had depicted cyborg-like entities mainly as disembodied brains (Lewis, 1997). One novel published in 1948, *Scanners Live in Vain*, by Cordwainer Smith, did portray entities similar to the cyborgs of Kline and Clynes. In the novel, future humans elect to have their bodies altered as cyborg 'scanners' in order to travel in space. The sensory inputs to their brains are bypassed, so they do not feel pain, and are sent instead to a chest 'brainbox', which the cyborgs continuously monitor (scan) for their physiological conditions while exploring outer space (Lewis, 1997: 79–83). Cyborgs are not depicted as specially-fitted space explorers again in American science fiction until the mid 1960s (pp. 142–48).

Although clearly futuristic, the *Life* illustration accurately depicts the technical proposals made by Clynes and Kline in their 1960 symposium paper. The cyborg concept was too drastic, however, for one reader of *Life*. A self-identified 'technologist' wrote the editor that he 'was profoundly shocked by the inhuman proposal ... for the manufacture of "Cyborgs", artificially de-humanized, mechanized monsters'. The editor reassured him and other readers that 'Cyborgs would be humans with some organs only temporarily altered or replaced by mechanical devices. On returning to earth the devices would be removed and normal body functions restored' (Shelley & Editor, 1960).

Bioastronautics: NASA's Cyborg Study

As radical as these ideas seemed at the time (and perhaps even today), the space-medicine community took them seriously. A trade-journal account of the 1960 Air Force symposium said that most of the participants recommended surrounding astronauts with as much of an earth-like environment as possible, such as breathable air and artificial gravity. But a 'minority report filed by several of the experts questioned whether it might not be wiser to change man, making him more adaptable to space conditions as they are'. A psychologist suggested using hypnosis; a professor of surgery recommended hypothermia. 'The most imaginative alteration in man' was the cyborg concept proposed by Clynes and Kline (Beller, 1960: 38, 40). Another writer described how the 'Cyborg, a man-machine system' would help solve the vexing problem of protecting astronauts from the radiation in outer space. 'A servo-mechanism would signal an increase in radiation count, and trigger the administration of anti-radiation drugs' (David, 1960: 40).

NASA took notice and funded research on the cyborg technique. The United Aircraft Corporation (UAC) in Connecticut presented a proposal to the life sciences unit at NASA's Ames Research Center in April 1962.[21] That August the newly formed Division of Biotechnology and Human Research, a branch of a reorganized Office of Advanced Research and Technology (OART) at NASA headquarters (Pitts, 1985: 78, 80), signed an 8-month contract with UAC's bioastronautics unit to conduct a study of cyborgs in space (David, 1963b: 43). Heading a group of seven researchers, including medical doctors, physiologists, and engineers, director Robert Driscoll issued an interim report in January 1963 and a final report, entitled 'Engineering Man for Space: The Cyborg Study', that May (Driscoll, 1963: I-1, I-3). The nearly 200-page document presented the results of Phase I of the contract, a feasibility study of five aspects of the cyborg concept: artificial organs, hypothermia, drugs, sensory deprivation, and cardiovascular models. Although the study referenced the symposium paper by Kline and Clynes only once (III-28), it explicitly stated their concept of the cyborg technique and its broad implications. 'Circumventing the slow process of natural selection by integrating man with machine makes possible the special man with increased functional capabilities. This is the Cyborg, the cybernetically controlled man who functions servomechanistically to cope with environments he does not fully comprehend' (II-1).

The optimistic goal was introduced in the section on artificial organs (lungs, heart, and kidney). The section concluded, however, that the extensive equipment required to support artificial organs at that time would not permit them to be used in space flights in the near future. 'The real significance of research into artificial organs lies in their use as experimental analogs for substitution into test conditions for evaluation *without* risking human life' (II-33, his emphasis). The report was more optimistic about hypothermia, predicting that the bulky equipment required to support it could be reduced in size and that the process could be automated for space travel within 5 to 15 years (III-17–18). More research was needed on drugs to induce hypothermia and to control the psychophysiology of astronauts (IV-13). The Cyborg Study also argued that sensory deprivation was an important factor to consider because of the recent experience of astronauts orbiting the earth (V-1).

Moving from literature surveys and theoretical speculations to experimental research, UAC built electrical and mechanical models of the human cardiovascular system, which they verified through experiments on animals. The goal was to understand how human physiology fared in simulated space environments, in order to establish a medical basis that could be used to create the type of cyborgs advocated by Clynes and Kline. In this regard, they referred to Clynes's recent research on the biocybernetics of cardiovascular systems (Driscoll, 1963: VI-13).

For Phase II of the Cyborg Study, which began in May 1963 (David, 1963b), the UAC dropped the areas directly related to building cyborgs (artificial organs, hypothermia, and drugs), proposed to continue their work on space medicine (the biocybernetic modeling of cardiovascular and other systems), and offered to design systems that addressed pressing needs of the space program (ways to overcome sensory deprivation and the observed loss of calcium during space flights) (Driscoll, 1963: VII-3). Although the life-support systems contradicted the 'cyborg technique' of Clynes and Kline by providing earth-like environments, the report restated the goals of that technique, albeit in a qualified manner.

> Out of the CYBORG program we will be able to understand considerably more about man, his systems and his subsystems. Methods for augmenting and extending his limitations, which will be compatible with the state of the art and the applicability of man in a space mission[,] will be derived from CYBORG in an effort to obtain the maximum integration of man into a man-machine complex (Driscoll,1963: VII-4).

While the eventual goal of this integration may have been the radically augmented and extended cyborg of Clynes and Kline, the UAC researchers emphasized their plans to conduct long-term research in 'Biocybernetics' (Driscoll, 1963: VII-1), of creating models to study human physiology in simulated space environments. The analogical method resonated well with Wiener's definition of cybernetics. This emphasis is evident in the report's concluding lines. 'A significant number of experiments will be performed on animals and man throughout this program to verify the modeling concepts which have evolved from the CYBORG theory', an allusion to Clynes's biocybernetics papers, not to the cyborg paper of Kline and Clynes. 'In this way CYBORG will have accomplished its mission by providing a better understanding of the biological design of man and relating the impact of this understanding to compatible hardware systems' (Driscoll, 1963: VII-4–5).

Apparently neither the long-term scientific goal nor the short-term design proposals were enough to continue the Cyborg Study. I have found only three references to it after UAC issued the final report on Phase I in May 1963: a brief account in a trade journal of Phase II as an ongoing project (Anonymous, 1963: 89), a speech by Eugene Konecci, director of NASA's Biotechnology and Human Research Division, reviewing NASA projects to an international astronautic congress in September 1964,[22] and a reference to the 'United Aircraft Cyborg Project' in a 1965 book on bionics (Halacy, 1965a: 173). UAC doesn't seem to have issued a report on Phase II.

It is not clear why the project was discontinued,[23] but NASA archives indicate some dissatisfaction with it. In August 1963, 3 months into Phase II, UAC submitted a three-page progress report to Frank Voris, director of the Human Research section of OART, detailing three research projects: in 'biocybernetics' (intensive experiments on blood pressure information sent to a dog's brain); mineral metabolism (early stage of human experiments on loss of calcium under immobilization); and sensory deprivation (proposed human experiments on psychological effects).[24]

The report did not satisfy. Two weeks later, Voris asked three researchers in space medicine – at a private laboratory, the Lockheed Company, and Brooks Air Force Base – to review the Cyborg Study. Voris acknowledged that changes in NASA management during the course of the project had resulted in a change of direction for it, then laid out his concerns. 'Presently there exists in the minds of some of us a question of whether the company has produced results commensurate with the monies spent. Also, there is some doubt as to the capability of the company to successfully pursue further work under this contract.' He asked for their 'expert opinions as to whether the NASA should continue to support this effort', and, if so, to what extent?[25]

Despite these problems, Warren McCulloch, who was an adviser to Voris's division, asked NASA for a copy of the cyborg report in December 1964.[26] McCulloch's involvement is not surprising because of his ubiquitous presence in cybernetics in the USA. More specifically, he was also a member of the Biocybernetics Committee of the Aerospace Medical Association, which Konecci chaired.[27] The fact that Konecci, a proponent of biocybernetics, resigned from NASA in 1964 (Pitts, 1985: 86–87) may help explain the demise of the Cyborg Study. NASA went on to build many cyborgs – the core of its 'manned' space program – but not the type proposed by Clynes and Kline.

