RISE OF THE MACHINES

A CYBERNETIC HISTORY

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4. ORGANISMS

THE VISION OF MACHINES AND ORGANISMS INTERACTING in novel ways had emerged already in the late 1940s but gained strong momentum in the early 1960s. The Cold War and technological competition between the United States and the Soviet Union played a major role in driving American innovators.

Organic machines could be realized in one of two ways. One was bolting machine parts onto existing biological organisms. From the beginning, the goal of merging the artificial and the natural was to enhance the performance of the organism. Machine modification could help make an animal—and ultimately humans—fit to survive and operate in previously hostile environments, such as outer space or the deep seas. Life was no longer bound by evolution. The resulting modification was a *cyborg*, shorthand for “cybernetic organism.”

The second possibility was even more ambitious: creating living machines without an organic base. Stand-alone machines, entirely without tissue, could be endowed with features of living organisms, such as the ability to reproduce, to mutate, to evolve, and to think—or to fight and kill autonomously. Endowing machines with lifelike attributes raised two hairy questions: when and if machines could come alive, and when and if machines could outperform human beings. Only the distant future would hold answers to these questions, if there were, in fact, answers. These were more philosophical than technical themes. But their appeal was bound to grow as technology advanced and as cybernetics offered an inspiring vocabulary for coming to terms with machines as organisms.

I

Already in 1943, Norbert Wiener discussed some of these questions with John von Neumann. The two debated similarities between the brain and computers in an interdisciplinary meeting with neuroscientists and engineers at Princeton.[1] That year, Wiener and von Neumann jointly founded the “cybernetic circle,” which led to the influential series of Manhattan meetings supported by the Macy Foundation. The two men, perhaps America’s two most resourceful mathematical minds at the time, shared a similar scholarly trajectory. But they were quite different in temperament: Wiener could be diffuse and incomprehensible; von Neumann was immaculate and paid thorough attention to minute details.

At that time, just as the war was ending, von Neumann was getting involved in the work on the ENIAC (Electronic Numerical Integrator and Calculator), a 30-ton, 80-foot-long giant machine powered by vacuum tubes to calculate artillery firing tables for the army. The era-defining device was built in 1944–45 at the University of Pennsylvania’s Moore School of Electrical Engineering.

The ENIAC presented a new problem to engineers: it could calculate faster than instructions could be read into the machine. Frustrated and inspired by this memory problem, von Neumann wrote a conceptual paper that is widely seen as the founding document of modern computing, “First Draft of a Report on the EDVAC,” dated June 30, 1945. The EDVAC (Electronic Discrete Variable Automatic Computer) was the successor to the ENIAC.[2] In 1946, Julian Bigelow—who, with Wiener, had tried in vain to predict flight patterns of pilots under stress—became chief engineer of von Neumann’s computer project at Princeton.[3]

By the end of 1946, von Neumann was irritated by the cybernetic research he had been discussing with Wiener for three years already. He felt that the human brain was simply too complex to study as a template for computers. So, in a remarkable letter to Wiener, von Neumann suggested narrowing the focus of their research.

“Dear Norbert,” he started, and he suggested a personal meeting a few days later. He then tried to nudge the father of cybernetics away from the human nervous system: “In trying to understand the function of automata and the general principles governing them, we selected for prompt action the most complicated object under the sun—literally.” He was referring to the human brain.[4]

Their work had made good progress, von Neumann admitted, despite its excessive ambition. But a breakthrough was unlikely. Instead, von Neumann suggested studying simpler organisms, organisms even simpler than single cells: “Viruses,” he proposed to Wiener, “possess the decisive traits of any living organism: they are self reproductive.”

“I did think a good deal about self-reproductive mechanisms,” von Neumann told Wiener. He was convinced he understood some of the main principles involved. The virus was an entity in the gray zone between the living and the nonliving. It seemed to von Neumann that this trait made it an ideal subject to study. “I want to fill in the details and to write up these considerations in the course of the next two months.” That time frame turned out to be too optimistic.

Coming up with a “Theory of Self-Reproducing Automata,” as he called a series of lectures on the subject, took von Neumann about two years. He outlined how machines could build other, similar machines from elementary parts. In the lectures, von Neumann liberally jumps from describing machines in organic terms to describing living beings in mechanical terms. This switch in perspectives wasn’t sloppiness; it was creativity at work.

“Anybody who looks at living organisms knows perfectly well that they can produce other organisms like themselves,” he told a small group of colleagues and friends in June 1948 at the Institute for Advanced Study.[5] He couched his theory in cybernetic terms, blurring the boundary between machine and organism. Plants and animals produce offspring. But the reproduction of life over generations was doing more than simply reproducing the same life. Natural reproduction introduced a steady stream of errors and modifications. The result was improvement: “It’s equally evident that what goes on is actually one degree better than self-reproduction,” von Neumann said. Nature wasn’t just reproducing the design of life. It was evolving and improving existing designs. “Evidently, those organisms have the ability to produce something more complicated than themselves.”

Von Neumann then switched the perspective, thinking not machine from organism but vice versa. But reproduction from a mechanical point of view led to the opposite conclusion: organic self-reproduction was evolutionary; mechanical self-reproduction was degenerative. The reason for the two opposing logics was simple: “Everyone knows that a machine too is more complicated than the elements which can be made with it,” he told his students. The machine designed to make other machines like it must contain its own component parts, the design description of the new machine, and the parts and tools for assembling the new machine. The parent machine, in short, was bound to be more complex than the child machine, von Neumann reasoned: “An organization which synthesizes something is necessarily more complicated, of a higher order, than the organization it synthesizes."[6]

How, then, could a machine build another machine that was at least as complex as itself? It was a theoretical question, of course. But building machines that could output fertile offspring was a tough nut to crack, even theoretically.

In theory, the machine needed eight parts. The biblical number in von Neumann's plan for creation was probably coincidence. The eight parts included a "stimulus organ," a "fusing organ" to weld or solder separate parts together, a "cutting organ" to unsolder a connection, and "a muscle" to produce motion. The professor then outlined the assembly in abstract mathematical terms. Significantly, he considered mutation, that crucial feature of evolution. "By a mutation I will simply mean a random change of one element anywhere," von Neumann told his small audience at Princeton. After such random change, he said, "the system will produce, not itself, but a modification of itself."[7]

As in nature, the outcome would, in most cases, be negative, not positive—a degeneration, not progress. But the possibility of random change emerged.

> So, while this system is exceedingly primitive, it has the trait of an inheritable mutation, even to the point that a mutation made at random is most probably lethal, but may be non-lethal and inheritable.[8]

John von Neumann did not discuss the question of whether his machines would be alive, like the virus that he suggested as a case study of self-reproductive design in his letter to Wiener—or indeed whether machines were alive like humans, the master inspiration of cybernetic pioneers. But he was certainly prepared to think that his primitive automata could die in some sense from "lethal" mutations.

The 1950s were an optimistic time. Utopia was more attractive than dystopia, perhaps because the dark memories of World War II were still too fresh and too close for comfort. Blue-sky thinking was a form of escape. Self-reproducing automata didn't have to be killer robots; nor did they have to resemble predators, or even animals such as worms. Self-reproducing machines might as well be more benevolent plants. And not just weeds, but useful plants that, in time, could be programmed to generate the desired harvest. Edward Moore suggested this design in 1956, in a much-noted *Scientific American* article.[9] Moore was a lecturer at MIT and Harvard simultaneously; then he moved to Bell Labs, which a dozen years earlier had revolutionized the business of ballistic prediction and gun laying.

Moore acknowledged that von Neumann had demonstrated the feasibility of self-reproducing machines. A thought experiment like that suggested by von

Neumann was fine. But such automata, Moore thought, could serve an actual purpose. The machine could be useful: “It would make copies of itself not from artificial parts in a stock room but from materials in nature.”[10]

Like a shrub in an English garden, Moore’s mechanical organism would grow and reproduce best if placed in just the right spot: direct sunlight, no frost. For that purpose, Moore suggested a beach: “For the first model of such a machine, a good location would be the seashore, where it could draw on a large variety of available materials.” The breezy air would provide nitrogen, oxygen, and argon; the seawater offered hydrogen, chlorine, sodium, magnesium, sulfur, calcium, carbon, and other elements; and the sand and soil had silicon, iron, and aluminum. “From these elements the machine would make wires, solenoids, gears, screws, relays, pipes, tanks and other parts,” Moore wrote, “and then assemble them into a machine like itself, which in turn could make more copies.”[11]

Such a machine, Moore suggested, could be harvested for materials that it had extracted or synthesized from the soil or water or air, in the same way that cotton, mahogany, or sugarcane was harvested from natural plants. Except the artificial plant could be designed to produce “any desired crop,” not just the limited crops that nature happened to be providing. Moore predicted the cultivation of freshwater, or growing gold from seawater. Even Antarctica, the unused continent, could be brought into production.

