profile

BART KOSKO

This optimistic engineer seeks to give machines a higher IQ—both in his neural and fuzzy systems work and in his prolific science fiction

SCI-FI AUTHOR ROBERT HEINLEIN WAS RIGHT," Bart Kosko says. "Specialization is for insects. The nature of brains is to generalize."

Kosko works with machine-like diligence. Just 36, he has already written three engineering textbooks, nearly 100 technical articles, and a best-seller science book, *Fuzzy Thinking*, as well as a forthcoming cyberthriller novel, a collection of essays and short fiction, and three symphonies. He organized the first IEEE neural networks conference at age 27 and holds degrees in philosophy, economics, and math, capped with a Ph.D. in electrical engineering.

Now, Kosko directs the Signal and Image Processing Institute at the University of Southern California, Los Angeles. He examines how nonlinear systems learn, with the goal of making machines act smarter. Such areas as multimedia, communications, and intelligent agents may eventually benefit from his results there.

When not working into the night, the tenured professor of electrical engineering seeks solace outdoors, whether hiking in the Mojave desert, fly-fishing in the Sierras, hunting boars with bow and arrow, or scuba diving in the Caribbean. These excursions often show up later in his fiction.

Fuzzy engineering

"Bart is by far the leading expert in the combined area of neural networks and fuzzy systems," said Robert Hecht-Nielsen, a neural network pioneer who heads HNC Software Inc., San Diego.

Marvin Minsky, Toshiba Professor of Media, Arts, and Sciences at the Massachusetts Institute of Technology, Cambridge, told *IEEE Spectrum* that Kosko is a "wonderful futurist with a polymathic combination of talents."

Lotfi Zadeh, the University of California, Berkeley professor emeritus and fuzzy logic doyen, called his former protégé "an outstanding intellect who has made original contributions in many areas of fuzzy logic and applications."

Kosko hopes to continue that with his new text, *Fuzzy Engineering* (Prentice Hall, Englewood Cliffs, N.J., 1996). The book suggests ways to cope with a vexing problem in fuzzy logic: the exponential growth in rules as the number of variables increases.

Currently, fuzzy systems often apply where the number of inputs and outputs is small and events happen relatively slowly. Fitting into that category are fuzzy washing machines, videocameras, and even subways. These applications have on the order of 20 to 100 rules; a few experimental models may have more than several hundred rules.

With the book's publication, Kosko hopes to spur fuzzy applications in more challenging endeavors, such as video-rich multimedia and virtual reality. These systems can require many more rules of greater complexity operating in milliseconds. Nothing motivates Kosko like a tough problem.

Music to math

Surely no one else has taken a more varied route to electrical engineering. Government eminent-domain plans for a highway uprooted the Koskos from Kansas City to a farm when Bart was three years old. There he trapped fox, mink, and muskrat with his father and envisioned a future living off the land in some place like Alaska.

When Kosko was 10, an electrical short burned down his house. Three months later his father died in a car accident. The financially strapped family split up and Kosko grew his hair long, hung out with a gang, and experimented with an array of drugs.

A bad LSD trip made Kosko disavow drugs and rock-and-roll at age 14. He plunged into classical music. He foreswore watching sitcoms and other "TV trash" and began his habit of often studying until 3:00 or 4:00 in the morning.

JOHN A. ADAM
Senior Associate Editor

The teenager took up the mandolin, the violin, and the piano. He began music studies at a local college, and learned orchestration from the scores and recordings of Beethoven's nine symphonies . As the sounds of strings, horns, and oboes filled the air, Kosko followed the parallel tracts of the written notes. All this sparked in him an undying interest in symbols and representation.

A music composition award at age 17 and an orchestral overture composed in high school let him "pole vault out of Kansas" to the University of Southern California (USC) on a full music scholarship. Kosko passed Ph.D. exams in music composition when he was 18 and hard at work on his first symphony, in G minor.

But the school's emphasis on atonal composition annoyed him, so he switched to philosophy and economics—the study, respectively, of thought and action. These interests meshed well with his libertarian views. No longer

0018-9235/96/$5.00©1996 IEEE

ALL PHOTOS: HENRY BLACKHAM

qualified for his music scholarship, Kosko took a night job and wrote essays and fiction for pay.