Bionics: From Living Prototypes to Prostheses and Human Augmentation

In 1960, the very year that Clynes and Kline coined the term 'cyborg', another Air Force symposium christened a new field with the name 'bionics'. Bionics later became known as the 'engineering term for working on the idea of cyborgs' (Gray, 1995b: 64) and, as an adjective, for a cyborg figure, as in the 'bionic man'. Yet the original purpose of the Cold War discipline of bionics was to imitate organic systems in the design of complex electronic systems, to borrow ideas from 'living prototypes', not to create cyborgs.

The beginnings of bionics owe a debt to the research of McCulloch and Pitts on neural nets, to Wiener on cybernetics, and to the Biological Computer Laboratory at the University of Illinois, established in 1958 by Heinz von Foerster (an Austrian emigre physicist, chief editor of the proceedings of the Macy conferences on cybernetics, and the instigator of Hayles's second wave of cybernetics). The BCL was a small lab; it was not as well known as MIT's Research Laboratory of Electronics, which McCulloch had joined in 1952. Von Foerster used the term 'biological computer' to mean a computer that mimicked the information-processing functions of biological organisms, such as the pattern recognition performed by a frog's eye, the subject of a well-known paper by McCulloch's group at MIT (Lettvin et al., 1959). The Biological Computer Laboratory and other centers of bionics, such as those at Cornell University, Bell Telephone Laboratories, General Electric, and the Radio Corporation of America, sought to build computers from artificial neural nets, not from biological elements (Corneretto, 1960; Von Foerster, 1960).

Von Foerster established the laboratory as a center for cybernetics on the basis of a grant from the Office of Naval Research; it received most of its funding from the Air Force and some from the National Science Foundation (NSF).[28] Ross Ashby was funded by the laboratory after he moved from Britain to join the University of Illinois in 1961 (Von Foerster, 1963b: 1). McCulloch consulted on the project, and his staff at MIT sent electronic neurons to Illinois.[29] Military agencies funded the Illinois lab and other projects in bionics because they thought biological organisms – which had adapted robustly to their environments through evolution – could provide clues on how to solve the reliability problems endemic to the complex electronic systems used to fight the Cold War (Savely, 1961).[30]

Major Jack Steele of the Air Force's Aerospace Medical Division recalls coining the term 'bionics' from Greek roots in the late 1950s to mean 'using principles derived from living systems in the solution of design problems' (Gray, 1995b: 62). Seven-hundred scientists and engineers from several disciplines in the cold-war military–industrial–academic complex attended the first Bionics Symposium, held at the Wright-Patterson Air Force Base in

FIGURE 4
United States Air Force, Wright Air Development Division (1961)


WADD TECHNICAL REPORT 60-600

BIONICS SYMPOSIUM

LIVING PROTOTYPES— THE KEY TO NEW TECHNOLOGY

13-14-15 September 1960

December 1960

DIRECTORATE OF ADVANCED SYSTEMS TECHNOLOGY
WRIGHT AIR DEVELOPMENT DIVISION
AIR RESEARCH AND DEVELOPMENT COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

5,000 – March 1961 – 23-899

Ohio in 1960 (Lipetz, 1961). Steele and John Keto, Chief Scientist at the Wright Air Development Division, organized the symposium, McCulloch chaired a technical session, and von Foerster wrote the preface to the conference proceedings (United States Air Force, Wright Air Development Division, 1961). The Air Force sponsored three more symposia in the 1960s, which popularized bionics as a new area flush with military funding, reported to be $100 million in 1963 (Heinley, 1963: 36).

In his keynote address to the first symposium, Keto said the new science aimed to 'cross-couple the know-how we have achieved, or are achieving, concerning live prototypes toward the solution of engineering problems' (Keto, 1961: 7). In an encyclopedia article on bionics, von Foerster defined it more extensively as:

> a new engineering science that in general applies organizational principles of living organisms to the solution of engineering problems. In particular, it considers living organisms as prototypes in dealing with the theory, circuitry, and technology of information-processing electronic components, systems of such components, and compounds of such systems. (Von Foerster, 1963a: 148)

Thus, the founders of bionics, as well as early workers in the field, did not view bionics as a merger of biology and electronics that produced cyborgs, as implied by later interpretations of the word 'bionics' itself and the symbol chosen for the Air Force symposia: a mathematical integration sign holding a scalpel at one end and a soldering iron at the other (Fig. 4) (Steele, 1961). The present-day cyborgian meaning of bionics, the technological enhancement of humans to give them super-human capabilities, dates to the popular television show, the 'Six Million Dollar Man' in the mid 1970s.[31]

The contrast between the scientific and popular meanings of 'bionics' is evident in one of the experimental projects von Foerster's lab completed in the early 1960s. The Numa-Rete, built in 1961, used a 20×20 array of photo-cells connected to a network of artificial neurons to detect edges of two-dimensional convex objects placed over the cells. By summing the differences in the number of edges detected and dividing, Numa-Rete could 'count' the number of objects in its field of vision (Von Foerster, 1962, 1963b: 5). Von Foerster's lab built the device from elements that resembled biological organisms – electronic neurons – rather than programming a digital computer to simulate perception, the competing method of symbolic Artificial Intelligence (Edwards, 1996: chap. 8).

Most of the participants at the Air Force bionics symposia in the 1960s did this type of research, focusing on the theory of neural nets and self-organizing systems, experiments on pattern and speech recognition in animals and machines, and artificial intelligence, rather than on cyborgs. The few cyborgs that populate the symposia exist on the margins of the conferences, in efforts to design prosthetic devices and human augmentations, often to operate weapons systems. At the first bionics symposium in 1960, Keto noted the military promise of bionics, then listed several 'humanitarian' uses, similar to those proposed by Wiener in the 1950s: 'Prosthetic devices to assist the crippled; aids to the blind to permit them to perform in a more normal fashion; means for restoring man's capabilities that deteriorate with age or due to disease – hearing, seeing and others' (Keto, 1961: 10).

A few instances of this type of cyborg research, termed 'medical bionics' by the Air Force (David, 1963a: 34), were presented at the symposia. At the third symposium in 1963, researchers at the Stanford Research Institute described a way to present spatial images by tactile means to assist jet pilots dealing with information overload (Halacy, 1965a: 172). At the Spacelab company in California, researchers developed a myoelectric servo control system that would enable a pilot to 'move his arm to certain positions in a space capsule under heavy *g* loads' (David, 1963a: 35). The system operated much like a Russian artificial hand (Halacy, 1965a: 146). At the fourth symposium in 1966, a researcher at the Philco Corporation described a joint project with Temple University, funded by the US Vocational Rehabilitation Administration, that used the new technology of integrated circuits to provide pattern recognition on EMG signals to control a powered prosthetic arm (Taylor, 1968: 885).

More research was conducted on prosthetics and human augmentation than that presented at the bionics symposia. The Stanford Research Institute was working on updated versions of Wiener's projects: a tactile hearing aid and a photocell device for navigation by the blind (Halacy, 1965a: 172). The Navy funded a so-called 'amplified man', who would myoelectrically control 'powerful mechanical arms and legs, not with levers and switches, but with thoughts' (Halacy, 1965a: 146–47). The Army funded 'giant walking machines' for soldiers, what contractor General Electric called 'cybernetic anthropomorphic machines' (Halacy, 1965b: 145). In the mid 1960s, NASA and the Atomic Energy Commission funded a study of such 'teleoperators', defining teleoperator as a '*general purpose, dexterous, cybernetic machine*' (Johnsen & Corliss, n.d.: 85, their emphasis). The study noted that GE called the field '*mechanism cybernetics*' (p. 87, their emphasis). Nonmilitary projects included an artificial arm developed at Case Institute of Technology and funded by the US Department of Health, Education, and Welfare, pacemakers, and baropacers to regulate blood pressure (Halacy, 1965a: 146, 150–51).

Daniel Halacy's popular-science book, *Bionics*, included a brief description of these cyborgs and called NASA's Cyborg Study 'an important bionics project' (Halacy, 1965a, 173). He defined bionics as 'the science of machines and systems that work in the manner of living things' (p. 181). The definition was broad enough to include the interpretation of the founders of the field – McCulloch, von Foerster, and Steele – as well as the increasing tendency to view bionics as human augmentation, the science and engineering of cyborgs.

