The Quiet Genius: Andrew J. Viterbi

by Trudy E. Bell

ON AUGUST 27, 1939, 4½-year-old Andrew Viterbi first stepped onto U.S. soil in New York City, home of a cousin. It was a foreign land to the youngster, an Italian Jew whose parents were fleeing their native Bergamo because of the inhumane racial policies of Benito Mussolini. And just in time. Five days later on September 1, 1939, Nazi Germany invaded Poland, starting World War II.

TALK ABOUT TIMING

From that moment of lucky escape on, "I'm the first to admit my life has been a history of being in the right place at the right time," Viterbi recounted to THE BENT. But that's undue modesty on his part. His life is practically a twentieth-century Horatio Alger story of rising from rags to riches through luck, pluck, virtue, cheerfulness, and sheer hard work—and of, in turn, reaching out to assist others to succeed as well.

In the last half-century, Viterbi has pioneered several industries. Underlying most of his work is a method he invented in the 1960s now called the Viterbi algorithm, fundamental to all military communications, spacecraft telemetry, and cellular telephony. Implementing the algorithm in circuits and software, he co-founded several companies including Qualcomm, a leader in cellular communications. Now retired from industry, he devotes his time and energy encouraging bright young engineers in developing new technologies, through both philanthropy and venture capital.

SPACE IS THE PLACE

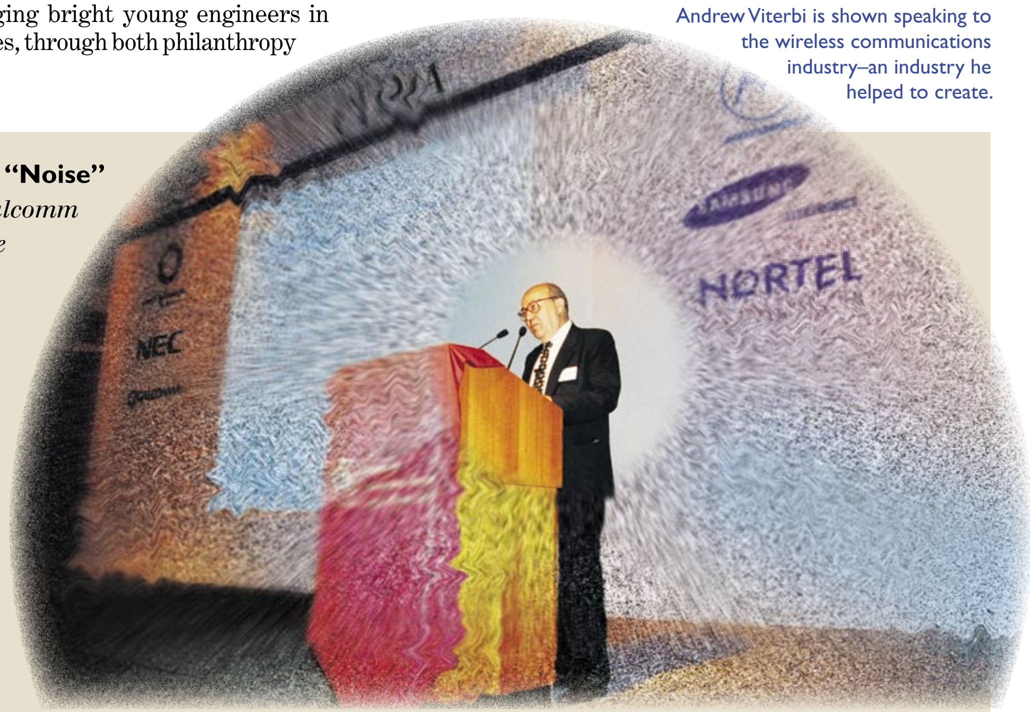
None of it was handed to Viterbi. In kindergarten, he wrestled with learning English. In 1941, his family moved from New York City to Boston; his father Achille, then 60, struggled to re-establish his ophthalmology practice this side of the Atlantic, while his 47-year-old mother, Maria Luria, did her best to make a home.

Andrew J. Viterbi, *Massachusetts Beta '57,* as a new teacher in 1963.

