CHAPTER 7

New Applications of the Computer

Thelma Estrin and Biomedical Engineering

THELMA ESTRIN

Figure 1. Thelma Estrin, former president of the IEEE Engineering in Medicine and Biology Society, former executive vice president of the IEEE, recipient of the Distinguished Service Citation and an honorary doctorate from the University of Wisconsin, winner of the IEEE Haraden Pratt Award, and current resident of Santa Monica, California.

At the beginning of 1942 the United States faced a severe labor shortage. Even before the US's entry into the war a month earlier, factories were expanding production and working overtime to make this country, in President Roosevelt's phrase, "the arsenal of democracy." In the first months after the attack on Pearl Harbor, millions of men left their jobs to enlist in the military, and the labor shortage became acute in the defense industries as the production of aircraft, ships, trucks, artillery, uniforms, munitions, and other matériel increased dramatically. The government concluded that the only solution was to "employ women on a scale hitherto unknown."[1] An advertising campaign, featuring Rosie the Riveter, urged women to serve their country by entering the work force. The campaign was successful—by the middle of 1945 the female work force had increased by 6.5 million, a 57 percent increase.

One woman who helped meet this need was an 18-year-old New Yorker who enrolled in a 3-month engineering-assistant course at the Stevens War

Industries Training School—recently established by the Stevens Institute of Technology in Hoboken, New Jersey—and then worked for two years at Radio Receptor Company. (See Figure 2.) The young woman went on to a distinguished career as an electrical engineer. Though wartime circumstances influenced the training and employment she took, her determination to pursue a career of her own predated the war.

Figure 2. Thelma Estrin in the machine shop of the Radio Receptor Company of New York City.

From Schoolgirl to Engineering Assistant

Thelma Austern was born 21 February 1924 to Jewish parents in New York City's Harlem section, then mainly a middle-class area.[2] Her father, I. Billy Austern, was a shoe wholesaler and traveled a great deal. Her mother, Mary Ginsburg Austern, was unusually independent for a woman at that time. Before her marriage she ran an automobile parts store; she also drove a car, which few women then did. After her marriage she gave most of her energy to maintaining a kosher home and rearing her only child, but continued to be active in the local Democratic Party and in the Order of the Eastern Star (a fraternal and service society associated with freemasonry).

The Depression brought hard times to the family. They moved to Brighton Beach in Brooklyn, first to a fairly nice apartment, then to a less expensive one. It was always Mary Austern's dream to own a piano and have her daughter take lessons, but this was never possible. Mary's hope that her daughter excel in her education was, however, fulfilled. She expected Thelma to go to college and follow a profession, preferably law, and she did not want her to study typing as many other girls then did.

Thelma did well in all subjects and liked mathematics especially. At Abraham Lincoln High School she took an extra math class during her senior year, partly through the influence of her friend Richard Bellman, who later became a famous applied mathematician (and recipient of the IEEE Medal of Honor). Thelma and Richard dated for some time, but went their separate ways. One factor was a difference in political orientation: Thelma was at the time active in the American Student Union, a liberal group, while Bellman was more conservative.

It was through the American Student Union that Thelma met Gerald Estrin in June 1941. He was a history major at the City College of New York; that January, Thelma had begun studies there. On 21 December, two weeks after the attack on Pearl Harbor, she and Gerald were married. It was also in that period that both of her parents died: Mary Austern of cancer in March 1941 and Billy Austern of polycythemia in January 1942.

The war caused Thelma and Jerry, like countless others, to change their plans. Jerry enlisted in the Army Signal Corps and, before being called to active duty in 1943, worked at Kurman Electric Company, which made electromagnetic relays. Thelma, as we have seen, enrolled in the engineering-assistant course at Stevens Institute of Technology and then worked at Radio Receptor Company in New York City. A company publication reported, "We have seen Thelma manipulating lathes, shapers and surface grinders and squinting at micrometers and surface gauges with all the aplomb of an experienced toolmaker."[3] The publication reported also that history and tennis were among her favorite hobbies (commenting, "From a casual survey of her physique, we would venture to guess that she spends more time with a racquet than with Beard and Prescott") and that radio was her chief interest. In accord with this interest, she was soon transferred from the tool and model shop to the company laboratory, where she assembled test equipment and repaired radio transmitters. She also took evening classes in engineering at City College.

In 1945 Thelma joined Jerry in Montgomery, Alabama for a short period before they were moved to San Bernardino, California. There Thelma worked as a radio technician for the Army Air Force. When the European phase of the war ended, Jerry was transferred to Salt Lake City. Thelma returned to New York City and resumed studies in engineering at City College. Mechanical drawing was the major challenge. She says she had little aptitude for three-dimensional visualization, and "Where most students would work for a half hour, I would work three times as long."[4] But she finally gained facility at mechanical drawing and, in later life, taught the subject.

When my husband Jerry was a senior in high school (1936), he was very interested in becoming an engineer, particularly electrical, because he was outstanding in mathematics (and disliked chemistry). However, it was commonly recognized that Jewish engineers would rarely be hired by large industrial corporations, particularly power engineering firms. In fact, many private universities would not allow Jewish young men to major in engineering, because they supported industry's biased point of view. City College in New York City did allow all qualified young men to enroll in engineering, but even in the radio and electronics field employment possibilities were very limited. Jerry therefore decided to go to the City College School of Business and Management, where we met. With the second world war, the electronics industry bloomed and Jerry entered the Signal Corps.

When Jerry obtained his Ph.D. in electrical engineering, in 1950, he was strongly recommended to Bell Telephone Laboratories by his professor, but Bell did not readily hire Jewish engineers. Jerry was interviewed and might have received a position if he hadn't decided to accept an offer from John von Neumann at the Institute for Advanced Study. Interestingly, RCA employed many electronic engineers who were Jewish (David Sarnoff who headed RCA was a Jew), but to our knowledge Bell employed no Jewish engineers.[5]

An EE Education at an Accelerated Pace

Jerry was discharged from the Army in December 1945, and three months later he and Thelma moved to Madison, Wisconsin, to enter the undergraduate electrical engineering program at the university. They managed financially because Jerry had GI Bill support, Thelma sold her mother's diamond ring, and both got part-time work as teaching assistants. Thelma reports, "At school nobody took me very seriously. Most of my classmates thought that Jerry was either keeping me in school to keep me out of mischief, or so that I could help him with his homework. But I took myself seriously and Jerry took me seriously. From the beginning, our marriage . . . has been a partnership. This was something that came to both of us quite naturally. I was an only child whose mother wanted me to be a professional woman. . . . Jerry's mother was a small business woman, so neither of us had to overcome the mindset of believing women's place was only in the home."[6]

They both had EE experience as well as college credits, and they were both extremely industrious. "By working 18 hours a day and not taking vacations, we both zipped through Wisconsin, obtaining B.S., M.S., and Ph.D. degrees in record time."[7] Thelma received her B.S. in 1948, her M.S. in 1949, and her Ph.D. in 1951. As a graduate student, Jerry received research assistantships—this helped him complete his Ph.D. a year earlier than Thelma—while she could get only teaching assistantships. She believes that this was the result of the prevalent attitude that her interest in engineering would last only until she and her husband had children.

Estrin, however, was determined to maintain a career, and she wanted to do this while still having children and raising a family. She therefore decided to concentrate on analytical rather than experimental EE, as she believed that analytical engineering would better permit interruptions and part-time work than would experimental engineering.[8] She asked Professor Thomas J. Higgins, an authority on numerical methods as employed in electrical engineering, to be her advisor. Her master's thesis was an extension of a known method (double Laplace transformations) to solve problems in electric circuit analysis and electromagnetic theory, and she coauthored with Higgins an article presenting her main results.[9] In her doctoral thesis she showed how to use the method of incremental areas to calculate, to any degree of accuracy, the charge distribution of a capacitor consisting of two planar plates.[10] Here too she coauthored with Higgins an article presenting her main results.[11]

As they were nearing completion of their Ph.D.s, Thelma and Jerry received identical telegrams from Bell Aircraft offering a job at $5000 a year. Jerry, however, had a much more exciting opportunity: to join John von Neumann's computer project at the Institute for Advanced Study in Princeton, New Jersey.

To Princeton and into Medical Electronics

Three papers written jointly by von Neumann, Arthur Burks, and Herman Goldstine in the years 1946 to 1948 presented for the first time a detailed description of an electronic stored-program computer, and in 1946 von Neumann began a project to build such a machine at the Institute for Advanced Study (IAS).[12] Von Neumann originally estimated that three years would be required to complete a functional machine. It turned out that it took six years, and in the summer of 1950 much work remained.

As soon as Jerry completed his Ph.D. in June 1950, the Estrins moved to Princeton. For three or four months Thelma also worked on the IAS computer project—to test and document the arithmetic unit of the machine. She then returned to her dissertation research. This involved complex and lengthy calculations, for which she drew on local resources—the simultaneous equation solver (an early analog computer) of the Radio Corporation of America, and the wife of an Institute physicist armed with a Marchant calculator.