Technology Policy: Social Concerns about Cyborgs

A striking instance of cyborg imagery exists in the personal correspondence between cyberneticians. In April 1969, Walter Pitts wrote his former collaborator on the theory of neural nets, Warren McCulloch, who was in the hospital recovering from a heart attack. 'I understand you had a light coronary ... that you are attached to many sensors connected to panels and alarms continuously monitored by a nurse, and cannot in consequence turn over in bed. No doubt this is cybernetical. But it all makes me most abominably sad.'[32] Walter thought he and Warren could perhaps one day draw up their wheelchairs and chat about old times. I interpret Pitts to mean that being cyborg-like in this manner was of scientific interest, that it was 'cybernetical' and therefore worthy of study. But the human aspect was sad. Pitts died a month later of complications from liver disease (Smalheiser, 2000), followed by McCulloch in September (Pozo-Olano, 1970).

That brings us to the topic of cyborgs as a concern in technology policy, which I'll discuss by comparing two books published in the mid 1960s. Wiener's *God and Golem, Inc.* (Wiener, 1964), a follow-up to *The Human Use of Human Beings* (Wiener, 1950b), discusses three 'points where cybernetics impinges upon religion': machines that learn, machines that reproduce themselves, and the coordination of humans and machines. The latter topic included automation and prosthesis. Wiener thought that a Russian-built artificial arm that operated from the amputee's EMG signals 'really makes use of cybernetical ideas'. He praised it as an example of the 'construction of systems of a mixed nature, involving both human and mechanical parts'. Although Wiener had warned the public for over a decade about the possible adverse consequences of cybernetics, especially through the advent of automatic factories and military applications, and although he had mentioned potential dangers in human augmentation in 1950 (Wiener, 1950b: 195), he did not warn readers of *God and Golem* about the dangers of a 'new engineering of prostheses' (Wiener, 1964: 74, 76).

The thrust of a more sensational, journalistic book, Halacy's *Cyborg – Evolution of the Superman* (Halacy, 1965b), was to educate readers about the promises and dangers of the evolution of humans into cyborgs and the cyborg into a 'superman'. Recognizing that humans have linked themselves with machines for centuries in a cyborg-like manner, Halacy worried about a speed-up in this process in the present. 'For better or for worse we are committed to what Clynes and Kline have termed "participant evolution". Man himself is now an important factor in his own development.' Scientists and engineers had lately turned science fiction into fact by creating artificial arms, pacemakers, and remote-controlled drones. Halacy, who wrote the book *Bionics* mentioned earlier, praised bionics as an 'offshoot science' of cybernetics, one that had a 'more apt and readily understood name'. Although Halacy imagined a bleak future in which cyborgs warred against humans – the theme of the *Terminator* movie 20 years later – he was not worried about the fate of humans. Since we cannot stop participant evolution, he reasoned, it was best to guide it in humane ways (Halacy, 1965b: 15, 41).

The science fiction writer Arthur C. Clarke was even more optimistic:

> I suppose one could call a man in an iron lung a Cyborg, but the concept has far wider implications that this. One day we may be able to enter into temporary unions with any sufficiently sophisticated machines, thus being able not merely to control but to *become* a spaceship or a submarine or a TV network .... when the individual human consciousness is free to roam at will from machine to machine, through all the reaches of sea and sky and space ... . If this eventually happens – and I have given good reasons for thinking that it must – we have nothing to regret, and certainly nothing to fear. (Clarke, 1962: 226–27, his emphasis)

These hopes and fears were amplified and reworked in the 1970s by other science-fiction writers (Lewis, 1997: chap. 6), futurists (for example, Rorvik, 1971; Stritch, 1972), and a budding literature on STS (for example, Krajewski, 1977).

Why are There so Few Cyborgs in Cybernetics?

My detailed account of where the cyborgs are in cybernetics – in prosthetics, bioastronautics, bionics, and technology policy – may leave the impression that cyborgs were a central concern in cybernetics. They were not. I have found only a handful of material cyborgs described in the major cybernetic texts published from 1948 to about 1970. In medicine and physiology, we have Wiener's hearing glove, aids for the blind, and proposals for myoelectrically controlled prosthetic arms and artificial homeostasis; updated versions of these systems in the 1960s (Clark, 1969); the myoelectric control systems presented at the Air Force symposia on bionics; and the now-famous technical report on NASA's Cyborg Study, inspired by the two papers published by Clynes and Kline.

Concerns about cyborgs (in a material and an imaginary sense) were evident in the journalistic literature on the social implications of cybernetics in the 1960s, but most of those who wrote about cybernetics and society up to that time were much more concerned about automation than about cyborgs (for example, Chase, 1950; Dechert, 1966). Only a few cyberneticians worried about cyborgs. I have noted Wiener's warnings about augmentation. John Diebold, the automation expert and US director of the International Cybernetics Association, warned in 1969, 'Even now the creation of "cyborgs" – men with artificial organs – has begun', a prospect that might threaten future generations by bypassing the evolutionary process (Diebold, 1969: 145).

We can find a few cyborgs outside of medicine and physiology by considering assemblages of humans and machines joined together and to their environments cybernetically (through feedback control) in order to perform a non-medical function. British cybernetician Stafford Beer's adaptive computerized management systems for firms (Beer, 1969) are good examples of this type of cyborg, as noted by Pickering (2002: 424). The 'musicolour machine' of Beer's colleague, Gordon Pask, which allowed a performer to interact with a musical instrument via feedback from colored lights keyed adaptively to the instrument's sounds (Pask & McKinnon-Wood, 1965), is also cyborg-like in this manner.

Outside of the writings of Wiener, Diebold, Beer, and Pask, I have found no references to cyborgs in the work of early cyberneticians in the USA and Britain. Cyborgs – whether related to medicine and physiology or not – are not mentioned in McCulloch's collected papers, *Embodiments of Mind* (McCulloch, 1965), von Foerster's publications relating to the Biological Computing Laboratory, Ashby's major works, including *An Introduction to Cybernetics* (Ashby, 1956), or in Gregory Bateson's *Steps to an Ecology of Mind*, which develops an 'epistemology of cybernetics' (Bateson, 1972: 315–19). Cyborgs in medicine and physiology did not turn up in my search of the English-language cybernetics journals through 1971 (*Cybernetica*, est. 1958, and *IEEE Transactions on Systems Science and Cybernetics,* est. 1965), the proceedings of the conference that succeeded the Macy conferences through 1971 (*Proceedings of the International Congress of Cybernetics*, est. 1958), and the *Journal of Cybernetics* during its first three volumes (1971–1973). These serials described a few cyborgs outside of medicine and physiology, the systems of

Beer and Pask. But they were in the minority. The cybernetic publications focused, instead, on automata, neural nets, biological systems, and social systems – not cyborgs – all analyzed under the cybernetic principles of feedback control, homeostasis, and information processing.

Why are there relatively few cyborgs in the first two decades of cybernetics? I would argue that the chief texts of cybernetics in these years are mainly concerned with *analogies* between humans and machines, not the *fusion* of humans and machines. Participants at the Macy conferences talked endlessly about how the human brain and nervous system functioned *like* electronic digital computers and electrical control and communication systems (Heims, 1991). Ross Ashby stated this point clearly at the conference in 1952. 'We can consider the living mouse as being essentially similar to the clockwork mouse and we can use the same physical principles and the same objective method in the study of both' (Ashby, 1953: 73). The method of analogy, of creating models applicable to animate and inanimate beings alike, applied equally to Ashby's homeostat, the research by McCulloch and his colleagues on neural nets, and the entire field of bionics.

The cybernetics journals and proceedings are filled with models, often highly mathematical models, of systems ranging from the cell to society. Ashby carried the method of analogy to such an extreme that he designed the homeostat to copy precisely the adaptive behavior of the brain, not to improve it. ' ... if the living brain fails in certain characteristic ways, then I want my artificial brain to fail too; for such failure would be valid evidence that the model was a true copy' (Ashby, 1952: 130). The method of analogy also held in the lab. Wiener's moth/bedbug modeled a Parkinsonian tremor (Wiener, 1950b: 195). When Wiener and physiologist Arturo Rosenblueth studied a nervous disorder in cats, they spoke in the engineering terms of amount of information and feedback (Rosenblueth et al., 1949). In *Cybernetics and Biology*, British psychologist F.H. George stated flatly that 'Cybernetics is concerned with models' (George, 1965: 30).

