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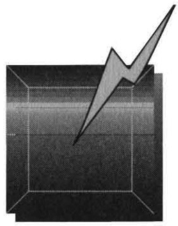

The Origins of the Internet

Katie Hafner and Matthew Lyon

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To the memory of J. C. R. Licklider
and to the memory of Cary Lu

Contents

Los Alamos' lights where wizards stay up late
(Stay in the car, forget the gate)
To save the world or end it, time will tell

—James Merrill,
"Under Libra: Weights and Measures,"
from *Braving the Elements*

Prologue

❑ September 1994

They came to Boston from as far away as London and Los Angeles, several dozen middle-aged men, reuniting for a fall weekend in 1994 to celebrate what they had done twenty-five years earlier. These were the scientists and engineers who had designed and built the ARPANET, the computer network that revolutionized communications and gave rise to the global Internet. They had worked in relative obscurity in the 1960s; a number of them had been only graduate students when they made significant contributions to the network. Others had been mentors. Most of them had never gained much recognition for the achievement.

Bolt Beranek and Newman, a computer company based in Cambridge, had been their center of gravity, had employed many of them, had built and operated the original ARPA network, then slipped into relative obscurity as the Internet grew like a teeming city around its earliest neighborhood. Now, a quarter-century after installing the first network node, BBN had invited all of the ARPANET pioneers to come together, hoping to heighten its own profile by throwing a lavish celebration marking the anniversary.

Many of those at the reunion hadn't seen one another or been in touch for years. As they filtered into the lobby of the Copley Plaza for a Friday afternoon press conference kicking off the celebration, they scanned the room for familiar faces.

Bob Taylor, the director of a corporate research facility in Silicon Valley, had come to the party for old times sake, but he was also on a personal mission to correct an inaccuracy of long standing. Rumors had persisted for years that the ARPANET had been built to protect national security in the face of a nuclear attack. It was a myth that had gone unchallenged long enough to become widely accepted as fact.

Taylor had been the young director of the office within the Defense Department's Advanced Research Projects Agency overseeing computer research, and he was the one who had started the ARPANET. The project had embodied the most peaceful intentions—to link computers at scientific laboratories across the country so that researchers might share computer resources. Taylor knew the ARPANET and its progeny, the Internet, had nothing to do with supporting or surviving war—never did. Yet he felt fairly alone in carrying that knowledge.

Lately, the mainstream press had picked up the grim myth of a nuclear survival scenario and had presented it as an established truth. When *Time* magazine committed the error, Taylor wrote a letter to the editor, but the magazine didn't print it. The effort to set the record straight was like chasing the wind; Taylor was beginning to feel like a crank.

Across the room at dinner that night at the Copley, Taylor spotted an elderly, heavyset man with a thick mustache. He recognized him immediately as the one person who could convincingly corroborate his story. It was his old boss, Charlie Herzfeld, who had been the director of ARPA when Taylor worked there. The two men had last seen each other years earlier, before anyone else cared about how the network began. Seeing Herzfeld now, Taylor was buoyed. He was back among the people who knew the real story. Now they'd straighten things out.

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The Fastest Million Dollars

❑ February 1966

Bob Taylor usually drove to work, thirty minutes through the rolling countryside northeast of Washington, over the Potomac River to the Pentagon. There, in the morning, he'd pull into one of the vast parking lots and try to put his most-prized possession, a BMW 503, someplace he could remember. There were few if any security checkpoints at the entrances to the Pentagon in 1966. Taylor breezed in wearing his usual attire: sport coat, tie, button-down short-sleeve shirt, and slacks. Thirty thousand other people swarmed through the concourse level daily, in uniform and mufti alike, past the shops and up into the warrens of the enormous building.

Taylor's office was on the third floor, the most prestigious level in the Pentagon, near the offices of the secretary of defense and the director of the Advanced Research Projects Agency (ARPA). The offices of the highest-ranking officials in the Pentagon were in the outer, or E-ring. Their suites had views of the river and national monuments. Taylor's boss, Charles Herzfeld, the head of ARPA, was among those with a view, in room 3E160. The ARPA director rated the highest symbols of power meted out by the Department of Defense (DOD), right down to the official flags beside his desk. Taylor was director of the Information Processing Techniques Office (IPTO), just a corridor away, an unusually independent section of ARPA charged with supporting the nation's most advanced computer research-and-development projects.

The IPTO director's suite, where Taylor hung his coat from 1965 to 1969, was located in the D-ring. What his office lacked in a view was compensated for by its comfort and size. It was a plushly carpeted and richly furnished room with a big desk, a heavy oak conference table, glass-fronted bookcases, comfortable leather chairs, and all the other trappings of rank, which the Pentagon carefully measured out even down to the quality of the ashtrays. (Traveling on military business, Taylor carried the rank of one-star general.) On one wall of his office was a large map of the world; a framed temple rubbing from Thailand hung prominently on another.