When Estrin received her Ph.D. in the summer of 1951, she sought employment. Because she didn't want to work at the same place as her husband, almost the only possibility in the Princeton area was the research laboratory of the Radio Corporation of America. Though she did receive an interview (with Jan Rajchman), she was not hired by RCA. She later said, "RCA was hesitant, and I'm sure it was because I was a woman."[13]

Estrin finally found a position in New York City, at the Electroencephalography Department of the Neurological Institute of Columbia Presbyterian Hospital, and began work there in November 1951. The EEG department consisted of a clinical laboratory and a research laboratory. Estrin later wrote: "I was responsible for the reliability of the clinical EEG equipment and supervised a technician who maintained the equipment. I was also given the opportunity to do research and to collaborate with physicians on EEG and EMG [electromyography] studies. At that time I was as much a rarity among engineers for my technical work as I was for my sex, for biomedical engineering had not yet become a field of engineering."[14] One of her first tasks was to take over the development of a frequency analyzer for bioelectric potentials; she improved the circuit design to increase the stability and ease of tuning of the device.[15] She also collaborated on a study of the action potential and refractory period of striated muscle.[16]

Despite the job in New York and the two-hour commute each way, Thelma was part of the social life of the Institute for Advanced Study. The Estrins were good friends with Jule and Elinor Charney—Jule was directing the effort to use the IAS computer for numerical weather forecasting—and with Julian Bigelow, chief engineer for the computer project. Bigelow, aware of Thelma's work at the EEG department, encouraged her to consider using an electronic computer to do statistical analysis of brain waves (something she did in later years). Thelma and Jerry went out to dinner many times with Johnny and Klari von Neumann. Johnny always questioned Thelma in detail about her work on the electrical activity of the nervous system, because of his interest in the relation between the computer and the brain.[17]

Israeli Interlude

In December 1952 Gerald Estrin was asked to be part of an effort to build an electronic computer at the Weizmann Institute of Science in Rehovot, near Tel Aviv.[18] At that time plans were underway to build versions of the IAS computer at a dozen locations in the United States and Europe.[19] The Israeli effort received full support—including a complete set of plans—from the leaders of the Institute project, von Neumann, Bigelow, and Herman Goldstine.

The departure for Israel was delayed by the arrival of the Estrins' first child, Margo, in February 1953. Thelma had stopped work at Columbia shortly before. In September Jerry took a leave of absence from the Institute project, and he and Thelma, with a baby in tow, spent three months in Europe, visiting computer groups in England, Netherlands, France, and Italy. In late December they reached Israel.

When he arrived at the Weizmann Institute, Gerald Estrin was surprised to find that he was to be director of the computer project. Apprehensive because of the lack of equipment and materials in Israel at that time and because of the need to recruit and train staff, he nevertheless accepted the challenge. An enthusiastic team was gradually assembled, and by dint of hard work and resourcefulness the supply and fabrication difficulties were overcome one by one.

Except for one month—at the time of the birth of a second daughter, Judith, in November 1954—Thelma was a principal member of the engineering group. (See Figure 3.) Though the computer, known as WEIZAC (for WEIZmann Automatic Computer), was closely modeled on the IAS computer, significant redesigns were necessary, and Thelma played a large role in this process.[20]

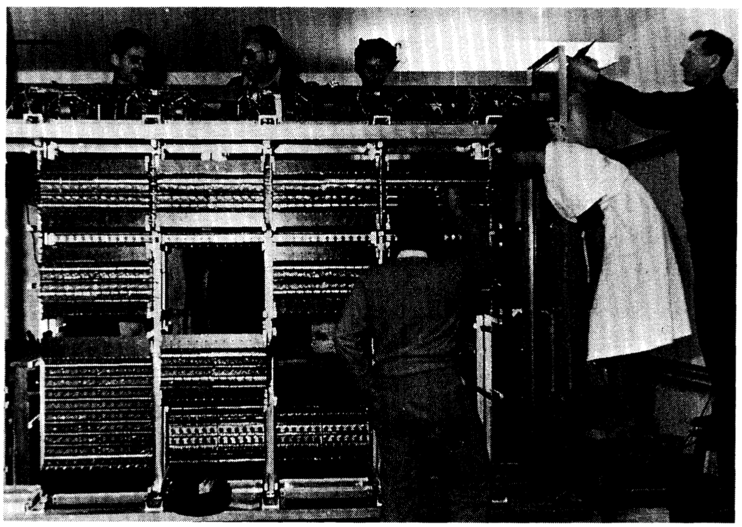

Figure 3. Mechanical assembly of the WEIZAC chassis. Thelma is at the right in the white lab coat.

After fifteen months in Israel the Estrins returned to Princeton in the spring of 1955. At that time the WEIZAC central processing unit and primitive input-output were complete; it performed its first calculation six months later and thus became the first electronic computer in the Near East. The time spent in Israel made Thelma and Jerry, neither of whom was religious, identify more strongly with Judaism; their daughters all speak Hebrew and maintain certain Jewish traditions. They returned to Israel for a year in 1963 and have visited the country almost every year since.

When we came to Israel to build this computer in 1954, everybody said to us, "Why does a little poor country like Israel have to spend its money on a computer?" When we left and they gave my husband a certificate which says, "For building the first electronic computer in Israel," I can remember thinking, the first! How many electronic computers do they think there are going to be here, or in Israel. We still, at that time, in 1954, did not realize the potential of it, aside from it being . . . a giant calculating device. A scientific computer for big [numeri-cal calculations], that we knew from modeling problems. . . .We didn't see its explosion into the business world, resource planning, [and] government use to keep track of data. I, at least, did not see that.[21]

In April 1955 the Estrins arrived back in Princeton, and Jerry resumed work on the Institute computer project. Thelma, though offered an engineering position at the Moore School of Electrical Engineering at the University of Pennsylvania, chose to work closer to Princeton as a mathematics instructor at Rutgers University in New Brunswick. In 1956 Jerry was hired by UCLA (as an associate professor in the School of Engineering and Applied Science and the Institute for Numerical Analysis) to initiate a program in computer engineering, and the family moved to Los Angeles. Nepotism rules prevented her from being employed by the School of Engineering, so she found a half-time teaching position at Valley College, a junior college in Los Angeles. (See Figure 4.) She taught there for two years and also did some work as a consultant. A third daughter, Deborah, was born in December 1959.

Data Processing Laboratory at the UCLA Brain Research Institute

In the mid-1950s H. W. Magoun, professor in the UCLA Medical School, initiated an interdisciplinary neuroscience program at UCLA, and this led in 1959 to the establishment of the Brain Research Institute, dedicated to study of the brain using methods from anatomy, physiology, chemistry, and biophysics. The following summer Thelma, because of her work at Columbia on electro-encephalography, was hired by the Brain Research Institute (BRI) to organize a conference on computers in brain research, which was held that fall.[22]

At that time very few biomedical researchers thought of the electronic computer as a research tool. One who did was Mary A. B. Brazier, a physiologist specializing in electroencephalography who was just then joining BRI. Another was a professor of anatomy at BRI, W. Ross Adey, M.D. and ham radio operator. It was at Adey's urging, and with the collaboration of the director of the BRI, Dr. John D. French, that a proposal to establish a data processing laboratory at BRI was drafted and sent to the National Institutes of Health (NIH). At that time local computing capability was a new concept; at universities almost all computing was carried out at a single facility. The grant application was entitled "The application of computing techniques to brain function," and the engineering aspects of that application were the work of Estrin.[23]

Thus in 1961 NIH (specifically, the National Institute of Neurological Diseases and Blindness) provided funding to set up the Data Processing Laboratory (DPL) of the Brain Research Institute. This was the first grant ever awarded by NIH for setting up a computer facility in a medical school, and DPL was probably the first computer facility established expressly for nervous system research. DPL was both a research laboratory for the development of computing techniques for neuroscience and a data processing facility for members of BRI. Because about half of the 90 or so research projects under way at BRI involved recording of electrical signals, it was clear to Estrin that there were many potential users of electronic data processing.[24] The NIH funding for DPL continued until 1981, the annual allotment usually exceeding a quarter million dollars.