By age 10, Andrew often gazed across the Charles River at the buildings of the Massachusetts Institute of Technology in Cambridge, determined to go there for college. And hard he worked to realize his dream: in high school he graduated fourth out of a class of 225 and excelled in science, winning a scholarship to MIT. He enrolled in the co-op program in electrical engineering, which allowed him to work part-time to earn his keep. In June 1957, the 22-year-old graduated with both bachelor's and master's degrees in EE and accepted the most intriguing job he was offered: to join a communications

The Calm Amid the "Noise"

The co-founder of Qualcomm and the inventor of the Viterbi algorithm that underlies all missile guidance, spacecraft communications, and cellular telephone technology started life as a penniless Jewish refugee who fled Italy for the United States on the brink of World War II.



Andrew Viterbi is shown speaking to the wireless communications industry–an industry he helped to create.

Andrew J. Viterbi receiving the Marconi international fellowship award from the late Dr. D. Allan Bromley, *CT A '48,* science advisor to the President,

research group at the Jet Propulsion Laboratory (JPL) in Pasadena, CA. That summer he moved not only himself but also his aging parents—who were finding Boston winters increasingly difficult—to the Mediterranean climate of southern California.

In the 1940s and '50s, JPL was operated by the California Institute of Technology under contract to the U.S. Army Ballistic Missile Command. Tensions were escalating during the cold war between the United States and the former USSR, then the world's only two nuclear powers. Viterbi had been hired by communications guru Eberhardt Rechtin *[CA B'46]*—the man who, after NASA was formed in 1958, designed what became the Deep Space Network still used for tracking interplanetary spacecraft. In 1957 though, Rechtin's group was building radio systems for guiding missiles being developed at Redstone Arsenal. The challenge was to design guidance systems that would work even in the presence of enemy jamming—spurious signals intended to drown out or foul the guidance signals and throw the missiles off-course. "JPL was on the cutting edge of anti-jamming research," Viterbi recalled, "ahead even of MIT's own Lincoln Labs in Massachusetts."

In October 1957, just months after Viterbi joined JPL, the Soviet Union stunned the world by launching the first satellite into orbit around the Earth—beeping, basketball-sized Sputnik 1, signifying the USSR's dominance of orbital space. The U.S. went into overdrive to play catch-up in the Space Age. Again, Viterbi found himself in the right place at the right time: Rechtin's section was immediately put on the Army's space program. Viterbi worked long hours with others in Rechtin's section—"I personally was working primarily on the tracking part, acquiring the signal"—on equipment for Explorer 1, the first successful U.S. satellite, launched in February 1958.

THE FAMOUS ALGORITHM

For six years, Viterbi helped pioneer missile and space communications systems at JPL (transferred to NASA in 1958)—not only for artificial satellites but also for spacecraft to be launched to other planets over distances so vast that data signals were buried in radio noise from the sun and the center of the galaxy. During that same six years, he earned his Ph.D. in EE from University of Southern California, then a much less well known private university and the only school that would allow him to pursue part-time graduate work while working full-time. He also married Erna Finci, herself a Jewish refugee from Yugoslavia, and celebrated the birth of the first two of their eventual three children.

As much as he enjoyed research at JPL, what Viterbi wanted to do was teach. So a year after receiving his doctorate in 1962, he accepted an invitation to become an assistant professor at the University of California, Los Angeles. There, he started teaching information theory and digital communications. When it came to teaching the problem of extracting digital signals out of noise, the standard way of presenting the subject was "complex and hard to teach," Viterbi said. So he set about trying to simplify the concepts "to teach the advanced course in a better way." After three months of concentrated thought, in March 1966 he figured out a simplified solution.

Thrilled at having devised a powerful new teaching aid, he wrote a paper (published in 1967 in *IEEE Transactions on Information Theory*) that first expressed what is now

Enjoying a moment at the Andrew Viterbi Computer Center at Boston Latin School, his former high school, in 2002.

called the Viterbi algorithm, for teasing a faint digital signal out of strong noise [see page 19]. But a colleague pointed out that the algorithm—if it could be implemented in hardware—also had powerful practical application in improving the actual performance of communication systems. In fact, it was so powerful that engineers using it for missiles,

Viterbi algorithm 101

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Every transmission, analog or digital, modulates a sinusoidal carrier wave of some specific frequency. So whether a transmitter is a missile, a spacecraft, or a cellular phone and whether transmissions are analog or digital, two fundamental challenges remain the same.