Inside the suite, beside Taylor's office, was another door leading to a small space referred to as the terminal room. There, side by side, sat three computer terminals, each a different make, each connected to a separate mainframe computer running at three separate sites. There was a modified IBM Selectric typewriter terminal connected to a computer at the Massachusetts Institute of Technology in Cambridge. A Model 33 Teletype terminal, resembling a metal desk with a large noisy typewriter embedded in it, was linked to a computer at the University of California in Berkeley. And another Teletype terminal, a Model 35, was dedicated to a computer in Santa Monica, California, called, cryptically enough, the AN/FSQ 32XD1A, nicknamed the Q-32, a hulking machine built by IBM for the Strategic Air Command. Each of the terminals in Taylor's suite was an extension of a different computing environment—different programming languages, operating systems, and the like—within each of the distant mainframes. Each had a different log-in procedure; Taylor knew them all. But he found it irksome to have to remember which log-in procedure to use for which computer. And it was still more irksome, after he logged in, to be forced to remember which commands belonged to which computing environment. This was a particularly frustrating routine when he was in a hurry, which was most of the time.

The presence of three different computer terminals in Taylor's Pentagon office reflected IPTO's strong connection to the leading edge of the computer research community, resident in a few of the nation's top universities and technical centers. In all, there were some twenty principal investigators, supporting dozens of graduate students, working on numerous projects, all of them funded by Taylor's small office, which consisted of just Taylor and a secretary. Most of IPTO's $19 million budget was being sent to campus laboratories in Boston and Cambridge, or out to California, to support work that held the promise of making revolutionary advances in computing. Under ARPA's umbrella, a growing sense of community was emerging in computer research in the mid-1960s. Despite the wide variety of projects and computer systems, tight bonds were beginning to form among members of the computer community. Researchers saw each other at technical conferences and talked by phone; as early as 1964 some had even begun using a form of electronic mail to trade comments, within the very limited proximity of their mainframe computers.

Communicating with that community from the terminal room next to Taylor's office was a tedious process. The equipment was state of the art, but having a room cluttered with assorted computer terminals was like having a den cluttered with several television sets, each dedicated to a different channel. "It became obvious," Taylor said many years later, "that we ought to find a way to connect all these different machines."

❏ A Research Haven

That there even existed an agency within the Pentagon capable of supporting what some might consider esoteric academic research was a tribute to the wisdom of ARPA's earliest founders. The agency had been formed by President Dwight Eisenhower in the period of national crisis following the Soviet launch of the first *Sputnik* satellite in October 1957. The research agency was to be a fast-response mechanism closely tied to the president and secretary of defense, to ensure that Americans would never again be taken by surprise on the technological frontier. President Eisenhower saw ARPA fitting nicely into his strategy to stem the intense rivalries among branches of the military over research-and-development programs. The ARPA idea began with a man who was neither scientist nor soldier, but soap salesman.

At fifty-two, Neil McElroy was a newcomer to the defense establishment. He had never worked in government, had never lived in Washington, and had no military experience except in the national guard. For thirty-two years, he had climbed the corporate ladder at Procter & Gamble, the giant soap manufacturer in Cincinnati.

A Harvard graduate, McElroy took his first job at P&G slitting envelopes as a mail clerk in the advertising department for twenty-five dollars a week. It was supposed to be a summer job; he had intended to enter business school in the fall. But he stayed on and began peddling soap door-to-door. Soon he became promotion manager. From there, he worked his way up by pioneering the selling of soap on radio and television. The TV soap opera was McElroy's brainchild, about which he once said without apology, "The problem of improving literary taste is one for the schools. Soap operas sell lots of soap." By 1957, P&G was selling about a billion dollars' worth of Ivory, Oxydol, Joy, and Tide every year. He had perfected the strategy of promoting brand-name competition—as if there were real differences—between similar products made by the same company. And for the past nine years, tall, handsome "Mac" as he was known to most (or "Soapy Mac from Cinci-O" to some), had been the company's president—until Eisenhower recruited him for his cabinet.

On the evening of Friday, October 4, 1957, President Eisenhower's new nominee for secretary of defense, McElroy, was in Huntsville, Alabama. He had already been confirmed by the Senate and was touring military installations in advance of his swearing-in.