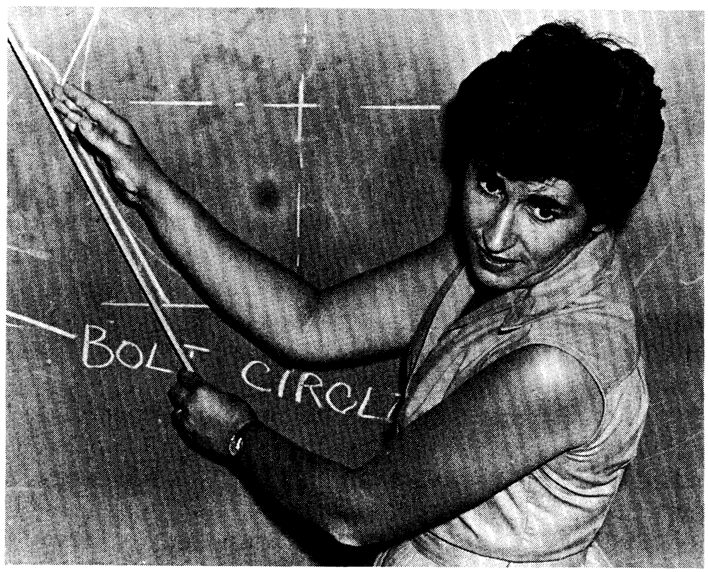

Figure 4. Estrin teaching engineering drawing at Valley College in Los Angeles.

The initial NIH grant included funding for Estrin's proposal: to design and implement an analog-to-digital conversion (ADC) system.[25] The typical electrical behavior of a neuron, as shown in a microelectrode recording, is a series of "spikes" (rapid rises and falls of electrical potential), and neurophysiologists hypothesized that the nervous system encoded information in the temporal pattern of the spikes. (See Figure 5.) Testing this hypothesis required statistical analysis of large amounts of data, a task ideally suited for a computer, but only if the analog recordings were first converted into numerical digits. Estrin, taking advantage of her experience with the digital logic of the WEIZAC, devised a system to do this automatically.[26] The system, incorporating a clock pulse and a count register, digitized the time interval between spikes and produced a magnetic-tape output that could then be analyzed by a computer. Because physiologists at that time seldom had immediate access to a computer, Estrin showed how to obtain, with a relatively simple, self-contained electronic system, real-time analysis of the firing patterns, which could be useful in monitoring an experiment.

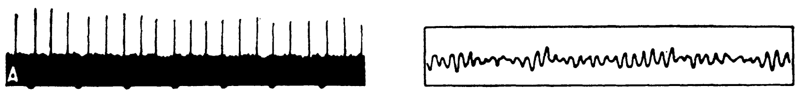

Figure 5. On the left is a microelectrode recording of a neuron, showing a series of spikes. On the right is an electroencephalograph, obtained by placing electrodes on the scalp.

With an electroencephalogram (EEG), which records electrical potentials on the scalp (see Figure 5), neurophysiologists wanted to digitize both amplitudes and time intervals. Estrin designed and built an appropriate ADC system that could be used either to convert an analog tape to a digital tape or to convert analog signals from recording instruments to digital signals for immediate input to a computer.[27] Analog-to-digital conversion is required in almost every use of computers by biomedical researchers (since data are recorded by analog devices and since digital computers require numbers as input), and Estrin's was one of the first ADC systems for biomedical data.[28] Ross Adey used this system for his pioneering work in spectral analysis of electroencephalograms.[29]

In 1962 Estrin obtained a Fulbright Fellowship to spend most of 1963 at the Weizmann Institute in Israel investigating the EEG patterns associated with epilepsy.[30] Because of difficulties with laboratory facilities, Estrin was unable to make much progress on this, but she did continue work on the design of systems for analog-to-digital conversion of physiological data.[31] She returned to the United States and the Brain Research Institute at the end of the year.

By the mid-1960s almost all universities in the United States had a computing center, and almost all of these centers consisted mainly of a large computer operating in "batch mode," which is to say that the computer executed one program at a time and users waited several hours or a day to retrieve their output. In this regime, debugging a program was extremely time-consuming, and some applications, requiring immediate response, were not possible. One solution to these difficulties was to have a computer dedicated to a single application. Indeed, a principal mission of BRI's Data Processing Laboratory was providing such "on-line computing." As so-called minicomputers became widely available in the early 1970s, more and more researchers adopted this approach.[32] Estrin took the initiative at BRI, acquiring for the Data Processing Lab a DEC PDP-12 minicomputer in 1970 and advising three neurophysiology labs to acquire their own PDP-12s.

Another solution, also introduced in the 1960s, to the problems posed by the batch processing regime was "time sharing": many users at remote locations have simultaneous access to the same computer, and each has the illusion of access to a dedicated computer. In 1965 Estrin designed a time-sharing system that permitted data processing in real time at a number of BRI laboratories.[33] As mentioned above, she had earlier designed a self-contained device to give simple data-analysis in real time, but now, for the first time, the experimenter could obtain sophisticated analyses (carried out by computer) as the experiment was being conducted. Not long after Estrin returned to UCLA following the Fulbright year in Israel, she went to work in the laboratory of Mary Brazier, and it was in Brazier's lab that Estrin built an on-line analog-to-digital system that time-shared the SDS 930 computer in the Data Processing Laboratory.

The impact of computers on EEG studies became apparent in the late 1960s. The study of "average evoked potentials" provides one example: Sensory stimuli cause changes in the EEG, but these changes are, in general, detectable only with the signal-averaging techniques made possible by on-line computers. Another example is the proliferation of studies of the alpha rhythm. This is a fairly regular wave, eight to thirteen cycles per second, which is the most pronounced of the rhythms exhibited by EEGs. The alpha rhythm itself was discovered decades earlier, and it was also known that waves of alpha frequency could be induced by repeated flashes, but the computer greatly facilitated the study of both of these phenomena. In the late 1960s Estrin collaborated with John S. Barlow on a study of both intrinsic and induced alpha rhythm.[34] They compared the phasing of the induced alpha waves with that of the intrinsic waves to cast light on the question of possible generating mechanisms.

It was also in this period that Estrin made use of the computer to present EEG information in a new form. A traditional electroencephalogram measures the electrical potential at a small number of electrodes placed on the scalp and displays potential differences for particular pairs of electrodes. Estrin recognized that recent technological advances in analog-to-digital conversion, in computing, and in graphic display made possible spatial display of EEG patterns. This could be done by increasing the number of electrodes on the scalp, digitizing the data, using a computer to complete the pattern by interpolation, and using a computer to generate a graphic display. Moreover, this scheme allowed one to generate a succession of EEG maps, to photograph the maps with a movie camera, and then to project an "EEG movie" that showed the temporal sequence of spatial patterns. (See Figure 6.)

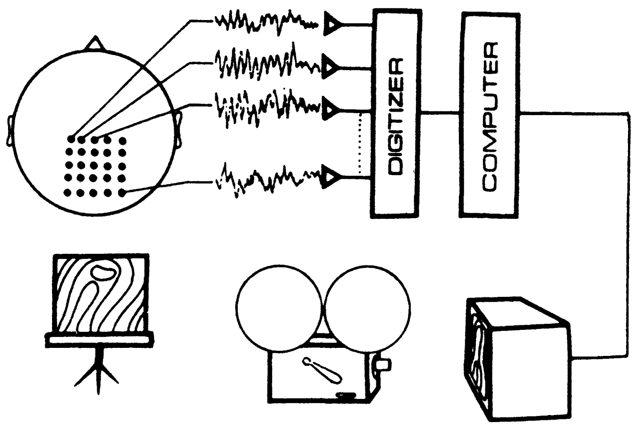

Figure 6. A diagram illustrating the method of generating "EEG movies."[35] The signals from the array of electrodes are amplified and digitized; the computer, through interpolation and map-projection techniques, forms a contour map of electrical potentials, which is displayed on a cathode-ray tube; a movie camera, synchronized with the CRT displays, photographs successive displays; and the resulting film is projected on a screen.

Collaborating with programmer Robert Uzgalis, Estrin solved the many problems required to make this scheme work.[36] Many considerations were involved in finding an appropriate map projection (so that the curved surface on which the electrodes are placed is represented with little distortion on a planar surface) and in devising interpolation routines. The rate at which the camera took pictures had to be controlled by an interface between computer and camera, so that one photograph is taken for each pattern displayed on the CRT; here Estrin and Uzgalis had the assistance of John Whitney, a pioneer in computer animation. Whitney was at that time using DPL equipment to produce one of the first films of computer animation.

In the period from 1965 to 1970 Estrin worked in the laboratory of Mary

Brazier—purchasing, designing, calibrating, and maintaining a variety of laboratory equipment—while also playing a large role in activities of the Data Processing Laboratory. (See Figure 7.) In the late 1960s DPL, which was without a director, encountered increasing budgetary and operating difficulties, and there was doubt about whether grant requests for continued funding would be approved. In 1969 the director of the Brain Research Institute, John French, asked Estrin to become acting director of DPL and to head a task force charged with making recommendations about how the lab ought to be organized.[37] French later wrote, "Dr. Estrin accomplished the task asked of her with industry, determination, skill and tenacity. I am confident the task force would have been unsuccessful save for these qualities of leadership which she exhibited."[38] The reorganization was carried out, and a $300,000 funding proposal, with Estrin as principal investigator, submitted and approved.