First, there's the **challenge of tracking a moving transmitter**. When a transmitter moves, its carrier frequency is Doppler-shifted: toward higher frequencies when the transmitter is approaching and toward lower frequencies when the transmitter is receding (just as the sound of the whistle from a moving train abruptly drops as it passes a listener). If the speed of the transmitter is known and constant, a receiver can be tuned to compensate. But if the transmitter accelerates or decelerates (as with a missile or with a spacecraft-tracking antenna on the rotating earth), or if its movements are unpredictable (as with a cellphone in a car driving city streets), how can the unpredictably shifting carrier frequency be tracked?

Second, there's the **challenge of extracting a faint signal from loud noise**. In space, a 100-watt transmitter may need to be tracked past the planet Neptune, and its signals recovered flawlessly despite interfering radio noise from the galaxy or from flares exploding on the sun. On Earth, an enemy may deliberately try to jam guidance signals by transmitting loud and random noise. And each cellphone user is surrounded by thousands of others, all changing their locations with respect to receivers and to one another and all sharing the same wavelengths. So how can each signal be reliably extracted from shifting carriers in such a noisy environment?

The tracking problem was solved by using phase-locked loops, substantially developed (although not invented) by Eberhardt Rechtin and several colleagues at JPL. Basically, a phase-locked loop is a tracking circuit that efficiently follows a moving carrier. A carrier is a sine wave. To transmit information, that sine waveform has to be modulated (altered) in a way that, for digital communications, signifies 0s and 1s. In phase modulation, **the carrier is altered by changing the phase of the carrier**—that is, by advancing or retarding part of the sine wave, typically so that a 0 is indicated by a phase of +90 and a 1 by a phase of -90. In spacecraft communications, only part of the carrier is modulated, with the rest deliberately left unmodulated. A receiver locks the phase of the received unmodulated carrier to the original phase of the known transmitted carrier, thereby obtaining a reference against which the phase-modulated signal can be compared. This process is repeated many times during every communication period between spacecraft and ground station (keep in mind, the ground station also moves with respect to the spacecraft, owing to the earth's rotation on its axis and revolution around the sun).

The problem of extracting a faint signal from loud noise was **solved by redundancy and coding.** Instead of representing each information bit (1 or 0) by just one phase shift, each 1 or 0 is represented by four or eight or more code symbols. Thus, "what you're extracting is not actual information bits—1s or 0s—but code symbols from which you reconstruct the actual information bits," Viterbi explained. So even if only some code symbols are badly distorted by noise and fading, an information bit can be reconstructed with high confidence.

But in a noisy environment, **"it turns out that it doesn't pay to decide right away whether received code symbols signify a 0 or a 1,"** Viterbi continued. "It's more efficient to say they are **probably** a 0 or a 1, and assign a level of certainty: very sure, moderately sure, sort of sure, barely sure. We call these **'soft decisions.'** The soft decisions then go to a decoder that tries to figure out whether an information bit is a 0 or 1 by comparing the results with neighboring bits."

Problem is, the brute force calculation appears impossibly complex.

Viterbi's algorithm cuts through that complexity by offering an efficient method of combining the soft decisions to select the most likely sequence of bits transmitted. "Indeed, **the algorithm turns out to be the optimal method,**" he said. "It was simpler than alternative methods, so it caught on at JPL for space and satellite programs" and ultimately also in military communications and cellular telephone systems.

Now, here's the power of combining phase-locked loops and the Viterbi algorithm. First, if it's possible to track an unpredictably shifting carrier frequency, it's also possible to track a predictably shifting carrier frequency. So **a carrier frequency can be spread over a wide region of the electromagnetic spectrum**. If the transmitter spreads it in a predetermined pattern and the receiver is programmed to follow that same pattern, then communications can be secured from eavesdropping. That's the reason such spread-spectrum communications are attractive for military use.

Moreover, if the signals are weak enough, they will look almost like background noise. Indeed, **tens of thousands of transmitters can operate in the same band in the same place at the same time,** each spreading its carrier by coding it with a different pattern and being followed by just one receiver, **completely impervious to interference from other transmitters.** That's the basis for today's code division multiple access (CDMA) digital cellular communications.

Hundreds of faculty, staff, students, alumni, and well-wishers crowded into the engineering quadrangle of the University of Southern California on Tuesday, March 2, 2004, to honor Andrew and Erna Viterbi for their $52-million gift to the engineering school. Viterbi received his Ph.D. in electrical engineering in1962 from USC. The gift is the largest naming gift ever given to an engineering school. In recognition of the couple's generosity, the school was renamed the Andrew and Erna Viterbi School of Engineering

spacecraft tracking, or cellular telephones could pick from a wonderful smorgasbord of choices: reducing transmitter power, reducing receiving-antenna diameter, extending the range of a transmitter, operating in a jammed environment, or increasing the number of users supported in a cellular system.