A large entourage of Pentagon staff was in tow for Mac's tour of Redstone Arsenal, home of the Army's rocket program. At about six o'clock in the evening in the officers' club, McElroy was talking to German émigré Wernher von Braun, the father of modern rocketry, when an aide rushed up and announced that the Russians had succeeded in launching a satellite into earth orbit. Now suddenly, even before taking office, McElroy found himself engulfed in a crisis of huge proportions. In one night, the Soviet achievement had reduced America's booming postwar confidence and optimism to widening fear and despair. Suddenly "the spectre of wholesale destruction," in the president's words, bore down on the American psyche.

Five days later McElroy was sworn in, with Washington fully consumed in controversy over the question of who had let the Soviets steal the march on American science and technology. Some people had predicted the Soviets would launch a satellite in observance of the International Geophysical Year. "Their earlier preaching in the wilderness was redeemed by the Soviet scientific spectaculars," one observer said. "It now took on the aura of revealed truth." "I told you so" became a status symbol. Genuine fear, ominous punditry, and harsh criticism flowed around the central issue of the new Soviet threat to national security. Hysterical prophecies of Soviet domination and the destruction of democracy were common. *Sputnik* was proof of Russia's ability to launch intercontinental ballistic missiles, the pessimists said, and it was just a matter of time before the Soviets would threaten the United States. The least-panicked Americans were resigned to disappointment over Russia's lead in the race to explore space.

Eisenhower hadn't wanted a seasoned military expert heading the Pentagon; he was one himself. The president distrusted the military-industrial complex and the fiefdoms of the armed services. His attitude toward them sometimes bordered on contempt.

By contrast, he loved the scientific community. He found scientists inspiring—their ideas, their culture, their values, and their value to the country—and he surrounded himself with the nation's best scientific minds. Eisenhower was the first president to host a White House dinner specifically to single out the scientific and engineering communities as guests of honor, just as the Kennedys would later play host to artists and musicians.

Hundreds of prominent American scientists directly served the Eisenhower administration on various panels. He referred to them proudly as "my scientists." Ike "liked to think of himself as one of us," observed Detlev W. Bronk, president of the National Academy of Sciences.

Two prominent scientists once had breakfast with the president, and as they were leaving Eisenhower remarked that the Republican National Committee was complaining that scientists close to the him were not out "whooping it up" sufficiently for the Republican Party.

"Don't you know, Mr. President?" replied one of the men with a smile. "All scientists are Democrats."

"I don't believe it," Eisenhower shot back. "But anyway, I like scientists for their science and not for their politics."

When the *Sputnik* crisis hit, Eisenhower pulled his scientists still more tightly into his circle. First, he held a number of private meetings with prominent scientists from outside the government. Eleven days after the news of the Soviet satellite, on October 15, 1957, Eisenhower sat down for a lengthy discussion with his Science Advisory Committee, a full contingent of the nation's best minds. Neither he nor any of them was as concerned about the actual significance of *Sputnik* as were those who were using the issue against Ike. For one thing, Eisenhower knew a great deal more than he could say publicly about the status of the Russian missile programs; he had seen the exquisitely detailed spy photographs made from a U-2 spy plane. He knew there was no missile gap. He also knew that the American military and its contractors had a vested interest in the Soviet threat. Still, he asked his science advisors for their estimation of Soviet capability. Eisenhower listened closely as they soberly assessed the meaning of the *Sputnik* launch. They told him the Russians had indeed gained impressive momentum. They said the United States would lose its scientific and technological lead unless it mobilized.

Many of the scientists around Eisenhower had been worrying since the early 1950s that the government either misused or misunderstood modern science and technology. They urged Eisenhower to appoint a single high-level presidential science advisor, "a person he could live with easily," to help him make decisions involving technology. The launch of *Sputnik II* just a month after the first *Sputnik* increased the pressure. The first satellite, a 184-pound object the size of a basketball, was bad enough. Its fellow traveler weighed in at half a ton and was nearly the size of a Volkswagen Bug.

A few days after the news of *Sputnik II,* Eisenhower told the nation that he found his man for science in James R. Killian Jr., president of the Massachusetts Institute of Technology. Killian was a nonscientist who spoke effectively on behalf of science. On November 7, 1957, in the first of several addresses to reassure the American people and reduce panic, the president announced Killian's appointment as science advisor. It came late in the address but made front-page news the following day. The president had drawn links between science and defense, and said Killian would "follow through on the scientific improvement of our defense." The press dubbed Killian America's "Missile Czar."

During the October 15 meeting with his science advisors, the president had spoken of his concern over the management of research in government. "With great enthusiasm and determination the president wanted the scientists to tell him where scientific research belonged in the structure of the federal government," said Sherman Adams, the president's executive assistant. In addition, Eisenhower told them he had a fine man in Secretary of Defense McElroy and urged the scientists to meet with the new secretary, which they did that very day.