One important aspect in designing the plants was time: How long would it take for the population of artificial living plants to double itself? Algae in a pond, for instance, can double in size in a week; a population of sequoias, by contrast, can take centuries. If the machine’s reproduction rate was fast enough, the investment in designing and building it would pay off handsomely. Any such calculation, Moore explained, had to take into account mortality among the machines. “A certain fraction of each generation would ‘die’ because of internal failures, degeneration or natural catastrophes,” he wrote.[12]

Moore was conscious of the limitations, of course. The artificial machines need not be made from ferromagnetic materials and electrical motors with gears and screws, wires, and valves. They could as well be made from organic materials, Moore knew. The only problem was that 1956 organic chemistry wasn’t yet advanced enough. The same applied to theoretical genetics: the human understanding of evolution wasn’t yet advanced enough “to enable us to endow a machine with evolutionary abilities.”[13] Thus, the machines, for the time being, had to be improved by their makers.

The most important limitation was the price. Designing such machines would be hard and expensive. But it was not as hard and expensive an achievement as other ambitious projects of the day, such as transporting humans to the moon and other planets. “The whole design problem could probably be solved in five to 10 years, for as little as $50 million to $75 million.”[14]

By 1961, Wiener was entertaining ever wilder ideas about living machines. “Can machines give birth to machines?” he asked. The second edition of *Cybernetics* came out that year. It included a summary of what had happened during the 1950s. Wiener’s conclusion: machines were on the cusp of acquiring two features of living systems—the power to learn and the power to reproduce—he told the *Christian Science Monitor* when the second edition of his best seller hit the book shops.[15]

John McCarthy, one of Wiener’s colleagues at MIT, agreed that “self-producing” machines would be entirely possible. A machine could be installed on a mountain of granite, he speculated. The machine could then melt the granite, refine any needed materials from the rock, and build other machines in its likeness. “Each machine would carry a sort of tail bearing a code describing how to make the body,” the *Christian Science Monitor* quoted McCarthy, somewhat incredulous in tone.[16]

Perhaps the best-known and one of the most influential articulations of machines coming alive is not science, but science fiction: Arthur Clarke’s monumental story *2001: A Space Odyssey*, about technological progress and machines acquiring human characteristics. Clarke was mesmerized by Norbert Wiener’s work. The British science fiction writer had read an essay published in *Science* by the father of cybernetics during the summer of 1960: “Some Moral and Technical Consequences of Automation.” In that essay Wiener wanted to take stock of the debate a dozen years after he started it. His tone was professorial, if not arrogant. Wiener sharply attacked “the man in the street” for assuming that machines cannot possess originality. Such a view was clearly naïve. For ordinary people did not understand modern machines. Wiener:

> It is my thesis that machines can and do transcend some of the limitations of their designers, and that in doing so they may be both effective and dangerous. . . . As is now generally admitted, over a limited range of operation, machines act far more rapidly than human beings and are far more precise in performing the details of their operations. This being the case, even when machines do not in any way transcend man’s intelligence, they very well may, and often do, transcend man in the performance of tasks.[17]

This was the kind of bold prediction of the future that would make Wiener’s books and articles such popular reading material among artists and science fiction authors, and Clarke was duly impressed when he read these lines. “The tool we have invented is our successor," Clarke wrote in *Playboy*, in July 1961, just overleaf of an article that featured iconic midcentury furniture and interviews with designers Charles Eames and Eero Saarinen. Biological evolution, Clarke believed, had given way to a far more rapid process, technological evolution. "To put it bluntly and brutally, the machine is going to take over."[18] *Playboy* illustrated the story with an evolutionary tree that showed the progress of evolution: from microbe to fish, dinosaur, monkey, Neanderthal, human, and eventually machine.

Clarke wrote these lines for the first time about seven years before he published *2001*. He was writing twenty years after the first electronic computers appeared, but two years before the network that preceded the internet was first suggested. Clarke was deeply impressed by the fast advance in sheer computing power, and he foresaw the possibility of building a machine that could pass as human itself: "We are still decades—but not centuries—from building such a machine," he suspected.

Yet he felt enough confidence to ridicule the naysayers and skeptics who made the argument, common at the time, that no machine could possibly be more intelligent than its makers, that nothing could come out of the machine that had not first been put into it. "The argument is wholly fallacious," Clarke was sure. Those who would still argue along such lines would be stuck in the past, "like buggy-whip makers who used to poke fun at stranded Model Ts."[19]

To bolster his confident case, the science fiction author quoted the cybernetic master himself: "as a careful reading of these remarks by Dr. Norbert Wiener will show." Clarke understood that machines could escape human control even if they were less intelligent than humans, simply by virtue of the sheer speed of their operation. And Clarke saw many reasons why machines would become not just faster, but also "much more intelligent" than their creators, and already "in the very near future." Machines that learn by experience already existed, and unlike human beings, they learned properly, never repeating their mistakes. All intelligent machines, Clarke argued, were inspired by what we know about the human brain, "the only thinking device currently on the market."[20] Clarke was practically parroting Wiener.

But of course, Clarke had the mind and the style of a science fiction author, and he was writing for *Playboy*, not *Science*. So he could reveal himself a little more freely. "It will take a little while for men to realize that machines can not only think, but may one day think them off the face of the Earth," he wrote.[21] Clarke foresaw entirely new and yet unimagined forms of human-machine interaction. "I suppose one could call a man in an iron lung a Cyborg." But that alone wasn’t too remarkable. Man-machine interaction had far wider implications: “One day we may be able to enter into temporary unions with many sufficiently sophisticated machines,” the science fiction author wrote in *Playboy*, predicting that future generations would be “able not merely to control but to become a spaceship or submarine or TV network.” The idea of becoming a spaceship formed the basis of the story that would define Clarke’s career. It would take decades for this thought to be articulated in more detail. But by 1961, Clarke was suggesting that networked machines could change not what humans do, but what they are.

The cyborg had been born in Texas barely a year earlier, at the end of May 1960, at Randolph Air Force Base. The challenge of flying at new altitudes is what led to the rise of the man-machine.

World War II had elevated the special field of aviation medicine. Flying at ever-higher altitudes and faster maneuvers during flight presented aircrews with unknown physiological and psychological problems. How much gravitational force could the human body take? What were the effects of low cabin pressure on cerebral activity? How would low or no gravity affect astronauts?

Cybernetics was all the rage among engineers at the time. In the 1950s, the School of Aviation Medicine at Randolph Field, in San Antonio, Texas, was one of the air force’s foremost research centers to explore these novel questions. As early as 1948, scientists at Randolph Field—a ten-hour drive from where the army was hosting the Third Reich’s leading missile engineer at White Sands Proving Ground—held meetings on topics as visionary as “aeromedical problems of space travel.” The Cold War nuclear arms race was on, and the accelerating space race added urgency to bleeding-edge aviation research.

On October 4, 1957, the Soviet Union successfully launched Sputnik 1, the world’s first artificial satellite, causing shock and consternation in the United States. NASA was founded the following year. Space travel came with a host of challenges, one of the most intricate and important of which was adapting the human body to extraterrestrial conditions. On May 26 and 27, 1960, the School of Aviation Medicine hosted its fourth space flight symposium to explore the physics and medicine of the upper atmosphere and space flight.

That May, two improbable researchers from the Rockland State Hospital presented a bold idea. The institute in a rural suburb of New York City seemed an odd place for a mesmerizing invention. New York State’s government had established a research facility at the previously neglected hospital in Orangeburg, just north of Manhattan, to boost morale. Nathan Kline, a doctor, was the hospital’s dynamic, young, and well-connected director of research. He was a dominant figure in psychopharmacology, a new discipline with a reputation at the time of rough treatment methods for the mentally ill. In 1955, Kline hired a highly gifted Austrian émigré, Manfred Clynes. Clynes had studied engineering and music at the University of Melbourne in Australia. Two years earlier he had performed Bach’s *Goldberg Variations* across Europe to critical acclaim, even performing solo in London’s newly built Royal Festival Hall.