One essay so impressed a teaching assistant that it was given to the USC philosophy department librarian, Ross Scimeca, a Ph.D. graduate. "At first I thought it might be Huxley," Scimeca recalled. But on closer look he determined that the author was indeed a precocious freshman. Scimeca developed reading lists for Kosko, by then enmeshed in logic and the philosophy of science.

Vital statistics

Name: Bart Kosko
Born: Feb. 7, 1960, Kansas City, Kan.
Personal: one daughter, Victoria, nine years old
Education: BA degrees in philosophy and economics (University of Southern California, 1982); MA, applied math (University of California at San Diego, 1983); Ph.D., electrical engineering (University of California at Irvine, 1987)
First jobs: fur-trapping, ginseng hunting, and bailing hay
Interests: history, hunting, deserts, fly-fishing, physical fitness, scuba diving, cigars
Pet peeves: no mail on Sunday—"and no one complains." Debt. Neckties. Rock and roll.
Personal heroes: John Stuart Mill, Herbert Spencer, Geronimo
Favorite composers: Richard Wagner, Anton Bruckner
Favorite award: winning young composers' contest at age 17 for his "Second String Quartet in A Major"
Favorite authors: Leo Tolstoy, Ernest Hemingway, Arthur C. Clarke
Car: Ford Explorer
Creative philosophy: "Vary your stimuli and remember what Big Al Capone said: Do it first. Do it yourself. And keep doing it."

Soon Kosko found that "math was the language of science and I could not speak it." He bought an old calculus book during the Christmas break and soon worked every homework problem from algebra in the first section to differential equations in the last. One year later, he was tackling a course in differential geometry—essential for understanding Einstein's general relativity—under eminent theorist Mark Kac (and former editor of the *Annals of Probability*). Kac persuaded his student in 1982 to pursue a graduate degree in math.

Then Kosko wrote what is still his favorite paper. He dashed it off just for "pure intellectual curiosity" after watching an episode of ABC News' "Nightline" on drug prohibition. Few read the piece—it took nine years for it to be published—but Kosko had derived his first equation. His math described the growing of marijuana as a nonlinear dynamical system of three groups of people: growers, thieves who prey on growers, and government narcotics agents who prey on both. The model used techniques of game theory and population biology. Its theorems turned out to apply to many other scenarios and some biologists now teach it in their classes. Kosko was hooked. He had mapped experience to symbols.

Markets and brains

Fuzzy logic and neural networks were obscure fields in 1982—and therefore wide open. Unknown to Kosko, his undergraduate studies had prepared him for both. Philosophy had grounded him in multivalued logic. The math-intensive economics of equilibrium theory had prepared him for neural work.

Studies by neural pioneer Stephen Grossberg at Boston University suggested that brain neurons act as a large self-organizing market economy. This possibility immediately attracted Kosko.

"Bart built on the work that Mike Cohen and I did on content-addressable memories," Grossberg told *Spectrum*. "He showed how learning could be incorporated into the Lyapunov function that enables the network to function as a stable memory. Bart also went on to develop a number of interesting applications."

Artificial intelligence (AI) was then in vogue. But Kosko found it fell short of a mass theory of machine intelligence. "I had two main problems with AI," he recalled. "AI was symbolic and relied on decision trees."

"The symbolic format would not let you apply the great bulk of modern mathematics to problems of machine intelligence," he said. (One cannot differentiate symbols, only smooth functions.) "Thought is not a mere string of text."

And AI's decision trees did not allow the combining of knowledge structures. In Kosko's view: "A tree plus a tree does not equal a tree."

"What I always liked about fuzziness was how it mapped language into numerical math," he explained. In addition, many fuzzy and neural models relied on feedback. Such systems could adapt to new conditions.

Independently around this time, Kosko developed an adaptive causal knowledge structure (known now as the fuzzy cognitive map). It changed with new feedback data with something Kosko called differential Hebbian learning. He based this in part on John Stuart Mill's writings on cause and effect. He also began exploring ways in which machines could learn on the basis of competition among neurons.