And therein lay the fundamental secret of the Viterbi algorithm's long, fruitful application in so many industries.

INCUBATING CELLULAR COMMUNICATIONS

Viterbi taught at UCLA for a decade (1963–73). But as the development of technology made it clear that his algorithm might have practical application in military and commercial communications as well as in space telemetry, he began consulting on small study contracts from the department of defense and NASA along with two professor colleagues, Leonard Kleinrock *[MA B '62]* at UCLA and Dr. Irwin M. Jacobs *[NY Δ '56]* at the University of California, San Diego. This consulting grew so fast that in 1969 the three incorporated as a startup company they named Linkabit. The next year, the firm had 10 employees; by 1973, it had 25 employees.

At this point, Viterbi felt he needed to choose between staying in academia or co-running Linkabit full time. So in 1973, he cast his fate with the fledgling company and moved with it to San Diego, where Jacobs had previously committed himself to it (Kleinrock withdrew, however, as he spent more time developing Arpanet, which eventually evolved into the Internet, for which Kleinrock helped invent packet switching). By the mid-1970s, Linkabit had won a contract to build all the jam-resistant two-way radios for the entire fleet of aircraft and ground stations in the U.S. Air Force's Strategic Air Command, installed in the late '70s and early '80s. The technology Linkabit developed was the predecessor for today's wireless "Wide Area Networks" or WiFi modems in laptop computers.

In 1980, Linkabit was acquired by Microwave Associates Communications (M/A-COM) in Burlington, MA. The merger "gave us the opportunity to expand into commercial products, such as developing modems for very small-aperture antenna terminals (VSATs) for early digital satellite transmissions," Viterbi said, referring to the antennas only a few meters in diameter used to interconnect widespread corporate locations. Viterbi also helped design and build the first scrambler for Home Box Office (HBO), using his anti-jamming technology in reverse to garble TV signals so that nonsubscribers could not view TV programs for which they had not paid.

Viterbi stayed with M/A-COM for five years, until a change in management in 1985 caused Jacobs and Viterbi to quit within a week of each other. Later that year, Viterbi and Jacobs plus five other former Linkabit employees founded Qualcomm—destined to become an industry giant.

QUALCOMM TAKES OVER

Initially the Qualcomm team sought defense work. But quickly they branched into commercial applications. Their first experimental license from the Federal Communications Commission was for OmniTRACS, a system using communications satellites in geostationary orbit to allow long-distance trucking companies to remain in constant contact with dispatchers via short text messages. From an initial 600 trucks in 1988, OmniTRACS has grown to handle more than half a million trucks worldwide today. "OmniTRACS really launched Qualcomm," Viterbi declared. "In the early 1990s it became profitable, and that financed the early days of CDMA wireless rollout."

Around 1990, after the early cellular communications industry had decided that time-division multiple access (TDMA) was the digital technology of choice, "we came along and said 'we have a better way'," Viterbi said—that way, of course, being digital CDMA. "Everyone laughed except for the predecessors of Verizon: Pactel Cellular (later Airtouch), Nynex, Bell Atlantic—three of the Baby Bells founded after the 1984 breakup of AT&T—plus Sprint Communications. They made a small investment." In 1993 CDMA for digital cellular communications had been standardized. In 1995, Qualcomm's first digital CDMA cellular communications system had been installed in Hong Kong, followed the next year by systems in Los Angeles and South Korea. Indeed, South Korea "had the largest number of digital cellphones in the world until about 2000," Viterbi said.

Today in 2006, "there are 300 million CDMA phones worldwide. They are used everywhere except in parts of Europe," he said. They've taken the world by storm because the efficiency of spread spectrum is so high that 15 times as many CDMA users can be accommodated in the same bandwidth as analog users, and three-to-four times as many as TDMA users. Thus, for the new 3G (*third generation*) of voice and high-speed data cellphones, some version of CDMA has been adopted throughout the world. Qualcomm went from seven employees in 1985 to a peak of more than 10,000 in 1999 when it was trying to do everything from building chips to licensing technologies to building base stations and handsets. It later sold the infrastructure division to Ericsson and the cellphone manufacturing to Kyocera, reducing the number of Qualcomm employees to "five or six thousand, but now it's much more profitable," said Viterbi. Now the company focuses on "building the brains for cellphones"—the smart chips that incorporate CDMA technology and the Viterbi algorithm in silicon and metal.