The Austrian-born inventor and artist took over Rockland’s Dynamic Simulation Lab. Kline bought a computer for Clynes in 1955, when such a machine was far more expensive than a decent family home. The ambitious engineer soon put the new device to work on calculations pertaining to the body’s nervous system and cybernetic control. In the coming years, Clynes would file eight patents in the fields of ultrasound, frequency modulation, and telemetering. Clynes was extraordinarily energetic and productive, both as a scientist and as a pianist. In 1960 he published an article in *Science* on the control of heart rate through respiration: “Computer Analysis of Reflex Control and Organization.” In the article, Clynes applied automatic control system theory to the body. Clynes had been fascinated by Norbert Wiener’s ideas on cybernetics and even discussed cybernetics with the famous MIT professor in Ukraine.[22]

Clynes and his boss considered presenting their findings at the symposium in San Antonio, Texas. After working on the paper, Clynes suggested using the word “cyborg” in the title. He asked Kline for his opinion. “Oh, this sounds kind of interesting,” Kline responded, “But it also sounds like a town in Denmark.”[23]

The basic idea of the cyborg was intuitive. On Earth, most of the body’s regulatory functions just work. We don’t have to remember to adjust our blood pressure. We don’t have to remind ourselves to breathe. The goal was to enable the same unconscious, automatic regulatory behavior in outer space. The goal was to liberate the astronaut from the limitations of the human body. In their presentation at Randolph—“Drugs, Space and Cybernetics: Evolution to Cyborgs”[24]—Clynes and Kline outlined a bold idea that would solve that problem by automating those newly required body functions.

To illustrate their point, the two scientists invoked a fish. Not just any fish, but a particularly intelligent and resourceful fish. If this resourceful fish wished to live on land, it could do so. It would need some background in biochemistry and physiology, and it would have to be a “master engineer and cyberneticist,” with excellent lab facilities available to it. If all those requirements were met, “this fish could conceivably have the ability to design an instrument which would allow him to live on land and breathe air quite readily,” they suspected. Humans in space were like that fish on land.

Their entire presentation was laced with ideas borrowed from cybernetics: the man-machine entity would improve “man’s homeostatic mechanism.” Implants into the lungs, heart, the nervous system, and various other organs would extend the self-regulatory control of an organism into a new environment, outer space. Drugs would be injected into the bloodstream from within the body. The implanted machines would even regulate the astronauts’ sleep and sensory input. Problems would be solved automatically, “leaving man free to explore, to create, to think, and to feel.”[25]

Clynes and Kline invoked America’s frontier spirit, a popular comparison to outer space at the time. Space was the “new frontier,” and cybernetics would help the pioneers colonize this mythical space that only very recently had seemed entirely out of human reach.[26]

A few months later they published the paper as “Cyborgs and Space” in *Astronautics*, a leading journal on America’s space program.[27] The article included a picture of the first cyborg, a white, 220-gram lab rat with an osmotic pump implanted under the skin of its tail. The implant made the tail look like a white ball that was tied to the rodent’s backside. The pump allowed continuous injection of chemicals into the rat’s bloodstream—controlled by the machine, not the animal.

A range of problems could be solved during flight through machine-controlled counteraction: sensors could detect radiation and automatically inject pharmaceuticals into the pilot’s body to counter the effects of radiation, for instance. Sleep could be automated, as well as fluid intake and output, cardiovascular activity, and body temperature. Clynes and Kline were conscious of the limitations of their suggestions. They pointed out that they had not discussed motion sickness. They also didn’t discuss “erotic requirements” during space flight in their ambitious five-pager, apparently deciding that suggesting some sort of sex machine would be an idea ahead of its time. Some of their solutions, they understood, would have appeared “fanciful” in 1960.

The presentation must have appeared fanciful indeed: so far, no human had even been in outer space. Yuri Gagarin would complete an orbit of Earth only eleven months later, on April 12, 1961. Yet the cyborg pioneers were acutely aware of the high stakes, precisely because the enemy of the free world seemed so far ahead in science and technology: “There are references in the Soviet technical literature to research in many of these same areas,” they pointed out, still Sputnik-shocked. The researchers were confident of one necessity: “adapting man to his environment, rather than vice versa.” This advance would mark not just a significant step in human scientific progress; the cyborg, they hoped, “may well provide a new and larger dimension for man’s spirit as well.” If the human body could be machine-enhanced, enhancing the mind was only a question of time.

The two researchers from Rockland had captured the Zeitgeist. The idea would inspire the design of an entire range of machines and even philosophical inquiries in ways that even the two inventors from Orangeburg could not have imagined. *Life* magazine visited the Rockland laboratory, interviewed the two researchers, and covered their work in a story.

> Cyborgs will wear sealed skintight suits but will travel in unsealed cabins exposed to the near vacuum of space. Ordinarily, at these low pressures, the blood would boil and the lungs explode. But cyborgs’ lungs will be partly deflated and their blood will be cooled. To keep from getting numbed their brains will be warmed or fed energizers. Their messages to one another will be picked up electrically from their vocal nerves and transmitted by radio. Their mouths will be sealed and unused. Concentrated food will be piped direct into their stomachs or blood streams. Wastes will be chemically reprocessed to make new food. Totally worthless end-products will be kept in small canisters on their backs.[28]

The magazine illustrated the story with a large picture of two cyborgs working on the moon, complete with sealed mouths and waste canisters. Clynes mounted a big photograph of the story on his wall and had it up for years. He highlighted his artistic background in the interview. “Imagine,” he told *Life*, “what leaps a ballet dancer could take on the moon.”[29]

These ideas were controversial among serious scientists, yet they didn’t go far enough for some engineers who were in the business of beating back the Soviets technologically. Martin Caidin, a prominent space-aviation author, captured the mood in the early 1960s when he wrote of a new undercurrent: “That undercurrent is one of urgency.”[30] The fear was that the Soviets might get to the moon first. Michael Del Duca, the chief of biotechnology at NASA headquarters in the early 1960s, had a reputation for far-fetched ideas about life-support systems. Dr. Del Duca felt that the cybernetic possibilities for space exploration were quite literally boundless. Space would no longer be hostile and inaccessible.[31]

By May 1963, NASA came to somewhat more nuanced conclusions in the final report of contract NASw-512, an experimental project that explored how humans could be reengineered for extraterrestrial environments, titled *Engineering Man for Space: The Cyborg Study*. The project team concluded that the potential of fully artificial lungs, kidneys, and “extracorporeal pumps” was limited. But NASA remained more optimistic that astronauts could be “modified” through biocybernetics—for instance, by artificially cooling their body temperature and by managing sensory deprivation—to ensure “the success of prolonged space flights or interplanetary exploration.”[32]

II

The cyborg had obvious uses not just in space, but also on Earth. The military, naturally, was keen on the idea. One man in particular understood the potential, certainly the fundraising potential, of military cybernetics: Ralph Mosher, a General Electric engineer. He would rake in millions of dollars of funding for merging man and machine, over more than a decade, from all services—first the air force, then the army, and finally the navy.

Mosher’s streak had begun back in 1955. That year, General Electric started developing experimental atomic aircraft engines for the Aircraft Nuclear Propulsion program, run jointly by the Atomic Energy Commission and the air force. The Soviets, it was known, also tried to equip their bomber fleet with atomic reactors. GE had two experimental nuclear-powered gas turbine projects—the X-39 and the larger X-211 engine—that were powered by gigantic experimental reactors mounted on railcars to move them to remote test locations.[33]

The US Air Force had already designated a new super-long-range bomber, the B-72, as a nuclear-powered aircraft, able to fly for weeks at a time and at higher altitudes than most other aircraft could.[34] The biggest design problem was protecting the aircraft’s crew and engineers from the onboard reactor’s radiation. The experimental test plane had a 12-ton lead-shielded crew compartment with 10-inch-thick leaded-glass windows. The reactor would have been cooled by the airflow through the engine in flight, which meant that aircraft maintenance on the ground would be a vast engineering challenge.

General Electric’s research, as well as the predicted ongoing maintenance of the aircraft, required so-called manipulators, simple remote-controlled claws—with enough dexterity and sense of touch to turn screws, fit parts, and assemble components in high-radiation environments. In 1958, GE turned to one of its best engineers for help. Mosher, then thirty-eight years old, was a tall and husky man, sporting a crew cut and a smart outfit, usually a white shirt with dark tie. He worked at GE’s Schenectady factory in eastern New York. It was the same factory, close to where the Mohawk and Hudson Rivers meet, that had inspired Kurt Vonnegut to write *Player Piano* ten years earlier.