Kosko worked for General Dynamics and Verac, both San Diego aerospace companies, while in graduate studies. Amid hundreds of articles on his desk at General Dynamics, one referred him to a 1965 paper by Zadeh on fuzzy logic. This intrigued Kosko and he seized the initiative. He met Zadeh at a conference, sent him a proof of a fuzzy theorem, and so impressed Zadeh that the Berkeley professor advised Kosko to pursue a Ph.D. in fuzzy logic under Allen Stubberud, at the University of California at Irvine, an hour up the San Diego freeway.

Meanwhile, at work Kosko applied neural network ideas to Star Wars and air defense battle management architectures. The idea, he said, was to build a force of sensors and weapons that bargained for strike assignments on the model of a decentralized market economy. He bid against his Ph.D. advisor for an Air Force architecture contract and won. Kosko called the system Adam (for Air Defense Associative Memory).

The simulated system used a bidirectional associative memory (BAM), a feedback neural net area Kosko introduced in the mid-'80s. Associative memories are distributed and degrade gracefully, and so can sustain damage without complete loss of capability.

The year 1987 proved to be a big one for Kosko. As Chairman of the IEEE Computer Society Chapter in San Diego, he organized the first IEEE international neural network conference. This became the third-largest IEEE conference that year. Kosko also had a daughter and joined the USC faculty, having just earned his Ph.D. in electrical engineering on the foundations of fuzzy systems.

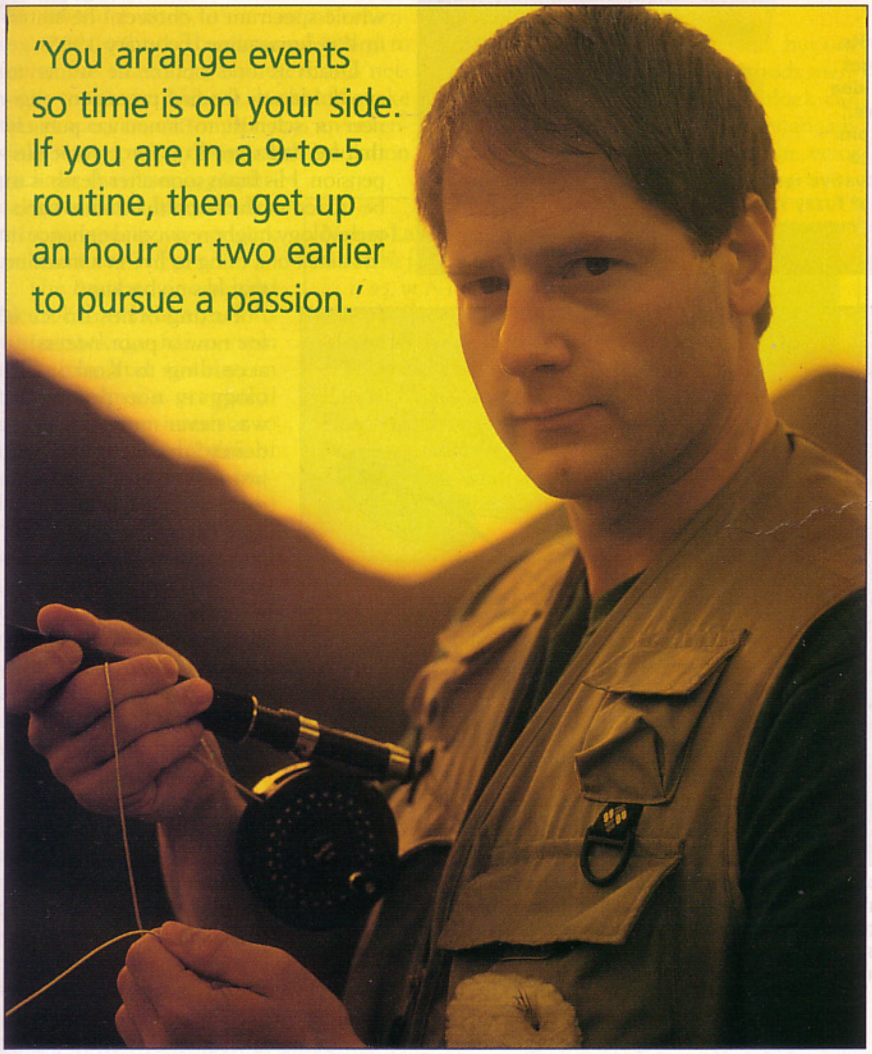
Why a Ph.D. in electrical engineering after music, economics, philosophy, and applied math? Said Kosko: "That's easy. Electrical engineering is really the science of information. This is the Wild West of the Information Age."