Thus in 1970 Estrin became DPL Director, supervising six to ten computer professionals and deciding how to allocate personnel and material resources to the many BRI projects. During the 1970s DPL, which earlier had concentrated on medical research, directed an increasing part of its effort to health care delivery.[39] In this period Estrin offered each year the course "Electronics for Neuroscience"; in addition, she and a colleague gave a graduate seminar on "Computer Applications in Health Care Delivery." She also edited a special issue of the journal *Computer* on "Information Systems for Patient Care."[40]

In the mid-1970s Estrin pioneered the use of interactive graphics as a tool for neuroscientists and neurosurgeons. She collaborated in this work with half a dozen other researchers, especially with Robert Sclabassi and Richard Buchness. In a 1974 paper, Estrin, Sclabassi, and Buchness described a computer system that combined diagnostic information from x-ray scanning of the patient's head with general neuroanatomical information from brain atlases to compute and graphically present a brain map scaled for that particular patient.[41] This work, which drew on the very recent development of computerized axial tomography (itself made possible by high-speed computers) and which made use of a large-screen IMLAC graphics processor interfaced with a DEC PDP-12 computer, could not only generate an individualized brain map, but also simulate and display the movement of an instrument as it is taking place during an operation. Estrin did further work to make this system useful in planning an operation (to allow simulation of the operation taking different trajectories to the targeted structure) and to adapt it to animal stereotaxic surgery.[42]

Estrin, Sclabassi, and Buchness collaborated on another application of interactive graphics, the analysis of the series of spikes produced by a neuron.[43] It is typical for neurophysiological experiments to generate enormous data sets. The ability to present data in graphic form can be

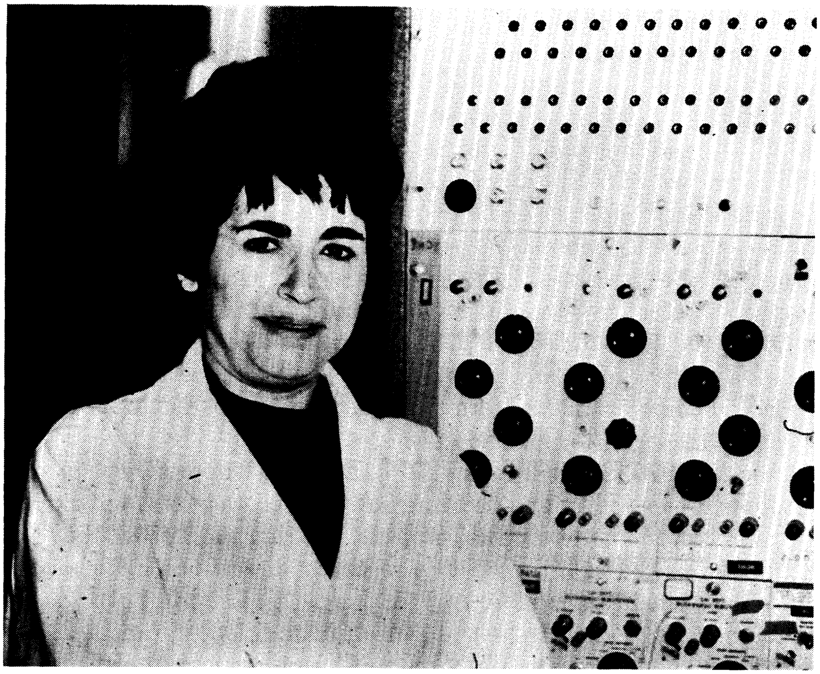

Figure 7. Estrin in front of some equipment that was part of an analog-to-digital conversion unit at the Data Processing Laboratory of UCLA's Brain Research Institute.

extremely helpful, both in providing insights into the data itself and in facilitating the comparison of experimental data and model predictions. Estrin and collaborators demonstrated this for spike-train data by designing and implementing a system that consisted of an IMLAC graphics terminal, a PDP-12 computer, and an IBM 360 computer.

Other work by Estrin in the 1970s included the use of computers to apply sophisticated statistical techniques to the analysis of EEG recordings (in sleep research) and the use of computers in a retrospective study of the efficacy of particular surgical treatments.[44] She also arranged for a long-distance connection of computers: the IMLAC terminal at DPL connected by telephone lines to the Burroughs B6700 at the Davis campus of the University of California, 500 miles away. (This was in order to make use of a computer language, MUMPS, developed specifically for medical applications.)[45]

In the mid-1970s personal computers, then usually called microcomputers, began to be widely used by researchers. Estrin worked to speed this process, especially by showing how microcomputers could be used for data acquisition, which in neurophysiology typically involved considerable preprocessing (such as filtering, artifact removal, digitization, and discrete-event sensing).[46] As Director of DPL, she provided computer support for a variety of research projects and helped dozens of researchers make use of computers (including studies of sudden infant death syndrome, multiple sclerosis, epilepsy, and evoked responses).[47]

In 1979 the NIH grant that had supported DPL for eighteen years was approved but not funded (the overall appropriation for NIH grants that year was lower than expected). There was also less support within BRI than Estrin had hoped. She notes that neuroscience as a whole has moved toward chemical and molecular-biological studies, and that investigation by means of electrical measurements has not been as vigorously pursued, partly because few researchers have had the requisite training or inclination, partly because some of these approaches have proved especially difficult.[48] Also, the Brain Research Institute required additional space, so DPL ceased to exist. Estrin remains optimistic about the prospects of computers in biomedical research, pointing to the growing body of successful computer-aided research and to such recent technological advances as the personal workstation, standard software, fiber-optical devices for data transfer over computer networks, and ever-more-powerful supercomputers.[49]

The Data Processing Laboratory had, however, already had a large impact on neurophysiological research. In the first years of the Brain Research Institute, investigators were generating large amounts of data, typically in visual form, that were assessed mainly by the naked eye; in 1980 BRI investigators were generating more data, most of it in digital form, that were processed and analyzed largely by computer programs. The Data Processing Laboratory of the Brain Research Institute had, along with the Communications Biophysics Group of the MIT Research Laboratory of Electronics, pioneered the use of computers for neurophysiological research. More than a hundred neurophysiological researchers had consulted with DPL staff, and many more were alerted to possible uses of computers by DPL activities.[50] Particular DPL contributions were made in the areas of analog-to-digital conversion, data acquisition and preprocessing, signal analysis, interactive graphics, modeling and simulation, distributed computing, and laboratory computer systems.

Medical Informatics

Though most of her work involved the use of computers in biomedical research, Estrin was also a proponent of computer use in medical treatment and hospital administration. She argued, ". . . clinical medicine is inherently an information processing activity and the clinician is a decision maker who depends on the quality of the data stored in the medical record. . . . Very little funding has been allocated for research on the storage and retrieval of patient information."[51] She believed that computerizing medical records could lead to improved patient care, more efficient administration and accounting, and the facilitation of epidemiological studies and evaluations of medical treatment.[52] Even as computers improved the quality of health care, she argued, they could lower costs and thus extend the reach of such care.[53]

Thus Estrin was an early champion of medical informatics—the application of computers to medical research and treatment—in all its branches. Estrin, however, did not have much success in generating interest at UCLA as, for example, in her effort beginning in 1964 to interest leaders of the medical school in exploring the application of computers to patient records.[54] Nor did she have success in finding a position for herself at UCLA that would allow her to develop medical informatics in a concerted way. In 1976 she was asked to be "coordinator of activities"—a temporary, part-time position—for a nascent institute for biomedical engineering, the Crump Institute. Estrin wanted a greater commitment on the part of the university to her role in forming this institute, and when this was not forthcoming she declined the offer.[55]

In 1980 Estrin became professor in residence in the Computer Science Department of the School of Engineering and Applied Science. (Nepotism rules at the university had been abolished.) That year she introduced a new course on computers in medicine, and the following year a new course on computer literacy for nonscience majors. (See Figure 8.) In her own work she began to give more attention to the use of computers for medical histories, patient management, and clinical decision making.

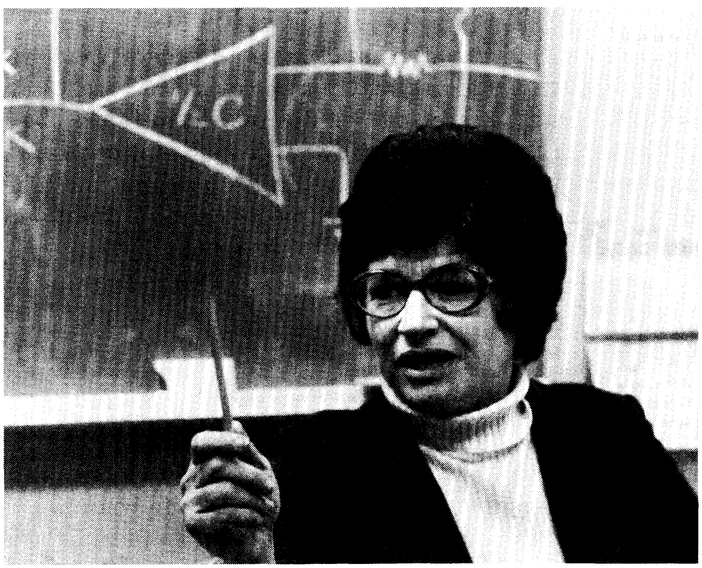

Figure 8. Estrin teaching at UCLA.