The locus classicus of the analogy principle is, of course, Wiener's original definition of cybernetics as 'the entire field of control and communication theory, whether in the machine *or* in the animal' (Wiener, 1948: 19, my emphasis). Although the analogic method of cybernetics blurs the boundaries *between* humans and machines, Wiener did not speak in terms of fusing humans *with* machines when describing the cyborg hearing glove. He only engaged in cyborg talk when describing artificial homeostasis in medicine. Since the main aim of cybernetics was to model existing biological, mechanical, and social systems using the same principles, it is not surprising that the few cyborgs that do exist in cybernetics are found in areas such as prosthetics and bioastronautics, which created new systems combining humans with machines.

From a History of Cyborgs to a History of Cybernetics

The existence of material cyborgs as a minor, mostly medical research area in cybernetics, which included space medicine, points to the criticisms I raised in the introduction about recent studies of cyborgs and cybernetics. In an earlier section, I critiqued Hayles (1999) for reading later social concerns about cyborgs into the early history of cybernetics. In this section, I extend my criticism of histories of cybernetics that ignore the multiple interpretations of that discipline, which I presented briefly in the introduction (Bowker, 1993; Galison, 1994; Kay, 2000: chap. 3). I focus on Bowker's claims about a universal cybernetics discourse in order to propose a basis for reinterpreting the history of cybernetics in the USA and Britain.

In many respects, prominent English-speaking cyberneticians, in the period from about 1945 to 1970, did interpret their new science as 'universal' in the manner analyzed by Bowker. They saw cybernetics as a universal discipline or metascience that provided – through the principles of control and communication engineering – a universal, analogic method that could analyze all complex systems, from the level of the cell to that of society. The universal language of cybernetics, expressed in terms of feedback, control, information, and homeostasis (Gerovitch, 2002, chap 2), enabled researchers to apply cybernetic concepts to the broad range of fields listed in Table 1. And several cyberneticians did use the rhetorical strategy of 'legitimacy exchange' to reciprocally link their field with established disciplines and garner research grants (Bowker, 1993: 116).

Although cyberneticians agreed on the universal character of their field when they engaged in the metadiscourse of cybernetics analyzed by Bowker, they disagreed on many points, even on how to interpret their field. The widespread interest in cybernetics led to multiple meanings of the term. The entry on cybernetics in the second edition of the *International Encyclopedia of the Social Sciences* noted confusion, vagueness, and 'conflicting attitudes toward cybernetics and what its subject matter really is'. The author, M.E. Maron, a researcher in artificial intelligence at the RAND Corporation, identified three major meanings of cybernetics: a collection of information-processing research techniques; automation; and a new science that could analyze all complex systems, 'from machines to society itself', in terms of a common language of information and control (Maron, 1968: 5).

These multiple interpretations existed below the metadiscourse of cybernetics as a universal discipline. At the local level of their own research, workers tended to interpret cybernetics from the point of view of their specialty and social concerns, a point noted by a sociological study of cybernetics conducted in the early 1970s (Apter, 1972: 112). Ironically, most cyberneticians were specialists. McCulloch wrote about the philosophy of cybernetics, but focused his research on neurophysiology (McCulloch, 1965). Von Foerster helped establish the radical epistemology of 'second-order cybernetics' (Hayles, 1999: chap. 6), but conducted his laboratory research on bionics. Ashby considered the heart of cybernetics to be a theory of all machines, organic and inorganic (Ashby, 1956). Philosophers and computer scientists saw cybernetics as synonymous with the theory of automata (Gunderson, 1967; Edwards, 1996: chap. 8), engineers as a synonym for control theory (Tsien, 1954). Diebold specialized in the management side of automation (Diebold, 1952), which was often called 'cybernation' at the time (for example, McLuhan, 1966). Wiener was the exception in crossing over into many areas to promote the new science of cybernetics (see Table 1).

The coinage of specific names for these area-specific meanings – biocybernetics, neurocybernetics, medical cybernetics, behavioral cybernetics, management cybernetics, engineering cybernetics (for example, Rose, 1969) – indicates a level of separation between the subfields of a 'maturing' discipline. In commenting in the early 1980s on an 'Introduction to Neurocybernetics' written by Wiener and Schadé (1963), Ross Ashby gave his interpretation of Wiener's view on these matters. Attributing the first part of the introduction to Wiener, Ashby said 'It discusses the applications of cybernetics to biological phenomena, and makes clear that Wiener in no way thinks of cybernetics as being a simple unifying principle but as a science of ever-expanding content' (Ashby, 1985: 408).

Despite his conception of cybernetics as a wide-ranging science, Wiener recognized some limits to cybernetics and was skeptical about applying it to social sciences like anthropology and economics. He thought they did not have enough consistent data collected over a long enough period of time to use the mathematical techniques for analyzing time-series to make an accurate prediction (Wiener, 1948: 33–34, 189–191; Heims, 1991: 28, 193), the World War II research from which he developed his cybernetic ideas (Masani, 1990: chap. 4; Galison, 1994). Wiener maintained this attitude even after extending cybernetics to social issues in *The Human Use of Human Beings* (Wiener, 1950b).[33]

The extensive enthusiasm for cybernetics did cause problems, leading to a loss of scientific status in the 1960s (Elias, 1997). In a 1969 survey of neurocybernetics, W. Grey Walter observed that a 'peculiar gap between theory and practice is a feature of cybernetics, and may account for the disrepute which has accumulated around the term' (Walter, 1969: 94). Philosopher of science Yehoshua Bar-Hillel explained in 1964 that 'the popularity of "cybernetics" declined rather quickly in the States, probably due to its having been usurped there by overt or covert science-fiction' (Bar-Hillel, 1964: 11), a tendency Wiener had fought against (Wiener, 1956: 270). Maron noted that the vagueness of cybernetics caused a 'pseudoscientific fringe' to make 'nonsensical claims ... under the banner of cybernetics' (Maron, 1968: 5). The sociological study mentioned earlier observed that cybernetics 'seemed to attract a lunatic fringe among scientists, particularly those with a penchant for the obscure and a facility for creating neologisms' (Apter, 1972: 111).

Donald MacKay, a leader of the British school of information theory, had warned Heinz von Foerster of that outcome as early as 1959. Writing confidentially and 'moved by our old friendship' nurtured at a Macy conference, MacKay was dismayed that von Foerster had lent his name to an English organization, ARTORG (Artificial Organism Research Group), which MacKay and his colleagues in the field of information theory and automata in Britain – Colin Cherry, Denis Gabor, and A.M. Uttley – considered to be a fringe group.

> It's for just this kind of reason that folk such as Gabor, Uttley, Cherry & I are chary of using the word 'Cybernetics' nowadays, and I do hope that the work of someone of your calibre won't lose some of the attention it deserves by this new connection. (I assume that you have seen the earlier 'Artorg' sheets? Even Warren [McCulloch] seemed a bit shocked by the one I showed him!).[34]

Information theorists in the USA criticized the hubris often associated with the interdisciplinarity of cybernetics and bionics. In a popular book on information theory, John Pierce at Bell Labs noted that 'few scientists would acknowledge themselves as cyberneticists, save perhaps in talking to those whom they regard as hopelessly uninformed' (Pierce, 1961: 228).[35] In 1962 Edward David Jr, a colleague of Pierce's at Bell Labs, published a satire, inspired by Pierce, on the tendency for physicists and engineers to rush into bionics projects with little or no knowledge of biology or psychology (David, 1962).

At the same time that cybernetics was losing scientific status in the USA and Britain, it became the scientific ideology of the Soviet Union (Elias, 1997; Gerovitch, 2002) and reached cult status in one area of American popular culture. In the late 1960s and early 1970s, Stewart Brand's *Whole Earth Catalog* helped create a 'cybernetic counterculture' by appropriating the interdisciplinary practices in research and development labs, embracing the technological utopianism of Buckminster Fuller, and promoting Bateson's interpretation of cybernetics as a radical epistemology of systems thinking, rather than the science of dehumanizing automation and cold-war militarism (Turner, 2006: chap. 2). While the strategy of legitimacy exchange had lost its value for cyberneticians in scientific circles by the 1960s, it was exploited by the counterculture – which may have hastened its decline among elite scientists.