Viterbi retired from Qualcomm in 2000 at age 65. When he's not on the ski slopes or serving on the boards of 13 companies and not-for-profit organizations, he devotes his remaining time three ways: professional activities (such as writing review papers and giving lectures at universities and keynote addresses at conferences), investment in startup companies ("I get a kick out of companies with new technologies going after established or emerging markets—and I want to make money, like any other investor!"), and philanthropy through the Viterbi Family Foundation.

The foundation's largest endowment was $52 million to the engineering school of his *alma mater* USC in 2004. The university then renamed the school the Andrew and Erna Viterbi School of Engineering [page 20], now ranked among the top 10 engineering schools in the country. Other grants have gone to his former high school (the Boston Latin School in Boston, alma mater also to the likes of Benjamin Franklin, Ralph Waldo Emerson, Leonard Bernstein, and Joseph P. Kennedy), to Scripps Research Institute, to MIT, to Technion in Israel, and to programs preparing disadvantaged young people for higher education.

ADVICE FROM A LIFE AT THE TOP

What does Andrew Viterbi have to say to today's engineering students about to launch into their own careers?

"Work on something you enjoy—because then it isn't work," he declared. "Concentrate in an area where you think you're good at it. Don't spread yourself too thin." He's had great satisfaction from engineering, because it's allowed him to explore the gamut from scientific research to business and law, and "making technology work, and making value for others."

And what about being at the right place at the right time? "All the decisions I made seemed to be logical at the time," he reflected. "I didn't spend a lot of time worrying about the right thing to do." He stopped, and added, "The difficult one was leaving academia to move to San Diego and taking on an industrial entrepreneurial role full-time. But it's been an exciting ride!"

Last, "I believe in giving back," Viterbi said quietly. "I'm an immigrant. I came to this country when I was four years old. And I've had a career I couldn't have had anywhere else. I'm very concerned for the future of our nation. We've had 50 wonderful years of growth from scientific inventiveness."

He continued after some reflection, "I very much support the National Academies' initiative in funding continued scientific and technology research so ably presented in the report "Rising above the Gathering Storm" *[www.nap.edu/books/0309100399/html]*. We must preserve our nation's leadership in technological innovation. That requires preserving and growing our institutions of higher education for both research and teaching. And if we cannot recruit enough of our own American students into science and engineering graduate studies, well," he shrugged and smiled, "we must continue welcoming well-prepared students from Asia and Europe, encouraging them to stay here upon completion of their studies so as to contribute to the innovation which fuels our economic growth."

Which is, after all, just what Andrew Viterbi did.

References

Telephone interviews with Dr. Viterbi were supplemented by information from a 1999 interview by David Morton for the IEEE history center, *www.ieee.org/organizations/history_center/oral_histories/transcripts/viterbi.html* . USC has information at *viterbi.usc.edu/about/viterbi/* .
More history and photographs appear in "A Proper Name: Viterbis Name School of Engineering," by Carl Marziali, *USC Engineer* (vol. 2, no. 2, pp. 24–30, Spring/Summer 2004).
Viterbi's classic paper first describing his algorithm is "Error Bounds for Convolutional Codes and an Asymptotically Optimum Decoding Algorithm," *IEEE Transactions on Information Theory*, vol. IT-13, April 1967, pp. 260-269.
The USC site has an introduction to the Viterbi algorithm at *viterbi.usc.edu/about/viterbi/viterbi_algorithm.htm* .

Trudy E. Bell, managing editor for the *Journal of the Antique Telescope Society*, has an M.A. in the history of science and American intellectual history from New York University (1978). While a senior at the University of California, Santa Cruz, she worked weekends at NASA's Ames Research Center as a mission controller for the sun-orbiting spacecraft Pioneers 6, 7, 8, and 9—where over the voice link to JPL, she often heard the operations chief speak of "locking" onto a spacecraft's signal (a process driven by Viterbi's algorithm).

A former editor for *Scientific American* (1971-78) and *IEEE Spectrum* (1983-97), she has written or edited a dozen books and more than 300 articles on the physical sciences, technology, bicycling, and history of exploration; she covered the Voyager 1 and 2 flybys past the outer planets from JPL and writes often for the popular Science@NASA website. Contact: *t.e.bell@ieee.org* and *home.att.net/~trudy.bell.*