In the early 1980s Estrin served as advisor to Donna Hudson, a UCLA graduate student in computer science. A large part of Hudson's dissertation research was the design of an expert system for medical decision making. Called EMERGE, the rule-based expert system was designed to be machine-independent and to be capable of running on a microcomputer. Because the cardiology division of the UCLA medical school had recently completed a study of decision making in the treatment of chest pain, Hudson and Estrin chose this area for the initial application of EMERGE, producing an expert system for use by emergency room personnel.[56] As part of this work, Hudson and Estrin devised a procedure for deriving rule-based knowledge from medical audits.[57]

Administrative Work at the National Science Foundation and at UCLA Extension

In 1982 Estrin accepted a two-year rotating position at the National Science Foundation, that of division director for Electrical, Computer, and Systems Engineering, and she moved to Washington 1 October 1982. There she was responsible for oversight of more than 400 grants totaling some $30 million annually, and she established a new program, Bioengineering and Research for the Handicapped. Bioengineering had been part of a program that included automation and sensing systems, while research for the handicapped had been a separate, small program; Estrin believed both were strengthened by placing them together in a new program.

A big issue that came up [when I was at NSF] was, should there be a computer science directorate? Nobody who was at NSF wanted another directorate, because it would impinge on their directorate funds. Differences in our division occurred on whether grants were computer science or communication engineering. The program manager for Computer Engineering only had two million dollars in funds, and needed an increase. The manager for Electrical and Optical Communications had about six million dollars in funding, and thought all of the network research were communication issues. There was a Division of Computer Research in the Directorate for Mathematical and Physical Sciences headed by a young man whom I liked very much, but he has died. He did not want to change the structure, nor did the manager of the Information Science and Technology Division in the Directorate for Biological, Behavioral, and Social Sciences. The three directors with computer research funds gave [NSF Director Edward] Knapp a talk on the subject. I did give reasons to support the other directors, but I was leaving in a few weeks and didn't really give my point of view, to bring all of computer research together.

As soon as Erich Bloch arrived at NSF, he formed the Computer Science Directorate. ECSE became Electrical and Communications Systems, which is the name today. I was pleased by the change. While I was at NSF I was treated very well, and I loved working there and being in Washington. We sublet an apartment in Watergate, with *a view of the Potomac. It was great. Jerry joined me for the second academic year.*

. . . When you have one person who has been the director of a program for many years, that program director will have funded a large group of the same people over those years. They visit these people, are abreast of their work, use them as reviewers for new grant applications, et cetera. They often become friends with the people they support. These funded people become well known in the field and are liked for what they have accomplished. Then a new young investigator applies for funds, and money is very tight. They just don't get the same kind of reviews, unless their original research is absolutely super.

NSF does sponsor very superior research, probably fifteen percent of the time. The rest of the funding is high quality . . . . In parts of engineering and in computer science the field changes every two to three years. An NSF program director (or manager) may know the field very well, but may not be up to date with new emerging areas. They may not get new reviewers because they have their own reviewers, frequently professors whom they also fund, and whom they know will return a review quickly. There are contradictions in the present system of reviews, but in general, I think it's a pretty fair system . . . . It is important to change directors of programs and divisions. That is why the rotating director from academia is a good idea.[58]

While at NSF, Estrin lobbied strongly for funding for the first grant in 1984 to the National Technological University (NTU)—a university in which all courses are given by video by means of C- and Ku-band satellite transmission. NTU made it possible for people, many of whom had no access to other forms of advanced technical education, to earn master's degrees. This experience and her conviction that "lifelong learning . . . has to become a way of life for the engineer" (because technology is changing so fast)[59] made her interested in a position in continuing education at UCLA—Director of the UCLA Extension Department of Engineering and Science. She held this position, serving also as assistant dean of continuing education, from 1984 until 1989.

In some respects Estrin found the work satisfying. The UCLA extension program is one of the largest in the country—the department Estrin managed offered some 550 courses to more than 15,000 students each year—and is highly regarded.[60] She worked to increase the number of courses conducted at high-tech companies, such as Northrop and Rockwell. She introduced courses in artificial intellegence, manufacturing engineering, and optical communications and a program in telecommunications and communications engineering. And she worked to revamp a master's program between Extension and the School of Engineering.

In other respects, however, Estrin found the work frustrating. The main problem was that bureaucratic inertia made it almost impossible to be entrepreneurial. She wanted to introduce videotaping of courses and to establish a library of videotaped lectures. She wanted to provide remote instruction with lectures conveyed by satellite.[61] She wanted to set up an institute in the South Bay to offer courses mainly for aerospace engineers. She wanted to turn some certificate programs into external master's programs. But University Extension was a large, bureaucratic organization, and proposed changes faced the additional hurdle of approval by the University as a whole. Moreover, because the extension program had to be self-supporting, it was almost impossible to find money for new ventures. So Estrin was unsuccessful, despite her best efforts, in bringing about these new activities.

In her last years of teaching, 1989/90 and 1990/91, Estrin introduced two new courses, one on technology and society (concerned both with the nature of engineering and the role of technology in modern society) and one on women in engineering, and revamped an undergraduate course on the engineer in society. In July 1991 she retired from UCLA and was named professor emerita.

IEEE and Other Organizations

In the late 1970s Estrin came to feel that the advances in neuroscience made by molecular biologists and biochemists were more significant than the studies of the gross electrical activities of the brain. This was one of the reasons she left the Brain Research Institute and accepted an appointment in the School of Engineering (and there were no longer nepotism rules that forbade this). Another reason was that she began devoting more and more of her time to professional activities, particularly for the Institute of Electrical and Electronics Engineers but also for the Association for the Advancement of Medical Instrumentation and other biomedical societies. These activities involved a great deal of travel and countless hours of arranging things from her office by telephone, correspondence, and, later, electronic mail. In 1981 she said, "[professional activities] is what takes up my time and so I decided brain research and I had sort of come to our end."[62]

Estrin had joined the American Institute of Electrical Engineers (one of the two predecessor societies of IEEE) as a student at the University of Wisconsin in 1948, but she had hardly been active in the Institute until 1973 when she was encouraged to run for the Advisory Committee of the Engineering in Medicine and Biology Society (one of the technical societies within IEEE). She was elected and found this work rewarding, and in 1977 she was elected to be president of the Engineering in Medicine and Biology Society.

In 1979 Estrin ran successfully for the position of director of Division Six of the Technical Activities Board, which encompassed six IEEE technical societies. Division Directors are also members of the IEEE Board of Directors, and she thus became the first woman to be elected to the

Board.[63] In 1982 she was elected executive vice president of IEEE and thus again served on the Board of Directors. She instigated the process to establish the Judith A. Resnik Award, which was finally established in 1986 to recognize an electrical engineer for contribution to space engineering.[64] Aside from remaining active in the Engineering in Medicine and Biology Society and besides her work within IEEE for women in engineering (discussed below), Estrin has served, from the mid-1970s to the present, on about a dozen IEEE committees.[65]

IEEE honored her work in biomedical engineering by naming her a Fellow in 1977 "For contributions to the design and application of computer systems for neurophysiological and brain research" (the sixth woman to attain this honor)[66] and by awarding her a Centennial Medal in 1984. IEEE honored her "for outstanding service to the Institute" by awarding her the Haraden Pratt Award in 1991.

Outside of IEEE Estrin has been active in the Association for the Advancement of Medical Instrumentation (AAMI) and in the Biomedical Engineering Society (BME). She served several years on the Board of Directors for each of these societies, and she was a member of the editorial board for BME's *Annals of Biomedical Engineering*. In the late 1970s Estrin was vice president of the Alliance for Engineering in Medicine and Biology (a group of 23 engineering, scientific, and medical societies in the US founded in 1969 to facilitate cooperation in sponsoring an annual conference), and she was the US member on the administrative committee of the International Federation of Biomedical Engineering (to which the Alliance belonged). In the 1980s Estrin served on two boards of the National Research Council (Telecommunications and Computer Applications, and Energy Engineering) and on several accreditation committees. She has also been active in the American Association for the Advancement of Science (AAAS); she was elected chair of the AAAS Engineering Section for 1989 and chair of the Computer Section for 1994.