They found that Secretary McElroy had a similar appreciation for them. One aspect of his career at P&G that he was most proud of was the amount of money the company had devoted to research. He believed in the value of unfettered science, in its ability to produce remarkable, if not always predictable, results. McElroy and P&G had created a large "blue-sky" research laboratory, had funded it well, and rarely if ever pressured its scientists to justify their work. It was one of the first corporate research operations of its kind, one in which scientists were left to pursue almost anything and were well supported from the top.

Significant technological advances had come from a similar arrangement between universities and government during World War II: radar, nuclear weapons, and large calculating machines resulted from what Killian called "the freewheeling methods of outstanding academic scientists and engineers who had always been free of any inhibiting regimentation and organization."

In consultation with Killian, whose support was crucial, McElroy began discussing the idea of establishing an independent agency for research. Perhaps McElroy was aware that the U.S. Chamber of Commerce had floated the notion of creating a single research-and-development agency for the federal government during congressional hearings months before *Sputnik*. Such talk was in the air. The idea now emerged in discussions with an informal advisory committee of astute industrialists who met regularly with the secretary of defense.

In the days immediately following the Soviet launch, two men had been to see McElroy: eminent nuclear physicist Ernest O. Lawrence, and Charles Thomas, a former CEO of the Monsanto Chemical Company and an occasional advisor to the president. In a meeting lasting several hours, they discussed the idea of a strong advanced R&D agency that would report to the secretary, and both visitors urged McElroy to run with it. Physicist Herbert York, director of the Livermore Laboratory and close confidant to both Eisenhower and Killian, joined the conversations. At the same time, McElroy himself was consulting frequently with Killian and the president. In Killian's view, the traditional missions of the armed services had been outmoded by modern science and technology. Here was a way to move the Pentagon into the new age. One of the principal attractions of the research agency concept, in McElroy's mind, was the ability it would give him to manage the fierce competition within DOD over R&D programs and budgets. The competition was reaching absurd new heights. Army, Navy and Air Force commanders treated *Sputnik* like the starting gun in a new race, each vying against the other for the biggest share of R&D spending.

McElroy believed that a centralized agency for advanced research projects would reduce interservice rivalry by placing federal R&D budgets substantially under his own close supervision. Moreover, it would almost certainly appeal to the president, since the military's often selfish claims and special-interest hype usually met with disdain in the White House.

Eisenhower liked the secretary's proposal. While the administration had larger plans in store—the creation of the National Aeronautics and Space Administration (NASA), passage of a Defense Reorganization Act, establishment of the office of a Director of Defense Research and Engineering—those things would take time. The Advanced Research Projects Agency concept was a response the president could point to immediately. And it would give him an agile R&D agency he and his scientists could call on in the future.

On November 20, 1957, McElroy went to Capitol Hill for the first time as secretary. In the course of testifying about U.S. ballistic missile programs he mentioned that he had decided to set up a new "single manager" for all defense research. In the near term, he told Congress, the new agency would handle satellite and space R&D programs. The next day he circulated to the Joint Chiefs of Staff a draft charter and directive for the new agency, asking for their review and comments.

The military bristled at the implied criticism. It was one thing to have civilian science and technology *advisors,* but McElroy was now clearly invading their turf, planning to manage and operate a central office that would control defense R&D programs and future weapons projects. They were prepared to fight back. Secretary of the Air Force James Douglas wrote, "The Air Force appreciates that the proposals are suggestions." That is, message received, not accepted. The Army, Navy, and Joint Chiefs of Staff returned the draft charter with numerous revisions. They fiddled deviously with language concerning the new agency's contracting authority, their revisions peppered with subversive word changes, crafty additions, and sly deletions all designed to weaken and confine the agency.

McElroy conceded a few minor points but made two things clear:

The agency's director would have contracting authority, and the scope of the agency's research was to be unlimited.

On January 7, 1958, Eisenhower sent a message to Congress requesting startup funds for the establishment of the Advanced Research Projects Agency. Two days later he drove the point home in his State of the Union Message. "I am not attempting today to pass judgment on the charges of harmful service rivalries. But one thing is sure. Whatever they are, America wants them stopped."

Eisenhower also affirmed "the need for single control in some of our most advanced development projects," then delivered his coup de grâce to the generals: "Another requirement of military organization is a clear subordination of the military services to the duly constituted civilian authority. This control must be real; not merely on the surface."

In early 1958, Roy Johnson, a vice president of General Electric, was appointed ARPA's first director; five days after the appointment, funding was approved by Congress (as a line item in an Air Force appropriations bill), and ARPA went into business.