In all of these ways, asking where the cyborgs are in cybernetics helps us think about early cybernetics in a contextualized, multi-faceted manner, and helps us imagine a history that disengages cyborg studies from cybernetics, one that recognizes multiple interpretations of a discipline that claimed to be universal. In the 1950s and 1960s, cyberneticians and their critics in the USA and Britain contested the meaning of cybernetics, viewed the protean field as separate areas of research, and witnessed a decline in its scientific status. These contestations provide ample material to reinterpret the science, technology, and imagination of cybernetics – the work of scientists, engineers, journalists, and novelists who created a web of relations among humans, machines, and the new concept of information in the Cold War.

Notes

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1. See also Clynes & Kline (1960: 27).
2. A similar point has been made by Gray (1999).
3. In *Modest Witness* (Haraway, 1997), the term 'cyborg' refers to such protean technoscientific objects as the microchip, seed, gene, and OncoMouse™. In a later interview, Haraway placed the genetically engineered mouse alongside the primate and the cyborg as three literal hybrids that 'are also simultaneously figurations involved in a kind of narrative interpellation of ways of living in the world .... So you have animal-human for primate; machine-animal for cyborg; and nature and labor for OncoMouse™' (Haraway,

2000: 140). Earlier, Haraway (1995) analyzed the Terminator, a robot covered with a human skin, as a cyborg figure.

4. Other uses of the cyborg concept in STS include interventionist 'cyborg anthropology' in emerging science and technology (Downey et al., 1995; Downey & Dumit, 1997; Dumit & Davis-Floyd, 1998); critiques of the proliferation of cyborgs (Gray, 1997); and the history of operations research, game theory, and a transformed management science and economics as 'cyborg sciences' in Cold War America (Pickering, 1995; Sent, 2000; Mirowski 2002). For criticisms of cyborg studies, see Galison (1994), Hacking (1998), and Wajcman (2004: chap. 4).
5. Exceptions to this approach are Hayles (1999), who identifies three periods of cybernetics, Pickering (2002), who notes substantial differences in British cybernetics, and Gerovitch (2002), who describes contested meanings of the universal language of cybernetics.
6. Bowker, Edwards, and Kay also conflate cybernetics with information theory, ignoring the intense boundary work performed by American information theorists to exclude cybernetics from their emerging field. See Kline (2004).
7. See Heims (1991), Richardson (1991: chap. 4), Bowker (1993), Galison (1994), Edwards (1996: chap. 6), Kay (2000), Gerovitch (2002), Mindell (2002: chap. 11), Pickering (2002), Light (2003), Mindell et al. (2003), Bowker (2005: chap. 2), and Dunbar-Hester (2009).
8. On the post-war debate on automation, see Bix (2000: chap. 8).
9. The IEEE Professional Group on Systems Science and Cybernetics merged with the IEEE Professional Group on Man-Machine Systems to form the present-day IEEE Society on Systems, Man, and Cybernetics in 1971. See Ferrell (1971).
10. For a photograph of Wiener using the device, see Mann (1997: 434).
11. *Salt Lake City Tribune*, clipping, n.d., ca. January 1950, box 7-110. See also *Boston Globe*, 29 December 1949, clipping in box 25c-378. Both in Norbert Wiener Papers, Institute Archives and Special Collections, MIT Libraries, Cambridge, MA, USA.
12. See, for example, Norbert Wiener to B.M. Frost, 2 March 1949, box 6-93; J.B. Wiesner to K.L. Raheja, 16 September 1949, box 7-104; Wiener to Peter L. McLaughlin, 5 January 1950, box 7-109. On Helen Keller's interest and visit, see Thornton Fry to Wiener, 30 December 1949, box 7-108; and Wiener to Keller, 11 February 1950; and Keller to Wiener, 12 February 1950 (quotation), box 7-111. All in Wiener Papers.
13. Norbert Wiener to President Killian, 2 December 1951, box 10-144; Wiener to J.B. Wiesner, 17 November 1952, box 11-159, and Wiesner to Wiener, 1 December 1952, box 11-160. All in Wiener Papers.
14. Wiener repeated the passage on the hearing device that first appeared in Wiener (1950b: 196–203; 1954: 167–73), and briefly mentioned it as an incomplete project in Wiener (1956: 287).
15. See Marshall McLuhan to Norbert Wiener, 28 March 1951, Wiener Papers, box 9-135; and McLuhan (1951: 31, 34, 92).
16. Norbert Wiener to Scott Allan, 17 July 1963, Wiener Papers, box 23-328.
17. John E. Mangelsdorf to Norbert Wiener, 16 April 1953, box 23-325; Wiener to Mangelsdorf, 22 April 1963, box 23-325; and Manfred Clynes to Wiener, 13 November 1961, box 21-305. All in Wiener Papers.
18. For his definition of the term, see Clynes (1961: 946). For a later usage, see Wiener & Schadé (1964).
19. Arthur W. Martin to Warren McCulloch, 1 June 1959; draft of letter from McCulloch to Martin, n.d. [ca. June 1959]; Manfred Clynes to McCulloch, 4 January 1960; 'Curriculum Vitae [of Clynes]', n.d., ca. January 1960; and McCulloch, recommendation for Clynes, n.d., ca. March 1960, all in Warren McCulloch Papers, American Philosophical Society, Philadelphia, PA, Manfred Clynes Correspondence.
20. Warren McCulloch to Hudson Hoaglund, 13 January 1969, McCulloch Papers, Nathan Kline Correspondence.
21. G. Dale Smith to Richard J. Preston, 12 April 1962; and Smith and Alfred M. Mayo, 'NASA Procurement Request', 24 April 1962, attached to Arthur B. Freeman to Mayo, 25 April 1962. All documents in Records of NASA Ames Research Center, Record Group 255.4.1, Moffet Field, CA, Series 19, Central Files, 1959–1967, box RMO-3.

22. Eugene Konecci, 'Advanced Concepts in Man-Machine Control: A Review', speech, 7–12 September 1964, McCulloch Papers, folder NASA Committee on Biotechnology and Human Research, November 1964, # 1, pp. 42–45.
23. On this score, Gray et al. (1995: 8) say that 'after this study the agency [NASA] seemed almost allergic to the term "cyborg" and instead used more technical, and usually specific, locutions like teleoperators, human augmentation, biotelemetry, and bionics'.
24. R.T. Allen to Frank Voris, 27 August 1963, Ames Research Center Records, Series 19, Central Files, 1959–1967, box RMO-5.
25. Frank B. Voris to James D. Hardy, 9 September 1963, Ames Research Center Records, Series 19, Central Files, 1959–1967, box RMO-5.
26. G.M. McDonnel to Warren McCulloch, 14 December 1964, McCulloch Papers, folder NASA Committee on Biotechnology and Human Research, March 1965, # 3.
27. Eugene Konecci to Warren McCulloch, 29 April 1966, NASA folder, McCulloch Papers.
28. On receiving the initial ONR grant, see Marshall Yovits to Heinz von Foerster, 30 December 1957, Heinz von Foerster Papers, University Archives, University of Illinois, Urbana, IL, box 7-McCulloch.
29. Warren McCulloch to Heinz von Foerster, 7 November 1957, box 7-McCulloch; and von Foerster to Jerome Lettvin, 20 March 1958, box 7-Lettvin, both in von Foerster Papers.
30. On reliability problems due to complex aircraft systems, see Downer (2006).
31. See *Oxford English Dictionary*, online edition, s.v., 'bionic'.
32. Walter Pitts to Warren McCulloch, 21 April 1969, McCulloch Papers, Walter Pitts Correspondence.
33. See, for example, Norbert Wiener to Waldo Frank, 21 November 1950, Wiener Papers, box 9-130.
34. Donald MacKay to Heinz von Foerster, 25 May 1959, Von Foerster Papers, box 7, MacKay folder. On ARTORG, see Cordeschi & Numerico (2003).
35. On Pierce's satirical remarks on cybernetics and criticisms of Wiener, see Kline (2004).

References

Anonymous (1949a) 'Code Device May Aid Deaf', *New York Times* (19 February): 9.

Anonymous (1949b) '"Hearing Fingers" May Soon Aid Deaf', *New York Times* (29 December): 3.