In the 1970s Estrin argued for the recognition of a new branch of engineering, clinical engineering, concerned with the development and implementation of technology for health care.[67] In 1974 the AAMI and seven other medical associations established a certification procedure for clinical engineers, with a provision that those who at that time already had considerable experience as clinical engineers could be "grandfathered" into certification (without going through the new procedure in its entirety). The fact that the clinical engineers were virtually all men and the sexist language of the certificate (including "Know All Men by these presents that . . . has given satisfactory evidence that he has met the qualifications. . . .") prompted Estrin to apply for certification. She explained, "My motivation to apply for certification stemmed from my desire to have a woman "grandmothered," as well as my interest in promoting the clinical engineering profession."[68]

In 1978 Estrin was appointed to the Board of Trustees of Aerospace Corporation, becoming the first woman member of that board. Her background in computing was probably a factor in this appointment, as Aerospace was then making special efforts to take advantage of computer technology. She served on the Board's Technical Committee and also the Compensation and Personnel Committees. She also supported the efforts of the Aerospace Women's Committee, which had been formed in 1972, to encourage the hiring and promotion of women. When she retired from the Board in 1982 on assuming the NSF position (a government employee cannot serve on the Board), she was honored "for her wisdom, friendship, and enduring contributions to the Corporation."[69]

Estrin was a member of the Army Science Board from 1980 to 1983 and a member of the NIH Biotechnology Resources Review Committee from 1982 to 1986. The former committee advised the Army on technological matters; the latter provided guidance for the Biotechnology Resources Program, which was established by NIH in 1962 "to provide support for complex technological capabilities in biomedical research."[70]

Women in Engineering

At many points in her career, Estrin encountered discrimination, though she was determined not to allow the prejudices of others to diminish her drive to achieve certain goals. There were a few occasions when she felt discriminated against because she was Jewish and spoke with a strong New York accent. She faced a second type of discrimination at the Brain Research Institute: discrimination against "technicians." Many BRI members saw a sharp distinction between scientists and technicians (including all engineers): The former do the important intellectual work, while the latter merely take care of technical problems. When told that Estrin had won a major award, a scientist who knew her registered surprise and commented, "But she's just a technician!"

Much more serious in Estrin's estimation, however, is discrimination against women. "I don't think we fully appreciate how difficult it is to overcome a socialization process in which women are brought up to be housewives, and men to be wage earners. As a result, many women lack confidence, have low esteem and fear success. The sexist attitude of men further drains our confidence and our energy and frequently we blame ourselves when we don't achieve our goals."[71] In most professions a woman must overcome both overt discrimination—something Estrin has encountered many times[72]—and the "covert barriers of early conditioning in a dominant-male culture [which] remain as fossilized attitudes."[73]

Though a long-time member of the Society of Women Engineers—she reported on her work at the first SWE convention in 1953—it was in the 1970s that Estrin became active in the effort to increase the number of women in engineering. Her most important work was as chair of the Committee on Professional Opportunities for Women (COMPOW) from 1975 to 1980. COMPOW is a committee of the IEEE that was organized by Julia Apter in 1971. Its purpose, as expressed by Estrin, is to promote the five Rs: recruitment of women as students of engineering, retention of women students enrolled in engineering programs, retraining or continuing education of women who have career interruptions, redress of grievances for women who suffer from discrimination, and re-education of the profession to the suitability and desirability of women as engineers.[74]

I was always in the Engineering in Medicine and Biology (EMB) Group, later a society, but I didn't think much about it. There was a woman by the name of Julia Apter, who was a physician and who died at a young age. She was on the Administrative Committee of EMB in about 1972. She began to write to the few women in EMB, and I responded. She was a very attractive woman who was very hostile with men, particularly those in NIH and in EMB, and was always in a battle with them. She could also be very charming. She was the woman who proposed the Committee for Professional Opportunities for Women [COMPOW] in IEEE.

. . . She wanted me to run for Ad Com [in 1972], and was going to get ten signatures to put me on the ballot. I replied that I was certainly pleased to run, but I'd get my own signatures, and put myself on the ballot, which I did and was elected to EMB Ad Com. I met Julia at my first meeting. She said that the men were never going to allow me to contribute, or would they socialize or invite me to dinner with them. None of this was true. I thought that the Ad Com of Engineering in Medicine and Biology was sincere, friendly, and interested in working with me.[75]

NEBEKER: *There's also the problem that you alluded to, that—at least in some environments—promotion depends on your visibility and your self-promotion, and many men are better at that than women.*

ESTRIN: *You do get some women who are considered very aggressive. They just have to be aggressive to overcome the barriers. Some women overdo that approach and become openly hostile, as Julia Apter, the founder of COMPOW, was. Men are more narrowly focused on the project they're doing than on the interaction with the environment around the project. Men are also more analytical, and women have a very good intuitive approach. Of course, I'm discussing men as a group, not as individuals.*[76]

Estrin provided COMPOW with five years of energetic and innovative leadership. She arranged for hospitality suites at professional conferences in order to facilitate women's networking. According to Estrin, "Professional women who are sent to conventions like NCC [National Computer Conference] by companies have a sense of isolation. They walk into a solidly male environment. Hospitality suites operated by the companies are generally smoke-filled rooms, jammed with a bunch of men. When a woman walks in, they rarely look at her as a professional or a colleague."[77] She established a newsletter for women engineering students, encouraging women to become more active in IEEE. She organized workshops at conferences, both IEEE conferences, such as Electro and Wescon, and other conferences, such as NCC (where in 1978 a workshop was entitled "Designing and Debugging Careers for Women in the Computer Industry").

It was not only through IEEE that Estrin pursued the cause of women in engineering. She has given many talks and published many articles on the topic. At UCLA she gave a course entitled "Women in Engineering," and she was cofounder of the UCLA Chapter of Association for Women in Science. In 1978 she tried unsuccessfully to establish a new organization, Advancement of Women in Technology (AWIT), with the goal of encouraging women to enter technical occupations and promoting upward mobility for women in such jobs. (Very recently an organization with similar goals, Women in Technology International, has been formed.)

Estrin has been a member of Systers, a computer network for female computer scientists. Two of the greatest barriers to success by women in science and engineering are the difficulty women have in finding mentors ("... most women have a tough time getting this important guidance") and the "old-boy network" ("the basic obstacle ... which is 'still very much in place'").[78] In 1987 Anita Borg and several other computer scientists established a computer network to ameliorate these difficulties.[79] The 900 current members of Systers use it in various ways, such as soliciting career advice, asking who is researching a particular topic, or requesting guidance on writing papers.

Estrin argues that in the modern world, engineering is increasingly done, not by individual effort, but by teamwork. This requires excellent communication skills and the ability to accommodate different ideas, approaches, and workstyles. While men often excel in competition, women tend to prefer a cooperative environment and to work well in larger groups. "Women make excellent managers because they tend to be more interpersonal, more sensitive to people's feelings, and better organized."[80] She argues also that a more realistic picture of electrical engineering—not just a lot of math, physics, and apparatus, but solving practical problems in complex contexts—would attract more women into engineering.

Estrin's efforts were recognized by the Society for Women in Engineering by its Achievement Award, and when the Association of Women in Computing was formed in 1982, Estrin was named an honorary member. In her acceptance speech for the SWE Achievement Award, Estrin briefly reviewed the careers of six outstanding women engineers and remarked, "I would like to tell you that at least one of those women was my role model. But the truth is, I was the first woman engineer I ever knew."[81]

I recall Emily Sirjane, who was an invaluable chief administrator of IEEE, who knew everything about the organization from A to Z. She retired because she was not well and also because of her age, and she did die shortly after that. She was not particularly interested in women, she was interested in everybody in IEEE, and was very pleasant and a wonderful worker. I remember when the Board was writing a farewell to her. They talked about her secretarial skills—she was very neat, and very precise, and she followed procedures—but it was the kind of talk that you would only write of a woman. . . . I recall saying this and mentioning the outstanding administrative leadership she provided. Well, the Board agreed with me and ultimately gave her a much nicer final letter.[82]

From a letter to Emily Sirjane from Thelma Estrin, 25 January 1979:

We both joined the IEEE in 1948; you as a staff member in New York and I as a student member in Wisconsin. . . .

Until the early 70's I harbored the notion, formed in my student days, that the Institute was run by a "group of stuffy old men." That myth was dispelled when I attended my first USAC meeting to consider accepting the leadership of COMPOW. I realized that I had become of an age with the "men" and that they were interesting people. At the time I did not know that behind the IEEE scenes was a wise, talented and beautiful woman, but I quickly found out as I became an active volunteer. Your intimate knowledge of IEEE, your effective implementation of policies and procedures, your wise judgement in making decisions, and your gentle firmness with people have been a joy to witness and work with. I will miss you very much.