Mosher, like Vonnegut, was familiar with Wiener's ideas on cybernetics. But the ambitious engineer got a very different kind of inspiration: "I realized that after a certain point improvements in mechanical dexterity added little to a manipulator's performance," Mosher remembered. He wondered why people were so efficient with their hands and why robots were so awkward. "Soon it was obvious," Mosher recalled. "The manipulator's operator was missing what he ordinarily experiences: a sense of feel."[35]

Feedback was missing. Mosher understood that a kinesthetic sense mattered, the sensing of forces in the body's bones and muscles. A man could open a door in the dark because he sensed the doorknob, sensed how it turned, and then sensed the door's circular opening motion. A robot would risk ripping the door out of its frame because it didn't sense the circular motion. So Mosher came up with the idea of force feedback for high-performance robots. "Such a device, possessing the properties of feedback and kinesthesis, can be described as a cybernetic anthropomorphous machine," he wrote in *Scientific American*.[36] That was a mouthful. Mosher suggested a shorthand, CAM. The results were dramatic. Touch and feel worked wonders. "We didn't just make a better manipulator," Mosher said about the new CAMs. "Adding touch created an entirely new *kind* of robot."[37]

The result was Handyman. Handyman was a pair of powerful mechanical arms, slightly longer than human arms but with a similar structure: shoulder joints, elbow joints, and two-fingered claws that could be twisted at the wrist. Each arm was capable of ten motions in three-dimensional space. The two tools were protruding from a black box with "General Electric" proudly printed on the front. The box was fed by bundles of hydraulic cables. The arms were made of black steel from the elbow downward, the biceps coated in thick black rubber. The claws were highly dexterous: one claw could pick up a thin wooden hammer while the other one held on to a block of wood with a nail sticking out, and then hit the nail with the hammer.

A man strapped into a harness controlled the mechanical claws. The harness looked like an exoskeleton for Mosher's arms. It was the equivalent of a mouse and keyboard—the human-machine interface, what the GE engineers then called an exoskeletal master station. "The cybernetic control method requires an exoskeletal master station that has precise spatial correspondence with the operator," the final report to the army explained in technical jargon.[38]

The hydraulic claws precisely mimicked the actions of the man's arms and hands. The man, in turn, received tactile feedback from the steel claws, in effect coupling the machine with the man's sensory and motor systems. GE called the harness the “follower rack” because the machine simply followed the man’s motions. The hope was that the movement could become natural, so that the operator would not have to think about using the machine—in effect, as the engineers wrote, “merging man and machine, using the best capabilities of both.”[39]

Handyman was designed for the air force, to handle “hot” radiation material inside a propulsion laboratory to build an experimental long-range bomber aircraft that was nuclear fueled and nuclear armed. But General Electric, keen to garner upbeat media coverage for its fancy devices, preferred showcasing more benevolent uses. At the debut press conference, Mosher was smartly dressed, strapped into the follower rack, with his remote iron claws twirling Hula-Hoops, two little girls in pretty dresses looking on in awe. In one story, *Life* showed an attractive young brunette with two GE steel claws helping her into her coat—Mosher in the background, several yards removed, strapped into the follower rack, smiling.[40]

In 1961, John F. Kennedy ended the air force’s program for a nuclear-powered bomber. But he also escalated the Vietnam War. This meant that Mosher would continue his work for a new client; as the air force walked out, the army walked in. By the early 1960s, the army was experiencing new and unexpected tactical problems in Vietnam. Tanks, trucks, and artillery guns were too clumsy for jungle warfare. Only infantrymen on foot—along with mules—were able to negotiate narrow trails, steep potholed roads, dense forests, swamps, and rice paddies. Worse, the Viet Cong preferred hit-and-run ambushes on US troops precisely in those remote locations. Then, in the early 1960s, the army’s top brass heard about GE’s Handyman.

The army faced a special problem. For the air force and the navy, mobility was easier. The nation’s ground force wasn’t particularly innovative in how it traveled in combat: airmen were looking at nuclear propulsion and space travel, and sailors had submarines and carriers; meanwhile, infantrymen were still wading through the mud. The reason was straightforward: air and sea were predictable and consistent travel mediums; terrain offered endless variety. It was therefore much easier to navigate ships and aircraft autonomously. GE promised a way out of this conundrum: a giant walking machine for jungle warfare, a “profitable symbiosis of man and machine.”[41]

The goal was to equip infantry units in the deep mountainous jungles of Southeast Asia with armor and heavy equipment while remaining highly mobile and versatile. Officials at the US Army’s Tank-automotive and Armaments Command (TACOM) in Warren, Michigan, were intrigued.

Balancing a large walking machine, however, wasn't trivial. So TACOM's Mobility Systems Laboratory funded an experiment to test whether a giant, two-legged walking tank could be kept in balance.[42] The outcome was the Pedipulator.[43]

The Pedipulator, built in 1964, was an 18-foot-tall experimental biped. The machine looked like a prototype of a *Star Wars* biped, thirteen years before the science fiction film came out: a cabin with a large front window, a little larger than a telephone box, was balanced on two thin legs. Eighteen feet was high. Some people refused to try the machine, because of its height.[44]

One reporter from *Popular Mechanics*, in a dark suit and skinny tie, came to test-drive the biped. The GE engineers helped him climb into the driver's cabin, showed him the skateboard-like control panel to stand on, fixed his torso between two bars, and then fired up the biped: "With a loud sigh of hydraulic valves the automaton I was commanding sprang to life," the reporter recalled. The machine started mimicking his moves. With no practice in balancing a giant biped, the reporter pitched too far forward on the swivel board:

> Using my toes for leverage, I frantically tried to stop our headlong plunge by throwing myself backwards. The robot's reaction was as quick as it was violent. Accompanied by a piercing shriek of valves, the automaton shuddered to a halt, then swiftly heaved back. Before I could react, it had crashed down on its heels with a jolt that rattled every bolt in its body.[45]

The prototype was tied to rails on the ground and could not actually walk, let alone topple over. Its purpose was to test the balance in a giant human amplifier. The *Popular Mechanics* reporter-turned-balance-tester quickly learned his moves and soon was able to go through a series of motions "as outlandish as the latest discotheque dance." Balancing the biped wasn't so difficult after all.

Mosher had become acutely aware of the limitations of robotics while working on the air force contract. "Compared with the versatility of man," he understood, "the things a machine can be programmed to do are extremely limited." It was impractical, he acknowledged, to build a machine that could walk on sand, mud, and rocks, as well as through a forest on its own. Machines were good at repetitive tasks that didn't change at all. But walking in rough terrain meant that every step was different. Moving in such environments was simply too complex and dynamic for microprocessors at the time. "But a man can do this," Mosher suggested, "and if you join man and machine, using the best capabilities of each—man's brains and the machine's great strength—then a machine can do it, too."[46]

"Cybernetic mechanisms," the GE engineers understood, had a range of advantages over conventional vehicles: effective man-machine integration eliminated levers, brake pedals, and clutches; it made programming obsolete; it required very little training; its force feedback reduced risk; and cybernetic machines would free operators to focus on the actual problem at hand. “The operator is able to react in such a natural manner that he subconsciously considers the machine as part of himself,” Mosher told the army’s transportation experts in Michigan.[47]

The army’s vision was to create some sort of intelligent full-body armor, turning the soldier, in effect, into a walking tank. When the experiments with the limited-motion Pedipulator were finished, GE mailed two enthusiastic reports back to the army: humans could indeed balance the machine, position it quickly and accurately, and retain “nearly perfectly” how they learned to operate the new gear.[48]

TACOM was impressed by the Pedipulator. But the Department of Defense was concerned that a biped could be knocked over with simple means during battle in forest environments and would not be able to get up again on its own. So the army decided to fund a four-legged walking machine. A quadruped was more stable; it was also lower, which made walking in jungle underbrush easier; and four legs could simply carry more load than two legs could.[49] In addition, quadrupeds just made more intuitive sense to cavalry officers.

Just before Christmas 1969, in a cluttered machine workshop, GE engineers had erected an 11-foot-tall beast of burden weighing 3,000 pounds. The Schenectady engineers called it the “walking truck.” The machine’s sturdy skeleton was made of aluminum beams. Bulky hydraulic muscles powered its four legs. Each leg had a hip joint, a thigh, a robust knee joint, calves, and small feet, but no ankle joints. The hips could move the thighs in all directions; the knees were limited to fore and aft motions.

One of GE’s innovations was the walking truck’s human brain: the operator had to climb into the machine’s belly on a small metal ladder that could be flipped down, suspend himself inside the skeleton, slip his feet into a pair of metallic holsters, and hold on to two joystick arms with handles and a number of triggers. The rider then revved up the 90-horsepower gasoline engine, pumping hydraulic fluid into the cyborg’s body and legs, through a tangle of tubes and gauges and valves, bringing it to high-pressured life. When the rider raised his right leg, the machine raised its right hind leg. When he turned his left forearm, the machine turned its left foreleg.