In the post-*Sputnik* panic, the race for outer space cut a wide swath through American life, causing a new emphasis on science in the schools, worsening relations between Russia and the United States, and opening a floodgate for R&D spending. Washington's "external challenge" R&D spending rose from $5 billion per year to over $13 billion annually between 1959 and 1964. *Sputnik* launched a golden era for military science and technology. (By the mid-1960s, the nation's total R&D expenditures would account for 3 percent of the gross national product, a benchmark that was both a symbol of progress and a goal for other countries.)

All eyes were on ARPA when it opened its doors with a $520 million appropriation and a $2 billion budget plan. It was given direction over all U.S. space programs and all advanced strategic missile research. By 1959, a headquarters staff of about seventy people had been hired, a number that would remain fairly constant for years. These were mainly scientific project managers who analyzed and evaluated R&D proposals, supervising the work of hundreds of contractors.

Roy Johnson, ARPA's first director, was, like his boss, a businessman. At age fifty-two, he had been personally recruited by McElroy, who convinced him to leave a $160,000 job with General Electric and take an $18,000 job in Washington.

Not surprisingly, Johnson approached America's R&D agenda as a management problem. Management skills were his strong suit. His job, as he saw it, was to exhort people to do anything necessary to get the edge on the Soviets. He argued often and vigorously with rooms full of generals and admirals, and aggressively took on the Air Force. It soon became apparent that Johnson was a serious and vociferous advocate of a strong military presence in outer space.

But of course Killian and other scientists around Eisenhower had wanted someone well versed in scientific and technological issues running ARPA. Johnson had been instructed to hire a military flag officer as his deputy, and to select a chief scientist to round out his leadership team. The scientific post had almost gone to Wernher von Braun, until he insisted on bringing his whole team of a dozen associates with him to the Pentagon. So Herbert York, whom Killian had been keen on, was given the job and moved to ARPA from the Lawrence Livermore Laboratory. When he arrived on the third floor at the Pentagon, York promptly hung a large picture of the moon on his office wall. And right beside it he hung an empty frame. He told visitors it would soon be filled with the first picture of the back side of the moon.

The rest of ARPA's staff was recruited from industry's top-flight technical talent at places like Lockheed, Union Carbide, Convair, and other Pentagon contractors. The staff's days were spent sifting for gold in a torrential flow of unsolicited R&D proposals.

ARPA's success hinged on Johnson's extremely vocal posturing about America's role in outer space and his simplistic view of Soviet-American tensions. He mistakenly defined ARPA's mission almost entirely in military terms, outlining the kind of space projects he envisioned: global surveillance satellites, space defense interceptor vehicles, strategic orbital weapon systems, stationary communications satellites, manned space stations, and a moon base.

Eisenhower and his civilian scientists had moved ahead with the rest of their agenda, and by the late summer of 1958 the National Aeronautics and Space Administration had been enacted into law. Almost overnight, while Johnson drummed for a military presence in space, the space projects and missile programs were stripped away from ARPA and transferred over to NASA or back to the services, leaving ARPA's budget whittled to a measly $150 million. ARPA's portfolio was gutted, its staff left practically without any role. *Aviation Week* called the young agency "a dead cat hanging in the fruit closet."

Johnson resigned. Before leaving, however, he commissioned his staff to draft a paper weighing four alternatives: abolishing ARPA, expanding it, making no changes, or redefining its mission. His analysts threw themselves into building a case for the fourth alternative, and their tenacity alone saved the agency from sure oblivion. They fleshed out a set of goals to distance ARPA from the Pentagon by shifting the agency's focus to the nation's long-term "basic research" efforts. The services had never been interested in abstract research projects; their world was driven by near-term goals and cozy relationships with industrial contractors. The staff of ARPA saw an opportunity to redefine the agency as a group that would take on the really advanced "far-out" research.

Most important of all, ARPA staffers recognized the agency's biggest mistake yet: It had not been tapping the universities where much of the best scientific work was being done. The scientific community, predictably, rallied to the call for a reinvention of ARPA as a "high-risk, high-gain" research sponsor—the kind of R&D shop they had dreamed of all along. Their dream was realized; ARPA was given its new mission.

As ARPA's features took shape, one readily apparent characteristic of the agency was that its relatively small size allowed the personality of its director to permeate the organization. In time, the "ARPA style"—freewheeling, open to high risk, agile—would be vaunted. Other Washington bureaucrats came to envy ARPA's *modus operandi.* Eventually the agency attracted an elite corps of hard-charging R&D advocates from the finest universities and research laboratories, who set about building a community of the best technical and scientific minds in American research.