Everything reduces to structured information, he said, whether it concerns markets, DNA, ecology, or the physics of black holes. "The media sees physics as king of science," Kosko said. "That's no longer true. Electrical engineering lies on the cutting edge of all disciplines."

Patch the bumps

No one knows the equations needed to govern platoons of smart cars traveling over curves and bumps, and up and down hills, at highway speeds. That's a case for fuzzy engineering, as Kosko and his students recently showed, testing cars on the I-15 highway near San Diego. Enough fuzzy rules can approximate any unknown function, something Kosko proves in the Fuzzy Approximation Theory.

The building block of a fuzzy system is a rule that maps inputs to outputs: IF X IS A, THEN Y IS B. ("If the room is cool, then set motor speed to slow.") Each rule defines a patch in the input-output state space [see graph, p. 62]. A chain of these patches approximates a function. Neural systems



move and shape the patches to better approximate the function.

New variables can make a system more realistic: for instance, adding humidity rather than just temperature for air-conditioning feedback. The problem is that the number of rules will grow exponentially.

This curse of "rule explosion" limits the further application of fuzzy systems, according to Kosko. Optimal rules make the best of a fixed rule budget. They "patch the bumps" or cover the turning points or extrema of the function. Rather than having 100 little patches to approximate a function, one might need only five by patching the bumps. The math is simple. Much of it involves "the old task of finding the zeroes of a derivative map," Kosko noted.

Ronald Yager, a professor at Iona College, New Rochelle, N.Y., and the editor of the *International Journal of Intelligent Systems*, told *Spectrum*, "Patching the bumps looks like a good way to reduce the number of rules."

Finding the best shape for a fuzzy set (or patch) remains a hard problem, which Kosko jokingly equates to finding the best filament for the electric bulb. He and his students found Claude Shannon's sinc function, sin x/x, the best of more than 100 shapes.

In *Fuzzy Engineering*, Kosko presents this patch-the-bumps theory and applies it to the control of smart cars, image compression, chaos modeling, spread-spectrum communication, hardware design, pattern recognition, multimedia, and virtual reality. He also extends prior work on fuzzy cognitive maps and fuzzy cubes (which model nonfuzzy sets as cube corners and fuzzy sets as points inside the cube).

In general, Kosko relies less on linguistics and more on math. "The math may come as a letdown to some. It shows there is no magic in fuzzy systems," he said. "I've tried to reduce fuzzy logic to geometry and algebra."

Fuzzy and neural systems have now matured to the point where they comprise many branches and yield scores of international conferences and journals. Kosko has concentrated on an area he developed called additive fuzzy systems.

Ian Stuart, a British mathematician at Warwick University, Birmingham, and a *Scientific American* columnist, stated that Kosko "has proved some genuinely interesting 'pure' theorems which go a long way towards convincing mathematicians that there is a serious subject to be studied here."

Another academician, George Klir, Distinguished Professor at the State University of New York and ex-president of the International Fuzzy Systems Association, credits Kosko with exploring different ways of thinking using fuzzy concepts. "He has applied this to a broad range of issues, including social problems," said Klir during a phone interview.

A former Ph.D. student of Kosko's, Julie Dickerson, now a professor in the electrical engineering department at Iowa State University, said his results and structures have been widely applied in industry because he explains them in down-to-earth terms and examples. "He's very persuasive," she said. "If he tires of academia, he should become a tele-evangelist."

Art and science

"Both science and art map experience to symbols," Kosko says. "Science symbols *reveal* the structure of the world. Art symbols *add* structure to the world. Music is the sound of math."