Controlling the quadruped was less intuitive than controlling the experimental biped. It took about ten hours to learn how to operate the machine. Mosher got rather good at it. With a bit of practice, the walking truck could go where no wheeled vehicle could go, across fallen trees and rocks lying in its way, at about 5 miles per hour. A person, amplified by machine, could reach with one arm and kick a 1,500-pound rock out of the way, toss a jeep out of the mud, or even push a small military vehicle over an obstacle. The metallic beast could walk forward as well as backward, and even balance on two legs. “What’s 11 feet tall, walks on four legs and drinks gasoline?” asked GE in an ad.

Despite its size and power, the quadruped wasn’t a brutal monster. The GE cyborg had tactile force feedback built in. Mosher, in his white lab coat and white helmet, could feel what the purring vehicle “felt.” When an aluminum foot touched the ground, the operator would feel, via feedback from sensors, the heavy leg touching the ground in his holster. The machine was capable of “great gentleness,” as one TV documentary put it at the time.[50] In the lab, GE demonstrated the cyborg’s haptic skill by having it step on a glowing lightbulb resting on a red pillow, gently touching it without breaking the glass. Yet by simply turning his wrist, the operator could also shove 175-pound railroad ties out of the machine’s way as if they were toothpicks.

Once an operator has enough practice, Mosher said about his four-legged vehicle, he “begins to feel as if those mechanical legs are his own.” The engineer had been the machine’s primary driver for a while at that point. It indeed started feeling natural to him: “You imagine you are actually crawling along the ground on all fours—but with incredible strength.”[51]

But operating the walking truck was harder than the engineers had hoped, because the rear legs were out of the driver’s line of sight. Walking by machine also was extremely tiring. It became difficult to concentrate after fifteen minutes. Another problem was that the machine’s high volumes of hydraulic fluid required external hookup even in advanced versions, when testing had already moved outdoors. TACOM was disappointed. GE’s promotional material had looked so promising, with a column of quadrupeds trotting along, crossing a jungle creek under giant tropical trees. But there were no hydraulic hookups in Vietnam’s underbrush. Only one cybernetic walking machine was ever built for the army.[52]

GE built the most visually stunning remote manipulator for the air force, to service the flying nuclear reactors of the planned long-range bombers: the “Beetle,” an 80-ton machine that looked like a giant tank on extra-large caterpillar tracks with two humongous mechanical arms and claws. The driver was shielded from hot radiation in a cabin behind 2-foot-thick lead glass.[53] Even Mosher thought the machine was “monstrous.”[54]

GE’s work pushed the engineers into philosophical terrain. There was a subtle difference between human control and automatic control.[55] For Mosher, a simple inert hand shovel used in the garden was a cybernetic anthropomorphic machine; it extended the human body and senses and could be used without training. “This simple device qualifies as a CAM!” he wrote about the shovel, excited by this fundamental insight.[56] The shovel, like the chisel of Ross Ashby’s sculptor, perfectly extended the user’s arm, functionally becoming a part of the operator’s body. But more complex machinery—for instance, a crane—broke up this union, cutting the operator off from “continuous sensory appraisal.”

For optimal control, the user needed to *sense* force, surfaces, position, speed, and direction—not simply see the end of the crane’s arm from a remote cabin. Operating a crane was a bit like trying to catch a ball while looking at yourself and the ball in a mirror; it was difficult and clumsy. Operating a cybernetic machine was like being a more powerful version of yourself, simply catching the ball—almost like being a spaceship or a TV network.

In November 1965, GE launched its boldest cybernetic project to date, combining all previous ideas into one machine: a fully functional exoskeleton for heavy loading. The device, again, looked like something that would be brought to the screen twenty years later by a cult film: James Cameron’s 1986 science fiction horror movie *Aliens*, which features Sigourney Weaver battling an alien in a power-loader exoskeleton, the fictional Caterpillar P-5000. Again, the idea wasn’t new.

GE’s power loader was called Hardiman (“man” was GE shorthand for “manipulator”). The US Navy’s Office of Naval Research and the US Army’s Natick Laboratories in Massachusetts jointly funded the development of this extravagant machine. Like Cameron’s rip-off in *Aliens*, it was designed for handling heavy material in extreme situations: bomb loading under the wings of fighter aircraft, underwater construction, and manual work during space travel. The company envisioned the exosuit in different sizes, from life-sized to a 50-foot giant, as tall as a five-story building. Force and position information could easily be scaled up or down, the engineers believed, with oil-powered hydraulic servos pressurized at 3,000 psi.

The exosuit’s arms would be mounted off the waist, for handling heavy loads and for ruggedness. “Load handling tasks such as walking, lifting, climbing, pushing and pulling can be performed with a lift capacity of 1,500 pounds,” GE wrote, matter-of-factly.[57] The force ratio for the prototype was 25:1, so a man picking up a load of 1,500 pounds would feel only 60 pounds. The operator’s hands were protected inside what the engineers called the slave housing.

By early 1967, the company expected the exosuit to be ready for testing and evaluation one year later, in the spring of 1968.[58] But the military funders weren't fully convinced of the near-term feasibility of the cumbersome exoskeleton. GE's work was never completed. Only an arm was built to specification, with nine joints. The navy contract expired after nearly six years, on August 31, 1971.[59] The Hardiman became yet another cybernetics-inspired project that failed in the initial development phase.

Mosher was undaunted. The engineer was already thinking about the next steps. "There's no reason why the operator has to be inside his CAM," he suspected, referring to his cybernetic machine. "You could link the two by radio."[60]

The Philco Corporation, headquartered in Philadelphia, was a major electronics contractor for the NSA, the Department of Defense, and NASA in the late 1950s and early 1960s. The company understood that putting human operators into space or the deep seas was too complicated and too expensive, machine-modified or not.[61] Instead, William Bradley and some of his colleagues at Philco suggested building a long-distance cyborg: creating a mock-up of the interior of a space capsule, or of an undersea environment, would be more elegant and efficient than sending a person into such hostile environments. The Philco engineers envisioned the remote machinery with elaborate sensors, recording sound and tactile sensations in real time. An operator could then stand at the remote-control interface and "see" and "hear" and "feel" the movements of a remote arm or hand.[62] The idea of using remote-controlled robots for hazardous tasks wasn't new. But Philco's implementation of the remote presence was new.

In 1961, two engineers at Philco—Charles Comeau and James Bryan—published some early results. They had built the first binocular head-mounted display, calling it "Headsight." The basic idea was simple: link a CCTV surveillance camera to a forehead-mounted monitor. Getting it to work, however, wasn't so simple.

The helmet was almost stylish, in keeping with the design of the time: a slick, black leather shell, a few black cables snaking down the neck, with a small antenna at the forehead for orientation, and a relatively small screen in front of the eyes. Comeau and Bryan's system used a spherical mirror close to the user's face to project a virtual 10-inch-high image that seemed to appear one and a half feet in front of the user.

A TV camera was slaved to the device. Three servos controlled the camera's movement in three dimensions: rotation, nod, and tilt. When the operator pointed his head up or down, or left or right, the camera followed at exactly the same angle. When the observer tilted his head, the camera also tilted, maintaining a constant horizon level. Through all of this manipulation, the operator’s hands remained free.

There were, however, two rather difficult problems. One was that the camera and display needed to be spatially in sync. If the viewer looked to the top right, the camera also needed to look to the top right—in exactly the same position. To couple display and camera, the Philco team set up rotating magnetic fields around both the helmet and the lens. Position-detecting coils could then sense the position of both camera and head, and provide precise coordinates. The viewer’s head and the camera’s spatial position were then compared. If an error was detected between the two, the camera’s motors would whirr into action and reduce the error to zero, bringing eye and camera in sync again. This was negative feedback at work.

The second problem was that all this took a bit of time. When the operator moved his head, his field of vision changed and his eyes swiftly refocused. The CCTV camera had to orient, make the same move, and focus. Doing all this created a significant lag, which was cumbersome, dizzying, and tiring. NASA research into displays would later reveal that lags of more than fifteen milliseconds caused dizziness and nausea.