The agency's new basic research and special-project orientation was ideally suited to the atmospheric change in Washington caused by the election of John F. Kennedy. With vigor, Washington's bureaucracies responded to the Kennedy charisma. At the Pentagon, Robert S. McNamara, the new secretary of defense, led the shift away from the philosophy of "massive retaliation" in America's strategic posture, and toward a strategy of "flexible response" to international threats to American supremacy. Science was the New Frontier.

In early 1961 ARPA's second director, Brigadier General Austin W. Betts, resigned and was replaced by Jack P. Ruina, the first scientist to direct ARPA. Ruina came with strong academic credentials as well as some military background. Trained as an electrical engineer, he had been a university professor and had also served as a deputy assistant secretary of the Air Force. He was on good terms with members of the science advisory panels to the White House.

A golden era for ARPA was just beginning. Ruina brought a relaxed management style and decentralized structure to the agency. Details didn't interest him; finding great talent did. He believed in picking the best people and letting them pick the best technology. He felt strongly about giving his program directors free rein. His job, as he saw it, was to build as much support and funding as he could for whatever projects they selected. Ruina had a theory that truly talented people wouldn't normally choose to hang around long in a government bureaucracy but could be convinced to spend a year or two if offered enough flexibility and large enough budgets. Turnover didn't bother him. The agency, he believed, would benefit from frequent exposure to fresh views. In keeping with all that, he saw himself as a short-timer, too.

In time, Ruina raised ARPA's annual budget to $250 million. Projects in ballistic missile defense and nuclear test detection, couched in terms of basic research, were the top priorities. (There were also programs like behavioral research and command and control which, though interesting, fell below the level of Ruina's close attention.)

Then in May 1961 a computer, and a very large one at that, demanded his attention. A program in military command and control issues had been started at ARPA using emergency DOD funds. For the work, the Air Force had purchased the huge, expensive Q-32, a behemoth of a machine that was to act as the backup for the nation's air defense early-warning system. The machine had been installed at a facility in Santa Monica, California, at one of the Air Force's major contractors, System Development Corporation (SDC), where it was supposed to be used for operator training, and as a software development tool.

Then the Air Force had been forced to cut back, which left the Santa Monica firm begging for some way to keep its employees working with the computer. The Air Force, which had already sunk millions into the SDC contract, suddenly had an embarrassing white elephant on its hands in the form of one massive, ungainly computing machine.

❑ Licklider

The relationship between the military and computer establishments began with the modern computer industry itself. During World War II, in the midst of a perceived need for faster calculating ability than could be provided by the banks of mechanical calculators run by human operators, the military funded dozens of computing experiments. The Navy supported Howard Aiken, the Harvard mathematics professor who dreamed of building a large-scale calculator and ended up with the Mark I, a fifty-one-foot-long, eight-foot-tall switchboard that could perform arithmetical operations without the intervention of an operator. The Army also supported the famous Electronic Numerical Integrator And Calculator (ENIAC) project at the University of Pennsylvania. Later at MIT, first the Navy and then the Air Force supported a computer called Whirlwind.

In the early 1950s computing meant doing arithmetic fast.

Companies, especially banks, put their machines to work doing large-scale calculations. In 1953, International Business Machines Corporation (IBM), already the country's largest manufacturer of time clocks as well as electromechnical tabulating equipment, jumped into the business of making large electronic computers. These were business machines of the future. The IBM machines weren't necessarily better than the Univac (the successor to the ENIAC), but IBM's sales staff became legendary, and before too long sales of IBM's machines had surpassed those of the Univac.

Then, in the late 1950s, just as IBM was passing the billion-dollar-sales mark, Ken Olsen, an individualistic and outspoken engineer, left MIT's Lincoln Laboratory with $70,000 in venture capital to exploit commercially the technology developed around a new machine: the TX-2 at Lincoln Lab. He formed the Digital Equipment Corporation to manufacture and sell computer components, and then he built something radically different from what had existed before: a smaller computer called a minicomputer that interacted directly with the user. Olsen's idea for an interactive computer had come from a pioneering group of computer researchers at MIT. A different, slightly younger group there came up with another dramatic concept in computing that was beginning to catch on, particularly in academic institutions. They called it "time-sharing," and it had obvious appeal as an alternative to the slow and awkward traditional method of "batch" processing.

Batch processing was a cumbersome way of computing. For even the smallest programming task, it was necessary to have the relevant code punched onto program cards, which were then combined with "control cards" to take care of the computer's administrative functions. A computer operator fed the cards into the computer or onto magnetic tape for processing, one batch at a time. Depending on the length of the queue and the complexity of the programs and problems, the wait could be long. It was not unusual to wait a day or longer for results.