In the middle of *Spectrum's* second interview, Kosko shares a 3-minute synthesized excerpt from his "Third Symphony in E Minor." It has an appealing brooding quality. The harmonic motion could support a variety of melodies. I ask him, Why not compose more?

"The hardest thing to do is to write a new tune," he replies. "It's harder than coming up with a scientific conjecture or a logical proof. I now keep only musical notebooks."

But he remains a prolific writer. He is finishing a new nonfiction book for Bantam. And he has just completed the cyber-thriller, *Black Sun*, about a "smart" World War III in the year 2030.

Kosko's lay discourses range broadly, similar to those of the classic philosophers whom he admires.

He uses latest advances in science and math to expand on a Pythagorean theme: "There may be no God but the Mathmaker, and Science is His Prophet," (*IEEE Expert*, February 1990). He later argues that God has a proper place in speculative thought—not in religion or philosophy—but as the ultimate plot device and character in science-fiction writing (*Free Inquiry*, Summer 1995).

A Caribbean shark dive goes bad in "Downdraft" amid the nonlinear hydrodynamics of Cozumel's offshore channel (*Buzz*, April 1996).

In "Cool Earth," a futuristic attempt to cool the earth by nudging its orbit with nuclear blasts on a nearby planetoid goes awry and causes disaster (*New Rave*, January 1995). "You can get the science right to only a few decimal places. That mismatch with fact leads sooner or later to chaos."

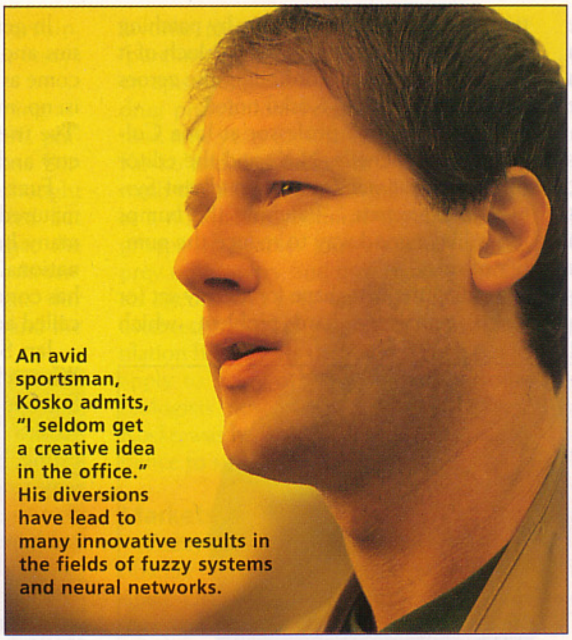
In the *Los Angeles Times* (Dec. 19, 1994), Kosko proposes a Digital Rights Act that would allow individuals to code their bits in their own way. "This would extend the First Amendment to the Information Age," he suggests.

Kosko often argues for a "fuzzy tax form" in radio or newspapers. Taxpayers would decide by multiple choice how, say, 50 percent of their payment was spent. One person might allot half of her discretionary funds to AIDS research, 30 percent to debt relief, and 20 percent to some miscellaneous cause. It would "give more say to those who pay."

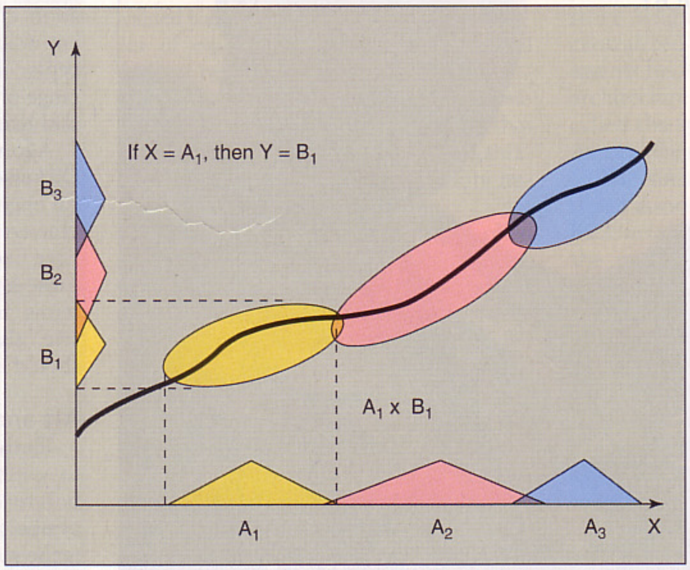
A fuzzy tax form could fund research contests in such areas as AIDS or cancer or electric cars, he observes in *Liberty* (September 1994). "One way to cure AIDS is to offer $1 billion to the first party to find a cure."