Nevertheless, head-mounted camera control, the engineers at Philco Corporation found, was more precise than navigating a camera with a joystick. Another Philco engineer, Stephen Moulton, took this vision a proverbial step further. He installed the camera on the roof of a company building in Philadelphia. When he moved his head, the camera would move with it, relaying the city vista back to the head-mounted screen downstairs. Wearing this helmet, the viewer had the impression of being on top of the building and looking around the city.[63]

When Moulton, in the safety of a Philco lab with his helmet on, leaned over, looking down, it was “kind of creepy.” Moulton then started playing with his new gadget. One of the best effects he achieved was amplifying the control movement: he put a two-to-one distortion on the neck twist. So when the viewer wearing the helmet would turn his head by 30 degrees, the normal range of a head turn, the roof-mounted eye would turn twice as far, by 60 degrees, giving the viewer the impression that he had a rubber neck, like a woodpecker’s.[64]

Yet head-mounted displays were serious business, deadly serious. The most powerful application, as the engineers illustrated with a large graph in one publication to showcase Philco’s achievements, was “to mount camera in drone or rocket." The operator could then sit on a chair "300 miles" away from a camera flying at double the speed of sound in the cone of a missile homing in on its target. Alternatively, a drone would make the technology reusable, and perhaps enable the surveillance of military combat. "The viewer, at home base, has the sense of being in the drone and can survey remote areas in complete safety," the defense contractors explained.[65] Other applications were to explore space or ocean depths, or to work in radioactive areas. By 1963, Philco was providing the display and control systems at NASA's Mission Control Center in Houston, Texas. The firm's visual control interface linked humans in Houston to the computers aboard spacecraft.

By 1965, the cyborg had begun to capture the popular imagination. "What is man?" was the opening line of the first full-length book on the subject, *Cyborg*. Its author, D. S. Halacy, took a grand and ambitious view, portraying the evolution from ordinary man to "superman," as the book's subtitle promised, in direct reference to Friedrich Nietzsche's Übermensch, as the author made clear in the text.[66] For millions of years, the evolution of humans had been left to nature. Now, by the early 1960s, humans had taken evolution into their own hands. Human progress wasn't any longer driven passively by evolution.

"Participant evolution" meant that man himself was now an active factor in his own development—in the masculine language of the 1960s. Radical changes would become possible to adapt the body to extreme environments: nose and mouth could be permanently sealed to enable life in the vacuum of the space beyond Earth's atmosphere, while a purpose-built implant would oxygenate the astronaut's blood. But there wasn't just outer space; the planet's "inner space" in the deep seas was equally promising. Already, ocean divers could breathe gases other than air; "a more drastic approach is that of learning to breathe *water*," Halacy wrote.[67] In fact, these changes were so drastic that the idea of human evolution itself was probably obsolete. Yes, there was an "evolution to the cyborg"—but then came the *cyborg revolution*.

The human urge to fight had already created primitive cyborgs: cavemen with clubs, lancers, swordsmen, and frogmen. Halacy was especially taken by the medieval armed warriors of King Arthur's day: lance at the ready, sitting astride a horse, protected by a cover of chain mail, the knight represented "a complex development of the military cyborg." For man had started to modify his body by adding protective coating, by converting the arm into a lethal weapon, and by "supplanting" his own legs with far sturdier ones.

Halacy's vision drips with the deeply modernist belief in progress: artificially produced human beings would have a body "superior to natural man," with none of the natural weaknesses and susceptibilities to disease and decay. Machines could even stop humans from ageing: “The cyborg will live not just a better, healthier life, but a much longer one as well.” Modern life was prolonged and improved by ceramic hip joints, titanium bones, silicon breasts, electronic bladders, pacemakers, plastic corneas, and lifelike mechanical hands.

By 1970, David Rorvik, a science writer for *Time* and the *New York Times*, foresaw markets to “trade in” body parts for more durable, “if not immortal,” mechanical spare parts. An individual with a family predisposition for heart disease could decide not to wait until fate strikes, choosing to preemptively purchase a perfected plastic heart “rather than risk middle age with a vulnerable flesh-and-blood pump.”[68]

Many incurable defects could be fixed. Those with failing sexual organs, Rorvik dreamed not long after San Francisco was celebrating the summer of love, would be able to buy “youthful potency” over the counter at a medical spare-parts consortium. Naturally, amputees would benefit as well, and the United States had too many, since badly injured Vietnam veterans were returning home by 1970. Man would abandon part of his old identity, “melting so that he can be forged anew,” Rorvik foresaw. A new man would be created, “welded to machines that amplify his senses, extend his grasp, deepen his understanding of himself and his world.”[69]

Meanwhile, the cyborg as a scientific idea had died of dry rot. That same year, 1970, *Astronautics* invited cyborg pioneer Manfred Clynes to write another article about his original idea. How far has technology come in the past dozen years in simplifying man’s approach to space travel? “Not very far yet,” Clynes thought. The human organism hasn’t “yet” been engineered to use sunlight “even like a plant” as a source for organic chemical energy. Automatic recycling of oxygen in the bloodstream remained impossible, despite the aim of “cyborg technology” to bypass the lungs’ in-out tidal breathing flow and oxygenate the blood directly through an implanted fuel cell. And even the body’s own regulatory system was still “floating” along, unstable, without improved and superior machine controls.[70]

Yet space exploration had made vast progress since 1960: In 1961 the first ape, a chimpanzee named Ham, and then the first human, entered orbital flight. By the mid-1960s, several planetary flybys had been accomplished, and one mission had reached Venus. The Soviet Union had sent a satellite around the moon. At the end of the decade, on July 21, 1969, the first humans landed on the moon, with the first manned orbital observatory to follow two years later.

Modifying humans for life in space, though, remained a distant dream. “There is a strange technological imbalance between man’s development of his tools and machines for the penetration of the nature of space, and his lack of progress in cyborg technology,” Clynes noted with frustration in 1970.[71] The first thing the astronauts had to do before landing on the moon was something as mundane as sleeping eight hours, the would-be body engineer observed: “We do not know why man needs to sleep.” Machines don’t sleep. And cybernetically engineered humans wouldn’t have to sleep either. In that respect, naked man was inferior to the very machine he had built to reach the distant destination in the sky. “If the spaceship had such pervasive unknown needs, it surely never would have made it to the moon!” To add humiliation to defeat, *Astronautics* rejected Clynes’s article and refused to publish it, without giving an explanation.

III

Man-machine interaction, of course, wasn’t limited to human physical capacities but could very well apply to human intellectual capacities. Consequently, the computer itself became the subject of man-machine interaction. Perhaps the most influential thinker and technologist to tackle this specific question was J. C. R. Licklider, one of the pathbreaking early pioneers of the internet and a participant in the Wiener circle. Licklider, remarkably, used the world’s most ambitious automation project to show the limits of automation.

Licklider was deeply familiar with cybernetics, as well as with the ever-more-urgent air defense problem. “There was tremendous intellectual ferment in Cambridge after World War II,” he recalled after participating in Norbert Wiener’s weekly cybernetic circle. “I was a faithful adherent to that.”[72] Licklider was a researcher and faculty member at Harvard University at the time. Nevertheless, he audited one of Wiener’s seminars at MIT: “There was a faculty group at MIT that got together and talked about cybernetics and stuff like that. I was always hanging onto that.” The discussion circle was so significant that Licklider would later try to emulate a “miniature Wiener circle” to discuss projects at the Air Force Office of Scientific Research. Licklider even presented a paper at the last Macy conference that Wiener attended.

Licklider was also intimately familiar with air force research on man-machine interaction for improved command and control. In 1951 he had consulted as a psychologist on the project that later became SAGE at MIT. The air defense network shaped Licklider's thoughts about information processing, and he had the idea of a "network of thinking centers" through the network.[73] Licklider's own work on the subject wasn't just funded by the air force, but was inspired by the problems of air defense. Already in 1957 he had written an unpublished essay: "The Truly SAGE System, or, Toward a Man-Machine System for Thinking."[74] Licklider served on the Air Force Scientific Advisory Board for about six years, leading up to 1962.[75]

Licklider saw that "the problems of command and control were essentially problems of man computer interaction." But viewing the computer as a more powerful abacus did not make sense, he was sure. The stress of battle didn't allow for preprogrammed scripts. Batch processing was a misguided approach; "I thought it was just ridiculous to be having command control systems based on batch processing," said Licklider.[76] In practice, chance and friction dominated the battlefield and commanders would have to react to the unexpected at every turn. It was simply impossible to preprogram the chaos of fighting, Licklider knew: "Who can direct a battle when he's got to write the program in the middle of the battle?"[77]

Yet this was exactly what SAGE had tried to do. "The main experience we have had with a large-scale man-machine system for situation analysis and control has been provided by the SAGE system," Licklider told an air force committee in late November 1958, just a few months after the system had become operational.[78] The air defense network was originally designed to be "very largely automatic," he explained. The many human operators were brought into the air force system to handle tasks that could not be automated at the time, so the air force treated human operators as a second-best machine part. Licklider implied to the air force that this had been a design flaw: SAGE was "too much a matter of men aiding the machine, and not enough a matter of true man-computer symbiosis."[79] Therefore, the network was not a very good preview of the air force information-processing and control systems that he hoped would be built in the future. Man-machine symbiosis, in short, was superior to automation.