Anonymous (1950) 'U.S. Science Holds Its Biggest Powwow', *Life* 28 (9 January): 17–23.

Anonymous (1960a) 'Spaceman is Seen as Man-Machine', *New York Times* (21 May): 31.

Anonymous (1960b) 'Man Remade to Live in Space', *Life* 49 (11 July): 77–78.

Anonymous (1963) 'Biotechnology Research Pushed by Big Companies', *Missiles and Rockets* 13 (25 November): 83–84, 86, 88–89.

Apter, Michael J. (1972) 'Cybernetics: A Case Study of a Scientific Subject-complex', in Paul Halmos (ed.), *The Sociology of Science*, *Sociological Review Monograph 18* (University of Keele): 93–115.

Ashby, W. Ross (1952) *Design for a Brain* (London: Chapman & Hall).

Ashby, W. Ross (1953) 'Homeostasis [with discussion]', in Heinz von Foerster, Margaret Mead & Hans L. Teuber (eds), *Cybernetics*: *Circular Causal and Feedback Mechanisms in Biology and Social Systems*. *Transactions of the Ninth Conference*, *March 20–21, 1952*, *New York, NY* (New York: Macy Foundation): 73–108.

Ashby, W. Ross (1956) *An Introduction to Cybernetics* (London: Chapman and Hall).

Ashby, W. Ross (1985) 'Comments on the Homeostasis-theoretic Papers of Wiener ... ', in Pesi R. Masani (ed.), *Norbert Wiener*, *Collected Works with Commentaries*, 4 vols. (Cambridge MA: MIT Press) 4: 407–08.

Bar-Hillel, Yehoshua (1964) 'Introduction', in Bar-Hillel, *Language and Information*: *Selected Essays on Their Theory and Application* (Reading, MA: Addison-Wesley): 1–16.

Bateson, Gregory (1972) *Steps to an Ecology of Mind*: *Collected Essays in Anthropology*, *Psychiatry*, *Evolution*, *and Epistemology* (San Francisco, CA: Chandler).

Bavelas, Alex (1952) 'Communication Patterns in Problem-solving Groups [with discussion]', in Heinz von Foerster, Margaret Mead & Hans L. Teuber (eds), *Cybernetics: Circular Causal and Feedback Mechanisms in Biology and Social Systems. Transactions of the Eighth Conference, March 15–16, 1951, New York, NY* (New York: Macy Foundation): 1–44.

Beer, Stafford (1969) 'Epilogue: Prospects of the Cybernetic Age', in J. Rose (ed.), *Survey of Cybernetics*: *A Tribute to Dr. Norbert Wiener* (London: Iliffe): 356–59.

Beller, William (1960) 'Ways Sought to Ease Ordeal of Space', *Missiles and Rockets* 6 (13 June): 38–40.

Bix, Amy S. (2000) *Inventing Ourselves Out of Jobs*? *America's Debate over Technological Unemployment, 1929–1981* (Baltimore, MD: Johns Hopkins University Press).

Bowker, Geoffrey C. (1993) 'How to be Universal: Some Cybernetic Strategies, 1943–1970', *Social Studies of Science* 23: 107–27.

Bowker, Geoffrey C. (2005) *Memory Practices in the Sciences* (Cambridge, MA: MIT Press).

Chase, Stuart (1950) 'The Next Industrial Revolution: An Age of Machines that Think [review of *The Human Use of Human Beings*]', *New York Herald Tribune Book Review* (20 August): 5.

Clark, J.H. (1969) 'Medical Cybernetics', in J. Rose (ed.), *Survey of Cybernetics: A Tribute to Dr. Norbert Wiener* (London: Iliffe): 109–42.

Clarke, Arthur C. (1962) *Profiles of the Future*: *An Inquiry into the Limits of the Possible* (New York: Harper & Row).

Clynes, Manfred E. (1961) 'Unidirectional Rate Sensitivity: A Biocybernetic Law of Reflex and Humoral Systems as Physiologic Channels of Control and Communication', *Annals of the New York Academy of Sciences* 92: 946–69.

Clynes, Manfred E. & Nathan S. Kline (1960) 'Cyborgs and Space', *Astronautics* 5(9): 26–27, 74–76.

Conway, Flo & Jim Siegelman (2005) *Dark Hero of the Information Age*: *In Search of Norbert Wiener, the Father of Cybernetics* (New York: Basic Books).

Cordeschi, Roberto & Teresa Numerico (2003) 'ARTORGA: The Artificial Organisms Research Group and Ashby's Legacy', Pisa, Italy, available at <www.slidefinder.net/A/ARTORGA_Artificial_Organisms/Research_Group_and/Ashby_s_legacy/586652> (accessed 11 December 2008).

Corneretto, Alan (1960) 'Electronics Learns from Biology', *Electronic Design* 8 (14 September): 38–54.

David, Edward E. Jr (1962) 'Bionics or Electrology?' *IEEE Transactions on Information Theory* 8: 74–77.

David, Heather M. (1960) 'Drugs May Halve Radiation Damage', *Missiles and Rockets* 7 (26 September): 39–40.

David, Heather M. (1963a) 'Symposium Points to More AF Emphasis on Hardware', *Missiles and Rockets* 12 (1 April): 41, 43.

David, Heather M. (1963b) 'UAC Cyborg Study in Second Phase', *Missiles and Rockets* 12 (13 May): 41, 43.

Dechert, Charles R. (ed.) (1966) *The Social Impact of Cybernetics* (New York: Simon and Schuster).

Deutsch, Karl (1963) *The Nerves of Government*: *Models of Political Communication and Control* (New York: Free Press of Glencoe).

Diebold, John (1952) *Automation*: *The Advent of the Automatic Factory* (New York: D. Van Nostrand).

Diebold, John (1958) 'Education for Data Processing: The Real Challenge to Management', *Cybernetica* 1: 32–38.

Diebold, John (1969) *Man and the Computer*: *Technology as a Agent of Social Change* (New York: Praeger).

Downer, John R. (2006) *The Burden of Proof*: *Regulating Reliability in Civil Aviation*, PhD Dissertation, Department of Science & Technology Studies, Cornell University.

Downey, Gary L. & Joseph Dumit (1997) 'Locating and Intervening: An Introduction', in Gary L. Downey & Joseph Dumit (eds), *Cyborgs and Citadels*: *Anthropological Interventions in Emerging Sciences and Technologies* (Santa Fe, NM: School of American Research Press): 5–29.

Downey, Gary L., Joseph Dumit & Sarah Williams (1995) 'Cyborg Anthropology', in Chris H. Gray (ed.), *The Cyborg Handbook* (New York & London): 341–46.

Driscoll, Robert W. (ed.) (1963) 'Engineering Man for Space: The Cyborg Study', Final Report [on NASA Contract] NASw-512, Corporate Systems Center, United Aircraft, Farmington, CT, 15 May.

Dumit, Joseph & Robbie Davis-Floyd (1998) 'Children of the Third Millennium', in Robbie Davis Floyd & Joseph Dumit (eds), *Cyborg Babies*: *From Techno-sex to Techno-tots* (New York and London: Routledge): 1–18.

Dunbar-Hester, Christina (2009) 'Listening to Cybernetics: Music, Machines, Nervous Systems, 1950–1980', *Science*, *Technology*, *and Human Values* (In the Press).

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

Elias, Peter (1997) 'The Rise and Fall of Cybernetics in the US and the USSR', *Proceedings of Symposia in Pure Mathematics* 60: 21–29.

Ferrell, William R. (1971) 'Editorial', *IEEE Transactions on Systems*, *Man*, *and Cybernetics* 1(1): 1.

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

George, F.H. (1965) *Cybernetics and Biology* (San Francisco, CA: W.H. Freeman).

Gerovitch, Slava (2002) *From Newspeak to Cyberspeak*: *A History of Soviet Cybernetics* (Cambridge, MA: MIT Press).

Gray, Chris H. (1995a) 'An Interview with Manfred Clynes', in Chris H. Gray (ed.), *The Cyborg Handbook* (New York & London: Routledge): 43–53.

Gray, Chris H. (1995b) 'An Interview with Jack E. Steele', in Chris H. Gray (ed.), *The Cyborg Handbook* (New York & London: Routledge): 61–69.

Gray, Chris H. (1997) *Postmodern War*: *The New Politics of Conflict* (New York: Guilford Press).