Time-sharing was, as the term suggests, a new method of giving many users interactive access to computers from individual terminals. The terminals allowed them to interact directly with the mainframe computer. The revolutionary aspect of time-sharing was that it eliminated much of the tedious waiting that characterized batch-process computing. Time-sharing gave users terminals that allowed them to interact directly with the computer and obtain their results immediately. "We really believed that it was a better way to operate," recalled Fernando Corbató, an MIT computer scientist. "I suppose if somebody had said, 'I will give you a free machine,' we might have said, 'We do not need time-sharing.' " But computers in those days were huge things. They took up large rooms and required continual maintenance because there were so many components. "They were just not a casual thing," Corbató went on. "You did not normally think of having a personal machine in those days—exclusive use maybe, but not a personal one. So we really saw a need to try to change that. We were frustrated." The appreciation of time-sharing was directly proportional to the amount of direct access one had to the computer. And usually that meant that the more you programmed, the better you understood the value of direct access.

What time-sharing could not do was eliminate the necessity of coordinating competing demands on the machine by different users. By its nature, time-sharing encouraged users to work as if they had the entire machine at their command, when in fact they had only a fraction of the total computing power. Distribution of costs among a number of users meant that the more users the better. Of course, too many users bogged down the machine, since a high percentage of the machine's resources were allocated to coordinating the commands of multiple users. As the number of users increased, more of the computer's resources were dedicated to the coordination function, which reduced actual usable processing time. If programmers had to do very small jobs (such as tightening code or minor debugging of a program), they didn't need a powerful machine. But when it came time to run the programs in full, many of which used a lot of machine resources, it became apparent that users were still in competition with one another for computing time. As soon as a large program requiring a lot of calculations entered the mix of jobs being done on-line, everyone's work slowed down.

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When the Air Force passed the Q-32 on to ARPA in 1961, Ruina didn't have anyone to administer the contract. Ruina had in mind a job with the potential for expansion far beyond the single contract that happened to be pressing at the moment: Computers, as they related to command and control, might one day provide high-speed, reliable information upon which to base critical military decisions. That potential, largely unfulfilled, seemed endlessly promising.

Coincidentally, Ruina also was looking for someone who could direct a new program in behavioral sciences that DOD wanted ARPA to run. By the fall of 1962, Ruina had found the candidate who could fill both posts, an eminent psychologist named J. C. R. Licklider.

Licklider was an obvious choice to head a behavioral sciences office, but a psychologist wasn't an obvious choice to oversee a government office focused on developing leading-edge computer technology. Yet Licklider's broad, interdisciplinary interests suited him well for the job. Licklider had done some serious dabbling in computers. "He used to tell me how he liked to spend a lot of time at a computer console," Ruina recalled. "He said he would get hung up on it and become sort of addicted." Licklider was far more than just a computer enthusiast, however. For several years, he had been touting a radical and visionary notion: that computers weren't just adding machines. Computers had the potential to act as extensions of the whole human being, as tools that could amplify the range of human intelligence and expand the reach of our analytical powers.

Joseph Carl Robnett Licklider was born in St. Louis in 1915. An only and much-beloved child, he spent his early years nurturing a fascination with model airplanes. He knew he wanted to be a scientist, but he was unfocused through most of his college days at Washington University. He switched concentrations several times, from chemistry to physics to the fine arts and, finally, to psychology. When he graduated in 1937 he held undergraduate degrees in psychology, mathematics, and physics. For a master's thesis in psychology, he decided to test the popular slogan "Get more sleep, it's good for you" on a population of rats. As he approached his

Ph.D., Licklider's interests narrowed toward psychoacoustics, the psychophysiology of the auditory system.

For his doctoral dissertation, Licklider studied the auditory cortex of cats, and when he moved to Swarthmore College, he worked on the puzzle of sound localization, attempting to analyze the brain's ability to determine a sound's distance and direction. If you close your eyes and ask someone to snap his fingers, your brain will tell you approximately where the snap is coming from and how far away it is. The puzzle of sound localization is also illustrated by the "cocktail party" phenomenon: In a crowded room where several conversations are taking place within one's hearing range, it is possible to isolate whatever conversation one chooses by tuning in certain voices and tuning out the rest.

In 1942 Licklider went to Cambridge, Massachusetts, to work as a research associate in Harvard University's Psycho-Acoustic Laboratory. During the war years, he studied the effects of high altitude on speech communication and the effects of static and other noise on reception by radio receivers. Licklider conducted experiments in B-17 and B-24 bombers at 35,000 feet. The aircraft weren't pressurized, and the temperatures on board were often well below freezing. During one field test, Licklider's colleague and best friend, Karl Kryter, saw Licklider turn white. Kryter panicked. He turned up the oxygen and yelled to his friend, "Lick! Speak to me!" Just as Kryter was about to ask the pilot to descend, the color returned to Licklider's face. He had been in tremendous pain, he said, but it had passed. After that, he stopped partaking of his favorite breakfast—Coca-Cola—before going on high-altitude missions.