Licklider didn't want to advocate more automation, or to delegate ever more decision authority to machines. He was sharply critical of the automation enthusiasts of his day. The very concept of mechanical extension, as he saw it, led to the idea that humans could and should be replaced by machines, that "the men who remain are there more to help than to be helped." Licklider wasn't opposed to this vision in principle. But it was impracticable, "fantastic," he thought.[80] Like Mosher at General Electric, who worked on a very different problem for the army, Licklider realized that the best systems were a blend of the best of both humans and machines. His suggestion for a “truly SAGE” system clearly spelled out this vision in 1957:

> The scientists and engineers combine their cerebral data-processing with the facilities of the machine to constitute a more effective system than either the human or the mechanical parts alone could make.[81]

Human and machine were not in competition; they complemented each other. Their partnership had a template in nature: a symbiosis. Licklider’s highly influential notion of “man-computer symbiosis” emerged in response to SAGE, during the summer of 1958 at committee discussions with Licklider’s air force funders on the future of command and control. Licklider articulated his vision in a famous paper, “Man-Computer Symbiosis,” in 1960. “The hope is that, in not too many years, human brains and computing machines will be coupled together very tightly,” he wrote, using a phrase that would become common in human-machine engineering: “coupling tightly.”[82]

Unsurprisingly, Licklider’s opening example was the fig wasp, a small insect that has evolved along with the fig tree over millions of years. The wasp’s larvae live in the plant’s ovary. The wasp needs the tree for survival, and the tree in turn needs the wasp for pollination and reproduction. Such a mutual and existential dependence between humans and machines would not yet exist, Licklider observed. But he hoped it would soon come about. Humans, he believed, were better at formulating questions and answers, at detecting relevance, and at reacting to unforeseen exigencies; machines, by contrast, were better at storing and retrieving large quantities of information precisely, at calculating rapidly, and at building and remembering a repertoire of routines.

“The intellectual power of an effective man-computer symbiosis will far exceed that of either component alone,” Licklider wrote in 1962.[83] By then, even military commanders who had simulated semiautomated maneuvers were eager to regain the initiative and flexibility they felt they had lost to machines in computer-centered command-and-control arrangements, and Licklider knew this. But air force officers would also want to retain the storage and processing capabilities of their computers. Symbiosis was the way forward.

Several problems, however, needed to be solved first. One was what was then known as “time-sharing,” dividing the processing resources of extremely expensive supercomputers among a number of human users. A second problem was improving the severely limiting input-output interfaces of these computers; electronic typewriters and SAGE-style light guns weren’t good enough. A third problem identified by Licklider was the speedy storage and retrieval of vast quantities of information and data.

Licklider suspected that graphical interfaces and speech recognition would be highly desirable. A military commander, for instance, would need fast decisions. The notion of a ten-minute war would be overstated, yes, but it would be dangerous to assume that leaders would have more than ten minutes for critical decisions in wartime. Only speech recognition was fast enough as a human-machine interface; an officer in battle or a senior executive in a company could hardly be taken “away from his work to teach him to type,” Licklider quipped. It would probably take five years, he concluded in 1960, to achieve practically significant speech recognition on a “truly symbiotic level” of real-time man-machine interaction.[84]

In 1962, Licklider moved on to the Pentagon’s Advanced Research Projects Agency, ARPA. He became the first director of ARPA’s newly founded Information Processing Techniques Office, a research and funding organization tasked to improve military command-and-control systems. At ARPA, Licklider continued to work toward improved man-machine communication. He especially supported university-based research projects working on time-sharing over long distances, just as the air force had done. Soon the vision of a global computer network began to take shape.

On April 25, 1963, Licklider wrote a famous memorandum, addressed to “members and affiliates of the Intergalactic Computer Network.”[85] This was meant in irony, “as you may have detected in the above-Subject,” he wrote to his colleagues and collaborators in the memo. “I am at a loss for a name.” Then Licklider articulated in more detail what this computer network was supposed to be all about: the advancement of the art of information processing, and “the advancement of intellectual capability (man, man-machine, or machine),” Licklider wrote. The memo went out to ARPA-contracted researchers at Stanford University, UC Berkeley, UCLA, MIT, the Rand Corporation, and several contractors in industry. To make progress in these endeavors, he reckoned, each researcher needed hardware facilities, as well as a software base more complex and more extensive than one person alone could build.

The only solution was a network of computers, a network of individual “thinking centers,” as he called it. The researchers played a key role in conceiving and funding ARPANET. But the kind of network that Licklider suggested in 1963 would take almost exactly twenty years to mature into what would later be called the internet. By the end of the ’60s, the myth of cybernetic organisms and living machines had begun to retreat into science fiction—and critical theory.

IV

The notion that machines could outthink humans was still hot among scientists in the 1960s. Irving "Jack" Good was a leading UK mathematician, then based at Trinity College, Oxford, and the Atlas Computer Lab in Chilton. He had worked as a cryptologist at Bletchley Park with Alan Turing during the war, and later at GCHQ until 1959.[86] Good had become convinced that "ultraintelligent machines" would soon be built. "The survival of man depends on the early construction of an ultraintelligent machine," he enigmatically opened his most-read paper, in 1965. In Good's view, a machine was ultraintelligent if it could "far surpass" all the intellectual activities of any human being, however clever. Once this was achieved, Good reasoned, then a singular moment in human history would have arrived. Humans would not be at the top of creation any longer.

> Since the design of machines is one of these intellectual activities, an ultraintelligent machine could design even better machines; there would then unquestionably be an "intelligence explosion," and the intelligence of man would be left far behind. Thus the first ultraintelligent machine is the last invention that man need ever make, provided that the machine is docile enough to tell us how to keep it under control.[87]

The notion that man might be able to create other new intelligent beings is as bold as it is old. Much bolder and grander was the idea that man could create an even better creator than himself or, indeed, than whoever had created him. Good took off where Wiener, who had died the year before, had left it. He didn't want just to play God, but to create an even better God.

By the 1970s, such ideas had found a home in science fiction—not least, thanks to Good himself, who had served as a consultant for Stanley Kubrick's *2001: A Space Odyssey*. One of the prime meeting places for science and science fiction at the time was *Omni* magazine. Founded by Bob Guccione, who also started *Penthouse* magazine, it was published in print between 1978 and 1995. Many futuristic ideas were either born or buried in *Omni*'s brightly illustrated pages.

One example was science fiction writer Vernor Vinge's word "singularity." Having read Good, Vinge chose to describe the British scientist's intelligence explosion as a "singularity," the expected future moment when machines would overtake humans in their intellectual capacities.[88] Vinge, himself an unsuccessful scientist at San Diego State University but a quite successful science fiction writer, compared that moment to a black hole: “When this happens,” he wrote in *Omni* in early 1983, “human history will have reached a transition as impenetrable as the knotted space-time at the center of a black hole, and the world will pass far beyond our understanding.”[89]

Meanwhile, a student in Germany was occupied with similar thoughts. Jürgen Kraus mentioned and analyzed computer viruses for the first time in his master’s thesis, written in the late 1970s: “Selbstreproduktion bei Programmen.”[90] Biology saw reproduction and mutation as crucial features of all life. Computer programs had some of the same features. “Is it perhaps even possible to speak of living programs, as is done in biology?” Kraus asked.