Gray, Chris H. (1999) 'Human-Machine Systems in Space: The Construction of Progress', paper presented at the annual meeting of the American Historical Association, Washington, DC, available at <http://chrishablesgray.org/CyborgCitizen/nasa.html> (accessed 11 December 2008).

Gray, Chris H., Steven Mentor & Heidi J. Figueroa-Sarriera (1995) 'Cyborgology: Constructing the Knowledge of Cybernetic Organisms', in Chris H. Gray (ed.) *The Cyborg Handbook* (New York & London: Routledge): 1–14.

Gunderson, Keith (1967) 'Cybernetics', in P. Edwards (ed.), *Encyclopedia of Philosophy* (New York: Macmillan): 1: 280–84.

Hacking, Ian (1998) 'Canguilhem amid the Cyborgs', *Economy and Society* 27: 202–16.

Halacy, Daniel S. Jr (1965a) *Bionics*: *The Science of* '*Living*' *Machines* (New York: Holiday House).

Halacy, Daniel S. Jr (1965b) *Cyborg – Evolution of the Superman* (New York: Harper & Row).

Haraway, Donna J. (1985) 'A Manifesto for Cyborgs: Science, Technology, and Socialist Feminism in the 1980s', *Socialist Review* 80: 65–108.

Haraway, Donna J. (1995) 'Cyborgs and Symbionts: Living Together in the New World Order', in Chris H. Gray (ed.), *The Cyborg Handbook* (New York & London: Routledge): xi–xx.

Haraway, Donna J. (1997) *Modest_Witness@Second Millennium.FemaleMan©_Meets OncoMouse™*: *Feminism and Technoscience* (New York & London: Routledge).

Haraway, Donna J. (2000) *How Like a Leaf*: *An Interview with Thyrza Goodeve* (New York: Routledge).

Hayles, N. Katherine (1999) *How We Became Posthuman*: *Virtual Bodies in Cybernetics*, *Literature*, *and Informatics* (Chicago, IL: University of Chicago Press).

Heims, Steve J. (1991) *The Cybernetics Group* (Cambridge, MA: MIT Press).

Heinley, David R. (1963) 'The Role of Biology in the Instrumentation Industry', *American Institute of Biological Sciences Bulletin* 13: 35–37.

Howland, B., O.H. Strauss & J.B. Wiesner (1951) 'Felix (Sensory Replacement)', MIT, Research Laboratory of Electronics, *Quarterly Progress Report*, 15 January: 75–76.

Johnsen, Edwin G. & William R. Corliss (n.d.) 'Teleoperators and Human Augmentation', NASA [Report] SP-5047, An AEC-NASA Technology Survey, reprinted in Chris H. Gray (ed.), *The Cyborg Handbook* (New York & London: Routledge 1995): 83–92.

Kay, Lily (2000) *Who Wrote the Book of Life? A History of the Genetic Code* (Palo Alto, CA: Stanford University Press).

Keto, John (1961) 'Keynote Address', in *Living Prototypes–The Key to New Technology* [*Proceedings of the First*] *Bionic Symposium*, *September 13–15, 1960*, WADD Technical Report 60-600, December 1960 (Wright-Patterson Air Force Base, OH): 7–12.

Kline, Nathan S. & Manfred Clynes (1961) 'Drugs, Space, and Cybernetics: Evolution to Cyborgs', in Bernard E. Flaherty (ed.), *Psychophysiological Aspects of Space Flight* (New York: Columbia University Press): 345–71.

Kline, Ronald R. (2004) 'What Is Information Theory a Theory Of? Boundary Work among Information Theorists and Information Scientists in the United States and Britain during the Cold War', in W. Boyd Rayward & Mary Ellen Bowden (eds), *The History and Heritage of Scientific and Technical Information Systems*: *Proceedings of the 2002 Conference*, *Chemical Heritage Foundation* (Medford, NJ: Information Today): 15–28.

Krajewski, Kathleen M. (1977) 'Scientists and Social Responsibility: University of Delaware, July 1975 [A Conference Report]', *Technology and Culture* 18: 56–61.

Kubie, Lawrence (1953) 'The Place of Emotions in the Feedback Concept [with discussion]', in Heinz von Foerster, Margaret Mead & Hans L. Teuber (eds), *Cybernetics*: *Circular Causal and Feedback Mechanisms in Biology and Social Systems*. *Transactions of the Ninth Conference*, *March 20–21, 1952, New York*, *NY* (New York: Macy Foundation): 48–72.

Law, John & Ingunn Moser (2001) 'Cyborg', in Neil J. Smelser & Paul B. Baltes (eds), *International Encyclopedia of the Social & Behavioral Sciences*, 3rd edn (Amsterdam: Elsevier) 5: 3202–04.

Lettvin, J.Y., H.R. Maturana, W.S. McCulloch & W.H. Pitts (1959) 'What the Frog's Eye Tells the Frog's Brain', *Proceedings of the Institute of Radio Engineers* 47: 1940–51.

Lewis, Barbara J. (1997) *Human Machines*: *The Treatment of the Cyborg in American Popular Fiction and Film*, PhD Dissertation, New York University.

Light, Jennifer S. (2003) *From Warfare to Welfare*: *Defense Intellectuals and Urban Problems in Cold War America* (Baltimore, MD: Johns Hopkins University Press).

Lipetz, Leo E. (1961) 'Bionics', *Science* 133: 588, 590, 592–93.

MacKay, Donald M. (1969) *Information*, *Mechanism*, *and Meaning* (Cambridge, MA: MIT Press).

Mann, Robert W. (1997) 'Sensory and Motor Prostheses in the Aftermath of Wiener', *Proceedings of Symposia in Applied Mathematics* 52: 401–39.

Maron, M.E. (1968) 'Cybernetics', in *International Encyclopedia of the Social Sciences*, 2nd edn, vol. 4: 3–6.

Masani, Pesi R. (1990) *Norbert Wiener, 1894–1964* (Basel: Birkhauser).

McCulloch, Warren (1965) *Embodiments of Mind* (Cambridge, MA: MIT Press).

McLuhan, Marshall (1951) *The Mechanical Bride*: *Folklore of Industrial Man* (New York: Vanguard Press).

McLuhan, Marshall (1964) *Understanding Media*: *The Extensions of Man* (New York: McGraw-Hill).

McLuhan, Marshall (1966) 'Cybernation and Culture', in Charles R. Dechert (ed.), *The Social Impact of Cybernetics* (New York: Simon and Schuster): 95–108.

Mead, Margaret (1951) 'Experience in Learning Primitive Languages Through the Use of Learning High Level Linguistic Abstractions [with discussion]', in Heinz von Foerster, Margaret Mead & Hans L. Teuber (eds), *Cybernetics*: *Circular Causal and Feedback Mechanisms in Biology and Social Systems*. *Transactions of the Seventh Conference*, *March 23–24, 1950, New York*, *NY* (New York: Macy Foundation): 159–85.

Mindell, David A. (2002) *Between Human and Machine*: *Feedback*, *Control*, *and Computing before Cybernetics* (Baltimore, MD: Johns Hopkins University Press).

Mindell, David A., Jérôme Segal & Slava Gerovitch (2003) 'From Communications Engineering to Communications Science: Cybernetics and Information Theory in the United States, France, and the Soviet Union', in Mark Walker (ed.), *Science and Ideology*: *A Comparative History* (London: Routledge): 66–96.

Mirowski, Philip (2002) *Machine Dreams*: *Economics Becomes a Cyborg Science* (Cambridge: Cambridge University Press).

Northrop, F.S.C. (1948) 'The Neurological and Behavioristic Psychological Basis of the Ordering of Society by Means of Ideas', *Science* 107: 411–17.

Pask, Gordon A. & Thomas R. McKinnon-Wood (1965) 'Interaction between Man and an Adaptive Machine', *Proceedings of the Third International Congress on Cybernetics, Namur, September 11–15, 1961* (Namur: Association Internationale de Cybernétique): 951–64.

Pickering, Andrew (1995) 'Cyborg History and the World War II Regime', *Perspectives on Science* 3: 1–48.

Pickering, Andrew (2002) 'Cybernetics and the Mangle: Ashby, Beer, and Pask', *Social Studies of Science* 32: 413–37.

Pierce, John R. (1961) *Symbols, Signals and Noise: The Nature and Process of Communication* (New York: Harper and Brothers).