Bruno Bettleheim . . . said "We deeply need women scientists and engineers who are committed, as human beings and as good workers, to their profession, and who are committed to it in line with their female genius." You have brought the female genius of a woman manager to IEEE.[83]

Family and Honors

Estrin gives a great deal of credit for her achievements to her husband: "So while I did not have a role model, and didn't have a mentor, I did have a supportive husband."[84] And she is obviously proud of her children, whom she calls "my three greatest contributions . . . joint authored with my husband. . . . "[85] The eldest, Margo, is a physician in private practice, specializing in internal medicine. "She calls herself the oddball of the family because she's the only one who is not an engineer."[86] Judith, a computer engineer with a master's degree from Stanford, is a founder and senior vice president of Network Computing Devices, a company with some 300 employees. She claims that she's the family oddball, because she doesn't have a doctoral degree. The youngest, Deborah, who, uniquely for this family, has not claimed to be family oddball, earned a computer science Ph.D. at MIT. Her speciality is computer networking, and she is now an associate professor of computer science at the University of Southern California. (See Figure 9.) The children became achievers, according to Judith, not because of any pressure to do so, but through the example of their parents' commitment to the work ethic.[87] All three daughters are married and have children.

Figure 9. A photo of the Estrin family taken in 1981.

Estrin is justifiably proud of the part she has played in the development of the discipline of biomedical engineering and of her work in showing the usefulness of computers in biomedical research and healthcare delivery. For these achievements she has won recognition: To the many honors already mentioned may be added Fellowship in the AAAS for "interdisciplinary research contributions to neuroscience and computer science" and an Honorary Doctor of Science Degree by the University of Wisconsin.[88] She is proud of her daughters and of the fact that her grandchildren will, in her words, "grow up knowing that men and women can be equal partners at work and at home; a very rare concept when I was married. . . . "[89] Perhaps she should be proudest of the fact that her example and her efforts on behalf of women in engineering will extend this concept to a great many besides her children and grandchildren.

[1] Quoted in William Chafe, *The American Woman: Her Changing Social, Economic, and Political Roles, 1920–1970* (New York: Oxford University Press, 1972), p. 137.

[2] The information about Thelma Estrin contained in this article comes mainly from the following sources: (1) an extensive oral history interview of Estrin conducted by the author 24 and 25 August 1992 (from which an edited transcript has been prepared); (2) a large collection of personal papers (referred to as the Estrin Papers); (3) e-mail correspondence between Estrin and the author; (4) Estrin's published writings; and (5) other published writings. (The transcript of the extensive interview, copies of personal documents and e-mail correspondence, and a full list of Estrin's publications are available at the IEEE Center for the History of Electrical Engineering.)

[3] Unsigned "Thumbnail biography" from a 1943 Radio Receptor Company publication (*Radio Receptor News*), Estrin Papers.

[4] Interview 1992, p. 11.

[5] Letter Estrin to Nebeker, 10 December 1992, Estrin Papers. In *Genius: The Life and Science of Richard Feynman* (New York: Pantheon Books, 1992), James Gleick writes (pp. 84–85), "On the eve of the Second World War institutional anti-Semitism remained a barrier in American science. . . . when he [Feynman] was at MIT, the Bell Telephone Laboratories turned him down for summer jobs year after year, despite recommendations by William Shockley, Bell's future Nobel laureate. Bell was an institution that hired virtually no Jewish scientists before the war."

[6] Estrin, "Women engineers—female magicians," *U.S. Woman Engineer*, October 1981, pp. 2–5.

[7] Ibid.

[8] "Plan for study" from a fellowship application submitted by Estrin (probably in 1949) to the American Association of University Women, Estrin Papers.

[9] Estrin, "Theory and application of multiple Laplace transforms to the solution of problems in electric circuit analysis and electromagnetic theory" (unpublished M.S. thesis, University of Wisconsin, 1949), and T. A. Estrin and T. J. Higgins, "The solution of boundary value problems by multiple Laplace transformations," *Journal of the Franklin Institute*, vol. 252, 1951, pp. 153–167.

[10] Estrin, *Determination of the Capacitance of Annular-Plate Capacitors by the Method of Subareas* (unpublished Ph.D. dissertation, University of Wisconsin, 1951).

[11] T. A. Estrin and T. J. Higgins, "Determination of the capacitance of annular-plate capacitors by the method of subareas," *Proceedings of the National Electronics Conference*, vol 20, 1964, pp. 939–944.

[12] William Aspray, *John von Neumann and the Origins of Modern Computing* (Cambridge MA: MIT Press, 1990).

[13] Quoted in Janet Noonan, "Thelma Estrin: computers on the brain," *Westside Women Today* (special supplement to the Santa Monica CA *Evening Outlook*), 26 July 1979, pp. 40–41.

[14] Estrin, "Computers, neuroscience and women: (1949–1999)," *Proceedings,*

Sixth Annual Conference of the IEEE Engineering in Medicine and Biology Society (1984), pp. 831–836.

[15] T. Estrin and P. F. A. Hoefer, "Revised frequency analyzer for bioelectric potentials in the sub-audio range," *Review of Scientific Instruments*, vol. 25, 1954, pp. 840–841. The earlier system is described in C. Markey, R. L. Shoenfeld, and P. F. A. Hoefer, "Frequency analyzer for bioelectric potentials in the sub-audio range," *Review of Scientific Instruments*, vol. 20, 1949, pp. 612–616. A full description of the revised analyzer, including twenty schematics and half a dozen photographs, is in the Estrin Papers.

[16] P. F. A. Hoefer, G. H. Glasre, C. Hermann, Jr., and T. A. Estrin, "Action potential and refractory period of striated muscle in man," *Federation Proceedings*, vol. 12, 1953, item 220.

[17] John von Neumann's Silliman lectures were published in book form as *The Computer and the Brain* (New Haven CT: Yale University Press, 1958).

[18] Gerald Estrin, "The WEIZAC years (1954–1963)," *Annals of the History of Computing*, vol. 13, 1991, pp. 317–339.

[19] Aspray, *John von Neumann*, especially pp. 91–94.

[20] A detailed account of the construction and use of the computer is contained in Gerald Estrin, "The WEIZAC years. . . ."

[21] Interview of Estrin conducted on 9 April and 9 May 1981 by Louise Marshall for Neuroscience History Research Project of the UCLA Brain Research Institute.

[22] The conference proceedings were published in 1961: *Computer Techniques in EEG Analysis*, edited by Mary A. B. Brazier (Elsevier, Amsterdam).

[23] Estrin, "The UCLA Brain Research Institute Data Processing Laboratory," *A History of Medical Informatics* (ACM Press and Addison-Wesley Publishing Company, 1990), pp. 157–173.

[24] T. Estrin, W. R. Adey, M. A. B. Brazier, and R. T. Kado, "Facilities in a brain research institute for acquisition, processing and digital computation of neuro-physiological data," *Proceedings of the Conference on Data Acquisition and Processing in Biology and Medicine* (Oxford: Pergamon Press, 1963), pp. 191–207.

[25] See memo, 10 November 1961 from Brain Research Institute Computer Committee (written by Estrin) to F. H. Sherwood in the Estrin Papers.

[26] Estrin, "Recording the impulse firing pattern of neurons utilizing digital techniques," *Digest of the 1961 International Conference on Medical Electronics,* 1961, p. 99.

[27] Estrin, "A conversion system for neuroelectric data," *Electroencephalography and Clinical Neurophysiology*, vol. 14, 1962, pp. 414–416.

[28] Slightly earlier ADC systems were built by W. M. Siebert and collaborators at the Massachusetts Institute of Technology (see Communications Biophysics Group of the Research Laboratory of Electronics and W. M. Siebert, "Processing neuroelectric data," MIT Technical Report 351, 1959) and by W. R. Uttal and P. A. Roland (see W. R. Uttal and P. A. Roland, "A terminal device for entry of neuroelectric data into an electronic data processing machine," *Electroencephalography and Clinical Neurophysiology*, vol. 13, 1961, pp. 637–640). Slightly later an ADC system for physiologic data was developed at the laboratory of Earl H. Wood at the Mayo Foundation in Rochester, Minnesota (see E. H. Wood, "Evolution of instrumentation and

techniques for the study of cardiovascular dynamics from the Thirties to 1980, Alza Lecture, April 10, 1978," *Annals of Biomedical Engineering*, vol. 6, 1978, pp. 250–309).

[29] W. R. Adey, "On-line analysis and pattern recognition techniques for the electroencephalogram," in G. F. Inbar, ed., *Signal Analysis and Pattern Recognition in Biomedical Engineering* (New York: John Wiley and Sons, 1975).

[30] Application for Fulbright Fellowship, 1962, Estrin Papers.

[31] Estrin, "Analog to digital conversion of physiological data," *Medical Electronics* (Proceedings of the Fifth International Conference, Liége) (Desoer, Belgium; 1963), pp. 638-648.

[32] Estrin, "Minicomputers in biology and medicine," *Proceedings of the Second Jerusalem Conference on Information Technology* (Jerusalem, July 1974), pp. 667–684.

[33] Estrin, "On-line electroencephalographic digital computing system," *Electroencephalography and Clinical Neurophysiology*, vol. 19, 1965, pp. 524–526. See also Estrin, "Neurophysiological research using a remote time shared computer," *1966 Rochester Conference on Data Acquisition and Processing in Biology and Medicine* (London: Pergamon Press, 1968), pp. 117–135.