Large mainframe computers, Kraus wrote in 1979, would already form a “universe” of circuits and bits.[91] The complexity of these systems was comparable to the complexity of a young planet Earth. Software, Kraus observed, never operated at 100 percent accuracy; it was never perfect. Therefore, the possibility of mutation among programs was real. The search for life among computer programs, Kraus was sure, was a matter of philosophy and theoretical biology.[92]

Kraus traced the parallels of biological systems and computers over 228 pages. He was obsessed by the question of whether programs, like biological organisms, were alive and whether they could *evolve* as all living entities do. A self-reproducing program, he reasoned, resided in the “environment” that is the computer, its hardware and software, and its memory. The environment, Kraus argued, was alive, “*belebt*”: the self-reproducing programs would put competitive pressure on each other, including “conflict behavior” and selection pressure. In effect, then, the “evolution” of self-reproducing programs had become a possibility.[93]

Kraus highlighted the technical differences between the biological virus and self-reproducing software: A biological virus “actively initiates its reproduction by intruding into the energy-providing system ‘cell,’” Kraus wrote. “A self-reproducing program can’t do that.” A computer virus, even if it was already inside the “memory-space and energy-providing system ‘computer,’” required activation on the part of the machine’s operating system.[94]

Kraus helped coin an expression that has since become ubiquitous: computer virus. But his entire analysis was off base, as he admitted later. His discussion was also somewhat quaint by the time he published it, inspired by ideas that had already fallen out of fashion among his English-speaking colleagues in computer science and engineering. The old cybernetic idea that machines—hardware or software, alone or networked—could come alive, self-reproduce, mutate, and turn on their creators would continue to appeal to science fiction authors and screenwriters. But it had only a short moment of scientific attraction. In science and engineering, the "cybernetics moment" had by the early 1970s passed.[95] Scientists and engineers moved on, no longer captivated by the idea of creating cybernetic organisms.

The cyborg was reborn as a powerful myth and metaphor a dozen years later. This new discourse on cyborgs quickly became pervasive and dominant. So dominant that by far the most widely read and most widely cited nonfiction articles and books on cyborgs are on feminism and postmodern thought, not engineering.[96]

Donna Haraway is the best known of these thinkers. Like Alice Mary Hilton a generation earlier, Haraway drew her inspiration from cybernetics and launched into an ambitious project of cultural engineering with socialist leanings. In 1985 she was a newly minted professor in the history of consciousness at UC Santa Cruz. That year, Haraway published an essay in the *Socialist Review* that gave her a name: "A Cyborg Manifesto," its title and its theme of a call to action drawn from *A Communist Manifesto*. The text's success fell only slightly short of its title's youthful ambition.

Postmodernism was about blurring science and fiction. Haraway, from the start, said she believed that the boundary between science fiction and social reality was "an optical illusion."[97] The goal of the radical philosopher was to advance what she dubbed "socialist-feminism." Reality was full of contradictions. And one of the best ways to deal with contradiction was irony. With this warning, Haraway opened her manifesto: "At the center of my ironic faith," she wrote, "is the image of the cyborg." The image mattered to her, the comparison, the metaphor—not actually engineered humanoid robots.

"A cyborg is a cybernetic organism, a hybrid of machine and organism, a creature of social reality as well as a creature of fiction," she wrote. To Haraway, the cyborg was everywhere. Science fiction, of course, was full of cyborgs. So was modern medicine, where it was normal to hook up organisms to machines. Industrial production was full of humans merged with machines. So was sex. "And modern war is a cyborg orgy, coded C3I, command-control-communications-intelligence," she wrote, referring to a military abbreviation that was then in fashion. We are all cyborgs, she insisted.[98]

The cyborg was highly attractive to postmodern philosophers; it embodied many of their ideals. Cyborgs, as the feminist philosopher saw it, were about "breached boundaries." Such boundary-breaching beings would "confuse" historical stories, question identities that are taken as given, and blur what counted as distinct categories. The cyborg breached borders left and right: between body and machine, human and nonhuman, mind and body; between nature and culture, man and woman, maker and made; between active and passive, total and partial, agent and resource. It even broke up distinctions of consciousness and simulation, of the natural and the artificial, of right and wrong, of truth and illusion, and—perhaps most important—of God and man. In the postmodern view, these dualisms of the dreaded establishment underpinned much of what was wrong: patriarchy, imperialism, capitalism, even militarism.

As Haraway put it, "High-tech culture challenges these dualisms in intriguing ways." With machines becoming ever more creative, it is no longer clear who makes whom. It is also no longer clear what is mind and what is body "in machines that resolve into coding practices," she wrote, cryptically.[99]

The cyborg wasn't susceptible to bourgeois values. It wasn't made out of mud and therefore could not dream of returning to dust. Unlike Frankenstein's monster, it didn't expect its father to "restore the garden" by creating a female mate for it. It didn't dream of the organic family as its preferred form of community. The cyborg was deeply subversive.

"The main trouble with cyborgs, of course, is that they are the illegitimate offspring of militarism and patriarchal capitalism," Haraway lamented. She knew of Clynes's Cold War vision and the military funding that had gone into exoskeletons at General Electric. But she could live with that. "Illegitimate offspring are often exceedingly unfaithful to their origins," she pointed out. "Their fathers, after all, are inessential."[100]

"Our machines are disturbingly lively, and we ourselves are frighteningly inert," Haraway wrote, mystifyingly.[101]

Haraway was a self-described vegetarian, feminist mystic, deeply suspicious of what she saw as the Cold War's military-industrial complex and its "patriarchal" technologies, especially that "heavy brew of cybernetics in the 1950s and 1960s."[102] Viewed from Haraway's elevated academic perch, the jump from Manfred Clynes's enhanced rat to Arnold Schwarzenegger's Terminator was preordained:

> Cyborgs do not stay still. Already in the few decades that they existed, they have mutated, in fact and fiction, into second-order entities like genomic and electronic databases and other denizens of the zone called cyberspace.[103]

The feminist philosopher employed a scholarly trick: she clandestinely flipped the causality on its head. Cyborgs were blurring boundaries, but blurred boundaries were also creating cyborgs. Hence, she argued, we are all cyborgs.

At first glance, such a bold statement seemed a stretch, to say the least. The editors of the *Cyborg Handbook*, a jargon-heavy tome of postmodern free-association writing, saw their favorite creature not as a subject of geeky science fiction, but as a common fact: "It's not just *Robocop*, it is our grandmother with a pacemaker."[104] By 1995, the *Handbook* would point out, about 10 percent of the US population were estimated to be "cyborgs in a technical sense."[105] This estimate included people with an array of implants, such as artificial joints, electronic pacemakers, insulin pumps, new corneas in the eye, or artificial skin or limbs.

But 10 percent is still a small number. A much higher percentage were involved in some sort of labor that made them "metaphorical cyborgs," the *Handbook* continued. That could be a worker at a computer keyboard joined "in a cybernetic circuit" with the machine, or a neurosurgeon guided by fiber-optic microscopes on the job, or teenagers merged with the video console in a local arcade. Even the man who had invented cyborgs agreed: "*Homo sapiens*, when he puts on a pair of glasses, *has* already changed," Clynes told the handbook editor in 1995. "When he rides a bicycle he virtually has become a cyborg."[106]

Everybody was a cyborg. Therefore, Haraway's manifesto wasn't written as a manual for androids; it was a manual for everybody. The boundary-smashing *Terminator* had wider symbolic significance. It didn't just represent the rise of the machines of Skynet; it represented the fall of dearly held dividing lines for everybody. Perhaps it is not surprising, then, that several postmodern scholars actually focused their attention on the T-1000, the evil robot made of liquid metal in James Cameron's *Terminator 2*, played with steel-blue eyes by the handsome American actor Robert Patrick.

In one scene the fictional T-1000 changes into three shapes in a matter of a few seconds: from a female character (heroine Sarah Connor's mother), to a metallic proto-android in neutral shape, and then to a uniformed male police officer. To some postmodern scholars, the scene had a deeper philosophical meaning. It showed "melting boundaries," how "sexual identities can be reformulated." The scholars note the attraction of seeing the fictional liquid-metal robot from the future change shape: "There is a highly erotic aspect to watching a virtuoso display of changes in human body-image."[107]

Another feminist thinker, also writing about Cameron's second *Terminator* movie, pointed out that the fashion preferences of the killer machines, both Terminators—the T-800 played by Arnold Schwarzenegger in black leather and the T-1000 played by Robert Patrick in cop regalia—"exaggerate homosexual types" and would therefore subvert the normative heterosexual authority structures.[108]

The phenomenal success of postmodern subversive cyborgs was lost on Clynes, who had presented the original idea at the air force conference at Randolph Field in Texas in 1960. Clynes suggested reengineering human bodies, but reengineering human identities didn’t jibe with him. When the original *Terminator* was released, in late 1984, Clynes was experimenting with computers interpreting classical music, and he tried to link one of Haydn’s sonatas to human expressions of emotions through touch. The maker of the first cyborg watched *Terminator* and was horrified. “Schwarzenegger playing this thing,” Clynes recalled, “dehumanized the concept completely.” It made a monster out of something that wasn’t a monster, as the former researcher from Rockland State Hospital saw it. “This is a travesty of the real scientific concept we had.”[109] That, of course, was the point.