By this time, Licklider had joined the Harvard faculty and was gaining recognition as one of the world's leading theorists on the nature of the auditory nervous system, which he once described as "the product of a superb architect and a sloppy workman."

Psychology at Harvard in those years was strongly influenced by the behaviorist B. F. Skinner and others who held that all behavior is learned, that animals are born as blank slates to be enscribed by chance, experience, and conditioning. When Skinner went so far as to put his own child in a so-called Skinner box to test behaviorist theories and other faculty members began doing similar experiments (albeit less radical ones), Louise Licklider put her foot down. No child of hers was going into a box, and her husband agreed.

Louise was usually the first person to hear her husband's ideas. Nearly every evening after dinner, he returned to work for a few hours, but when he got home at around 11:00 P.M. he usually spent an hour or so telling Louise his latest thoughts. "I grew up on his ideas," she said, "from when the seeds were first planted, until somehow or other he saw them bear fruit."

Everybody adored Licklider and, at his insistence, just about everybody called him "Lick." His restless, versatile genius gave rise through the years to an eclectic cult of admirers.

Lick stood just over six feet tall. He had sandy brown hair and large blue eyes. His most pronounced characteristic was his soft, down-home Missouri accent, which belied his acute mind. When he gave talks or led colloquia, he never prepared a speech. Instead, he would get up and make extensive remarks off the cuff about a certain problem he happened to be working on. Lick's father had been a Baptist minister, and Louise occasionally chided him by noticing the preacher in him. "Lick at play with a problem at a briefing or a colloquium, speaking in that soft hillbilly accent, was a *tour de force,*" recalled Bill McGill, a former colleague. "He'd speak in this Missouri Ozark twang, and if you walked in off the street, you'd wonder, Who the hell is this hayseed? But if you were working on the same problem, and listened to his formulation, listening to him would be like seeing the glow of dawn."

Many of Lick's colleagues were in awe of his problem-solving ability. He was once described as having the world's most refined intuition. "He could see the resolution of a technical problem before the rest of us could calculate it," said McGill. "This made him rather extraordinary." Lick was not a formalist in any respect and seldom struggled with arcane theorems. "He was like a wide-eyed child going from problem to problem, consumed with curiosity. Almost every day he had some new fillip on a problem we were thinking about."

But living with Lick had its frustrations, too. He was humble, many believed, to a fault. He often sat in meetings tossing ideas out for anyone to claim. "If someone stole an idea from him," Louise recalled, "I'd pound the table and say it's not fair, and he'd say, 'It doesn't matter who gets the credit; it matters that it gets done.'" Throughout the many years he taught, he inspired all his students, even his undergraduates, to feel like junior colleagues. His house was open to them, and students often showed up at the front door with a chapter of a thesis or just a question for him. "I'd put my thumb up and they'd pound up to his third-floor office," said Louise.

In the postwar years, psychology was still a young discipline, inviting derision from those in the harder sciences with little patience for a new field that dealt with such enigmatic entities as the mind, or "the human factor." But Licklider was a psychologist in the most rigorous sense. As one colleague put it, he belonged with those "whose self-conscious preoccupation with the legitimacy of their scientific activity has made them more tough-minded than a good many of their colleagues in the better established fields."

By 1950, Lick had moved to MIT to work in the Institute's Acoustics Laboratory. The following year, when MIT created Lincoln Laboratory as a research lab devoted to air defense, Lick signed on to start the laboratory's human-engineering group. The cold war had come to dominate virtually the entire intellectual life of the institution. Lincoln Lab was one of the most visible manifestations of MIT's cold war alliance with Washington.

In the early 1950s many military theoreticians feared a surprise attack by Soviet bombers carrying nuclear weapons over the North Pole. And just as scientists had coalesced during the 1940s to deal with the possibility of German nuclear armament, a similar team gathered in 1951 at MIT to deal with the perceived Soviet threat. Their study was called Project Charles. Its outcome was a proposal to the Air Force for a research facility devoted to the task of creating technology for defense against aerial attack. Thus Lincoln Laboratory was quickly formed, staffed, and set to work under its first director, the physicist Albert Hill. In 1952, the lab moved off-campus to Lexington, about ten miles west of Cambridge. Its main projects centered around the concept of Distant Early Warning—the DEW