[34] J. S. Barlow and T. Estrin, "Comparative phase characteristics of induced and intrinsic alpha activity," *Electroencephalography and Clinical Neurophysiology*, vol. 30, 1971, pp. 1–9.

[35] Figure 2 from T. A. Estrin and R. C. Uzgalis, "Computerized display of spatiotemporal EEG patterns," *IEEE Transactions on Biomedical Engineering*, vol. BME-16, 1969, pp. 192–196.

[36] Ibid.

[37] Memo 21 January 1970 from French to Carmine Clemente, and Memo 26 April 1971 from French to "Vice Chancellor Saxon through Associate Dean Rasmussen," Estrin Papers.

[38] Ibid.

[39] Application for Certification by Board of Examiners for Clinical Engineering Certification, Estrin Papers.

[40] *Computer*, vol. 12 , no. 11, 1979.

[41] T. A. Estrin, R. Sclabassi, and R. Buchness, "Computer graphics applications to neurosurgery," *Proceedings of the First World Conference on Medical Information* (MEDINFO) (Stockholm, Sweden; 1974), pp. 831–836.

[42] T. Estrin, J. V. Wegner, and R. Bettinger, "Computer generated brain maps," *Proceedings of the San Diego Biomedical Symposium* (San Diego CA: 5–7 February 1975), pp. 369–374. The shift of attention to animal surgery was prompted by organized student opposition at UCLA to stereotaxic surgery in humans (see Estrin, "Computers, neuroscience and women . . . ").

[43] R. J. Sclabassi, R. Buchness, and T. Estrin, "Interactive graphics in the analysis of neuronal spike train data," *Computers in Biology and Medicine*, vol. 6, 1976, pp. 163–178.

[44] R. N. Harper, R. J. Sclabassi, and T. Estrin, "Time series analysis and sleep research," *IEEE Transactions on Automatic Control*, vol. AC-19, 1974, pp. 932–943, and F. K. Gregorius, T. Estrin, and P. H. Crandall, "Cervical

spondylotic radiculopathy and myelopathy," *Archives of Neurology*, vol. 33 1976, pp. 618–625.

[45] R. Buchness, T. Estrin, and J. Sue, "Use of MUMPS for interactive graphics" (abstract), *Proceedings of the 1975 MUMPS Users' Group Meeting* (Washington, D.C., 17–19 September 1975).

[46] Estrin, "Information handling in brain research using a spectrum of computers," *Proceedings of the Ninth Hawaii International Conference on Systems Sciences* (Honolulu: University of Hawaii, February 1976), pp. 68–70.

[47] Estrin, "Information handling . . . ,"pp. 68–70, and Estrin, "A low cost micro-computer system for EEG data," *Proceedings of the 29th ACEMB* (Boston MA, November 1976), p. 188.

[48] Interview 1992, p. 70.

[49] Estrin, "The UCLA Brain Research Institute. . . ."

[50] Ibid.

[51] Estrin, "Computers, neuroscience and women. . . ."

[52] T. Estrin and R. C. Uzgalis, "Information systems for patient care," *Computer*, vol. 12, no. 11, 1979, pp. 4–7.

[53] Estrin, "Health care systems," *Proceedings, The Jerusalem Conference on Information Technology* (Jerusalem: ILTAM Corporation, 1971), pp. 37–38; and Estrin, "Federal policy and health care computing," *Proceedings of the 14th Annual AAMI Conference* (Las Vegas NV, 20–24 May 1979) (abstract), p. 73.

[54] Memo 23 April 1964 from Estrin to Dean S. M. Mellinkoff, Letter 12 May 1964 from John Field to Estrin, and Letter 22 May 1973 from Estrin to Dean A. F. Rasmussen, Estrin Papers.

[55] Memo 20 December 1976 from Estrin to Deans R. O'Neill and F.A. Rasmussen, and Letter 11 April 1977 from Estrin to UC President David Saxon, Estrin Papers. See also Interview 1992, pp. 75–78.

[56] D. L. Hudson and T. Estrin, "Microcomputer-based expert system for clinical decision-making," *Proceedings of the 5th Annual Symposium on Computer Applications in Medical Care* (Washington, D.C.: IEEE Computer Society, November 1981), pp. 976–978.

[57] D. L. Hudson and T. Estrin, "Derivation of rule-based knowledge from established medical outlines," *Computers in Medicine and Biology*, vol. 14 1984, pp. 3–13.

[58] Interview 1992, pp. 94–95.

[59] Quoted in Mary Love, "A woman whose time finally came," Santa Monica CA *Evening Outlook*, 3 December 1984, p. A-6.

[60] Estrin, "Continuing engineering education at UCLA—a comprehensive approach," *Proceedings of the 1986 Conference on Continuing Engineering Education* (7–9 May 1986), pp. 439–442.

[61] Estrin wanted UCLA to become a member university of NTU and brought the head of NTU to UCLA to meet with university administrators, but no action was taken.

[62] 1981 interview of Estrin by Marshall, p. 51.

[63] Irene Carswell Peden had earlier served on the Board, but was appointed.

[64] This award is sponsored by the IEEE Aerospace and Electronic Systems Society, and preference is given to an individual who has made the contribution prior to the 37th birthday (as 36 was the age of the engineer Judith Resnick when she died in the explosion of the Challenger space shuttle).

[65] Nominations and Awards Committee; Long-Range Planning Committee; Editorial Board, *Spectrum*; Vice President, Publications Board; Editorial Board, IEEE Press; Public Information Committee; Awards Board, Edison Medal Committee; Harry Diamond Memorial Award Committee; Education Committee; USAB COMAR Committee; and History Committee. (Though not described here, some problems arose for Estrin in the course of her work for IEEE. These are discussed in the 1992 interview.)

[66] The women who had already been named IEEE Fellows were Betsy Ancker-Johnson, Jenny Rosenthal Bramley, Grace Murray Hopper, Elizabeth Laverick, and Irene Peden; Edith Clarke was an AIEE Fellow (*Washington IEEE Bulletin*, vol. 16, no. 5, 1977). Estrin was also one of the first women to attain the status of IEEE Life Member; Grace Murray Hopper attained that status earlier.

[67] Estrin, "The responsibility of engineering societies," *Proceedings of the 13th Annual AAMI Conference* (Washington, D.C., March/April 1978) (abstract), p. 87.

[68] Estrin, "Computers, neuroscience and women. . . ," Various papers relating to certification, including copies of the application and the certificate, are in the Estrin Papers.

[69] Resolution, Board of Trustees, Aerospace Corporation, December 1982, Estrin Papers.

[70] Program Description, Biotechnology Resources Program, NIH, September 1978, Estrin Papers.

[71] "Achieving our goals," talk given in 1982 to a conference of the Association of Women in Computing, Estrin Papers.

[72] An example is her failure to receive from NSF a travel grant to an international conference for which she was an invited plenary speaker and a session organizer, when younger male colleagues with smaller roles at the conference received grants. (See Interview 1992, pp. 92–93, and various letters from 1979 in the Estrin Papers.)

[73] Estrin, "Women engineers. . . . "

[74] "COMPOW goes into action," unsigned article in a 1976 IEEE public relations release, Estrin Papers.

[75] Interview 1992, p. 98.

[76] Interview 1992, p. 112.

[77] Quoted in *The Institute*, vol. 2, no. 7, 1978.

[78] The quotations are from a special section, "Women in science," in the 13 March 1992 issue of *Science*, both in articles by Ann Gibbons (the first on page 1368, the second from page 1386). The second quotation contains a quotation of Margrete Klein, director of women's programs at NSF.

[79] Ann Gibbons, "Creative solutions: electronic mentoring," *Science*, vol. 255, 1992, p. 1369.

[80] Quoted in Alice Posner, *Women in Engineering* (Skokie IL: VGM Career Horizons, 1981), p. 78.

[81] Estrin, "Women engineers. . . ."

[82] An edited excerpt from Taped Comments on Documents Sent to the Center for the History of Electrical Engineering, 1 September 1992, Estrin Papers.

[83] Letter from Estrin to Emily Sirjane 25 January 1979, Estrin Papers.

[84] Estrin, "Women engineers. . . ."

[85] Estrin, "Computers, neuroscience and women. . . ."

[86] Estrin, "Women engineers. . . ."

[87] Garry Abrams, "The desire to achieve runs deep among members of Estrin family," *Los Angeles Times*, 5 January 1986, part VI, pp. 1–3.

[88] Still other honors are the following: Distinguished Service Citation from the College of Engineering of the University of Wisconsin (1975), Outstanding Engineer of the Year Award from the California Institute for the Advancement of Engineering (1978), Distinguished Professional Contributions to Engineering Award from the National Society of Professional Engineers and California Society of Professional Engineers (1985), and Founding Fellow of the American Institute for Medical and Biological Engineering (1992).

[89] Two-page autobiographical sketch (ca. 1988) beginning "I was married when I was 17 . . . ," Estrin Papers.