For his students, Kosko tries "to pull out some of that Edison or Einstein that's in everyone." Each year they compete for a $1000 prize in his popular Neural Fuzzy Systems course. Top designs have included a fuzzy pacemaker, a wardrobe selector, a star tracker, a robot arm, a boat docker, and a poker player.

Kosko finds that students often drift once they get their degrees. "My advice is to look for new problems, set goals, and vary your stimuli," he said. Besides the usual diet of technical periodicals, he reads at least a novel a week, rotating among the classics, contemporary literature, and science fiction.



An avid sportsman, Kosko admits, "I seldom get a creative idea in the office." His diversions have lead to many innovative results in the fields of fuzzy systems and neural networks.



A fuzzy system maps inputs *x* to outputs *y*. Each rule defines a patch, egg-shaped in this case. A finite number of fuzzy rule patches can cover any system function and approximate the system to any level of accuracy. Learning moves and shapes the rule patches. Lone optimal rules cover the bumps or turning points of the (unknown) function.

Exceptional individuals, wrote John Stuart Mill in *On Liberty* (which Kosko first read at age 18), "should be encouraged in acting differently from the mass." From his tee-shirt work attire to his outspokenness to his work, Kosko seeks the "new" in pushing boundaries, even if it shakes up the *status quo*.

Even Kosko supporters call him highly controversial. He can be brashly arrogant, and the wide range of his work means he has opportunities to offend engineers and scientists of all stripes.

His best-seller, *Fuzzy Thinking*, did a lot to popularize the field. It has been widely translated and was second only to Stephen Hawkings' *A Brief History of Time* among science books in Great Britain in the last few years. But the book angered some academics for its swagger.

Pro-choice on all issues

Both Kosko's die-hard libertarianism and the scientific basis of fuzziness extol multiple choices. "I am pro-choice on all issues," he said.

"Tyranny is one choice. Binary is next with two choices. Fuzz gives the whole spectrum of choices," he stated in *Wired* magazine (February 1995).

Death is one option he wants to avoid. He was the first prominent engineer or scientist to announce publicly that he had signed up for cryonic suspension. His brain soon after death is to be frozen in the hope that future nanotechnology might revive and enhance it. "It's a hell of a thing to live in a machine that has no backup."

Putting brains on ice is for now a poor necessity, according to Kosko. "Biology is not destiny. It was never more than tendency," he said. "It was just nature's first quick and dirty way to compute with meat."

The brain stores at least 10^{18} bits and can process information at about 10^{15} bits per second. If circuit density keeps doubling every two years or so, around 2020 the brain could fit into a chip the size of a sugar cube.

"Chips are destiny," Kosko said, calling them more suitable hosts for our synaptic structures—a second to a biological brain may seem days or weeks long to a nanochip brain. "That long life in a chip might be as close as we can come to heaven or hell in a universe made of matter and energy." ◆

To probe further

Other fuzzy works, besides those mentioned, include *Understanding Neural Networks and Fuzzy Logic*, by Stamatios V. Kartalopoulos (IEEE Press, Piscataway, N.J., 1996); *Fuzzy Logic With Engineering Applications*, by Timothy J. Ross (McGraw Hill, New York, 1995); *Fuzzy Sets and Fuzzy Logic: Theory and Applications*, by George J. Klir and Bo Yuan (Prentice Hall PTR, Upper Saddle River, N.J., 1995); and *Neural Networks and Fuzzy Systems*, by Bart Kosko (Prentice-Hall, 1992).