Pitts, John A. (1985) *The Human Factor: Biomedicine in the Manned Space Program to 1980* (Washington, DC: NASA).

Pozo-Olano, Juan de Dios (1970) 'Warren Sturgis McCulloch (1898–1969)', *Journal of the Neurological Sciences* 10: 414–16.

Quastler, Henry (ed.) (1953) *Essays on the Use of Information Theory in Biology* (Urbana, IL: University of Illinois Press).

Richardson, George P. (1991) *Feedback Thought in Social Science and Systems Theory* (Philadelphia, PA: University of Pennsylvania Press).

Rorvik, David M. (1971) *As Man Becomes Machine: The Evolution of the Cyborg* (Garden City, NJ: Doubleday).

Rose, J. (ed.) (1969) *Survey of Cybernetics: A Tribute to Dr. Norbert Wiener* (London: Iliffe).

Rosenblueth, Arturo, Norbert Wiener & Julian Bigelow (1943) 'Behavior, Purpose and Teleology', *Philosophy of Science* 10: 18–24.

Rosenblueth, Arturo, Norbert Wiener, Walter Pitts & J. Garcia (1949) 'A Statistical Analysis of Synaptic Excitation', *Journal of Cellular and Comparative Physiology* 34: 173–206.

Savely, Harvey E. (1961) 'Air Force Research on Living Prototypes', in *Living Prototypes – the Key to New Technology* [*Proceedings of the First*] *Bionic Symposium, September 13–15, 1960*, WADD Technical Report 60-600, December 1960 (Wright-Patterson Air Force Base, OH): 41–47.

Sent, Esther-Mirjam (2000) 'Herbert A. Simon as a Cyborg Scientist', *Perspectives on Science* 8: 380–405.

Shannon, Claude E. (1948) 'A Mathematical Theory of Communication', *Bell System Technical Journal* 27: 379–423, 623–56.

Shannon, Claude E. (1952) 'Presentation of a Maze-solving Machine [with discussion]', in Heinz von Foerster, Margaret Mead & Hans L. Teuber (eds), *Cybernetics: Circular Causal and Feedback Mechanisms in Biology and Social Systems. Transactions of the Eighth Conference, March 15–16, 1951, New York, NY* (New York: Macy Foundation): 173–180.

Shelley, Joseph & Editor (1960) 'Man and Cyborgs' [letter to editor and response]', *Life* 49 (1 August): 9.

Smalheiser, Neil R. (2000) 'Walter Pitts', *Perspectives in Biology and Medicine* 43: 217–26.

Smelser, Neil J. & Paul B. Baltes (eds) (2001) *International Encyclopedia of the Social & Behavioral Sciences*, 3rd edn (Amsterdam: Elsevier).

Steele, Jack E. (1961) 'How Do We Get There?' in *Living Prototypes – The Key to New Technology* [*Proceedings of the First*] *Bionic Symposium, September 13–15, 1960*, WADD Technical Report 60-600, December 1960 (Wright-Patterson Air Force Base, OH): 487–90.

Stritch, Thomas (1972) 'The Banality of Utopia', *The Review of Politics* 34(1): 103–06.

Taylor, Donald R. Jr (1968) 'A Bioelectric Pattern Recognition Control for Prosthesis', in *Bionics Symposium 1966, Cybernetic Problems in Bionics* (New York: Gordon and Breach): 885–93.

Tsien, Hsue Shen (1954) *Engineering Cybernetics* (New York: McGraw-Hill).

Turner, Fred (2006) *From Counterculture to Cyberculture: Stewart Brand, the Whole Earth Network, and the Rise of Digital Utopianism* (Chicago, IL: University of Chicago Press).

United States Air Force, Wright Air Development Division (1961) *Living Prototypes – The Key to New Technology* [*Proceedings of the First*] *Bionic Symposium, September 13–15, 1960,* WADD Technical Report 60-600, December 1960 (Wright-Patterson Air Force Base, OH).

Von Foerster, Heinz (1960) 'Some Aspects of the Design of Biological Computers', in *Proceedings of the Second International Congress on Cybernetics, Namur, September 3–10, 1958* (Namur: Association Internationale de Cybernétique): 240–55.

Von Foerster, Heinz (1962) 'Biological Ideas for the Engineer', *New Scientist* 15: 306–09.

Von Foerster, Heinz (1963a) 'Bionics', in *McGraw-Hill Yearbook of Science and Technology* (New York: McGraw-Hill): 148–51.

Von Foerster, Heinz (1963b) 'Final Report [on ONR contact Nonr 1834(210],' Electrical Engineering Research Laboratory, Engineering Experiment Station, University of Illinois (31 December).

Wajcman, Judy (2004) *Technofeminism* (Cambridge, MA: Polity).

Walter, W. Grey (1950) 'An Imitation of Life', *Scientific American* 182(5): 42–45.

Walter, W. Grey (1951) 'A Machine that Learns', *Scientific American* 185(8): 60–63.

Walter, W. Grey (1969) 'Neurocybernetics (Communication and Control in the Living Brain)', in J. Rose (ed.), *Survey of Cybernetics: A Tribute to Dr. Norbert Wiener* (London: Iliffe): 93–108.

Wiener, Norbert (1948) *Cybernetics: Or Control and Communication in the Animal and the Machine* (Cambridge, MA, & New York: Technology Press and John Wiley).

Wiener, Norbert (1949) 'Sound Communication with the Deaf', *Philosophy of Science* 16: 260–62.

Wiener, Norbert (1950a) 'Sensory Prosthesises [sic] [with discussion]', in Heinz von Foerster (ed.), *Cybernetics: Circular Causal and Feedback Mechanisms in Biology and Social Systems. Transactions of the Sixth Conference, March 24–25, 1949, New York, NY* (New York: Macy Foundation): 203–07.

Wiener, Norbert (1950b) *The Human Use of Human Beings: Cybernetics and Society* (Boston, MA: Houghton Mifflin).

Wiener, Norbert (1951a) 'Problems of Sensory Prosthesis', *Bulletin of the American Mathematical Society* 57: 27–35.

Wiener, Norbert (1951b) 'Homeostasis in the Individual and Society', *Journal of the Franklin Institute* 251: 65–68.

Wiener, Norbert (1953) 'The Concept of Homeostasis in Medicine', *Transactions and Studies of the College of Physicians of Philadelphia* 20: 87–93.

Wiener, Norbert (1954) *The Human Use of Human Beings: Cybernetics and Society*, 2nd edn (Garden City, NJ: Doubleday).

Wiener, Norbert (1956) *I Am a Mathematician: The Later Life of a Prodigy* (New York: Doubleday).

Wiener, Norbert (1964) *God and Golem, Inc. A Comment on Certain Points where Cybernetics Impinges on Religion* (Cambridge, MA: MIT Press).

Wiener, Norbert & J. P. Schadé (1963) 'Introduction to Neurocybernetics', in N. Wiener & J.P. Schadé (eds), *Progress in Brain Research*, vol. 2 (Amsterdam: Elsevier): 1–7.

Wiener, Norbert & J.P. Schadé (eds) (1964) *Progress in Biocybernetics* (Amsterdam: Elsevier).

Wiesner, J.B. & L. Levine (1949) '"Felix" (Sensory Replacement)', MIT, Research Laboratory of Electronics, *Quarterly Progress Report* (15 October): 54–55.

Wiesner, J.B., L. Levine & O.H. Strauss (1950a) 'Felix (Sensory Replacement)', MIT, Research Laboratory of Electronics, edited by Heinz von Foerster, Margaret Mead & Hans L. Teuber, *Quarterly Progress Report* (15 January): 67.

Wiesner, J.B., L. Levine & O.H. Strauss (1950b) 'Felix (Sensory Replacement)', MIT, Research Laboratory of Electronics, *Quarterly Progress Report* (15 April): 54–55.

Wiesner, J.B., L. Levine & O.H. Strauss (1950c) 'Felix', MIT, Research Laboratory of Electronics, *Quarterly Progress Report* (15 July): 86.

Wiesner, Jerome, Norbert Wiener & Leon Levine (1949) 'Some Problems in Sensory Prosthesis', *Science* 110: 512.

Wilson, Adrian, & T.G. Ashplant (1988) 'Whig History and Present-centered History', *Historical Journal* 31: 1–16.

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