Notes of a Fringe-Watcher

Fuzzy Logic

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When the prophet, a complacent
fat man,
Arrived at the mountain-top
He cried: "Woe to my knowledge!
I intended to see good white lands
And bad black lands,
But the scene is grey."

—Stephen Crane

Why does traditional logic have so little relevance to how we think? One reason is that, aside from terms in pure mathematics, formal logic, and some words in mathematical physics, almost all words have blurry boundaries. In set theory an element is either in or outside a set. In propositional calculus an assertion is either true or false. No in-betweens. Unfortunately, in the real world, as philosopher Charles Peirce observed, "All things swim in continua."

No sharp line divides day from night. Children grow imperceptibly into adults. Beasts evolved gradually into humans. Red fades into orange and into purple. When is a glass full? A banana ripe? A person rich? Is half an apple an apple? Is Japan a capitalist or socialist state? When is a novel obscene? Exactly what *is* a novel? Is a bar stool with a small back a chair? How can we measure the beauty of a poem, a painting, a melody, or a person?

Such vagueness must not be confused with ambiguity. "There is a bat in the attic" and Groucho Marx's "I shot an elephant in my pajamas" are ambiguous statements. Arguments over whether the moon rotates arise from the ambiguity of *rotate*. The moon rotates relative to the fixed stars, but not relative to Earth. By contrast, "Is there life on Mars?" is vague because "life" is vague. Are viruses alive? "Go wash your face" is vague. Does "wash" require soap? Are ears part of the face?

Problems in logic textbooks often involve such statements as, "If Bill is home, Mary is out." Is Mary home if she is in the garage or on a porch?

You might think that letters of the alphabet can be defined precisely. Far from it. Every letter can be gradually altered on a computer screen until it is any other letter, with unclassifiable intermediates. A well-known example:

THE CAT

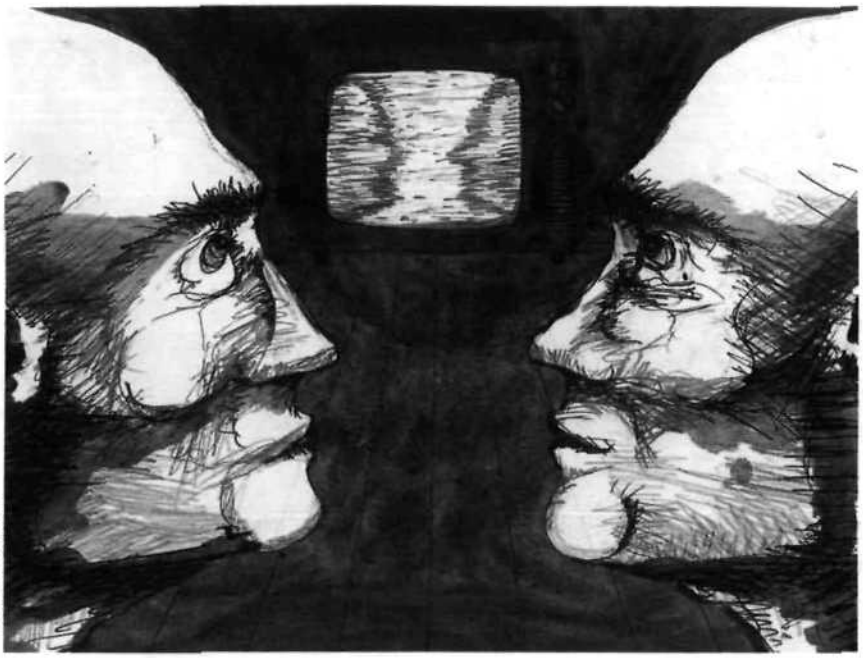
Is the middle symbol of each word an "A" or an "H"? Like so many words, the answer depends on the context. What is warm for an Eskimo may be cool to someone in the tropics. A small hippo is larger than a big ant. Jewelry expensive to a poor person is cheap to, say, Elizabeth Taylor or Donald Trump.

The ancient Greeks dramatized vagueness by the paradox of the heap. From a large heap of sand you remove one grain at a time. When does the heap cease to be a heap and become a few grains? How many is a "few"? How many hairs have to be missing from a man's head before he is bald?

From Aristotle on, logicians have, of course, been aware of vagueness and have proposed ways to overcome it. One way is to be more specific. Instead of vaguely declaring, "As someone once said, history is bunk," we specify it by saying, "As Henry Ford said in 1919. . . ." This helps, but still leaves "history" and "bunk" hopelessly vague.

Another way to avoid vagueness is to quantify. Vague words like *fast* and *slow* can be sharpened by saying that a car is going "too fast" on a thruway if its speed is more than 65 miles an hour, and going "too slow" if less than 40. Hot and cold can be made as crisp as you like by invoking degrees of temperature. Tall and short can be quantified with centimeters.

In recent decades logicians have tried to handle reasoning with vague terms by what are called "multi-valued logics." Instead of true and false, a three-value logic may introduce a third term such as *indeterminate*. Proposals



Patrick Hubenthal

have been made to apply three-value logics to quantum mechanics, where certain properties are unknowable. Modal logics distinguish between true, false, and possible. Hans Reichenbach and others have proposed multi-valued logics based on probabilities. True has a probability of 1, false a probability of 0. In between can be any number of truth values. Instead of saying vaguely that he or she thinks the big bang theory is true, a cosmologist would more accurately give the conjecture a subjective probability of, say, .9 of being true.

The latest, most ambitious, most radical effort to formalize reasoning with vague terms was named *fuzzy logic* by its inventor Lotfi Asker Zadeh, now a professor emeritus at the University of California, Berkeley. His new logic dates from 1965, when he published a little-noticed paper on *fuzzy sets.* (Zadeh was born Lotfi Aliaskerzadeh in Baku, Azerbaijan, in 1921, of a Russian mother and a Turkish-Iranian father. After graduating from the University of Teheran, he came to America and earned a doctorate in electrical engineering at Columbia University.)

Zadeh passionately believes that Aristotelian black-and-white logic is useless for reasoning about the real world. This view is shared by Alfred Korzybski, founder of *general semantics,* although this earlier movement by Korzybski had no influence on Zadeh. Just as firmly, Zadeh is convinced that fuzzy logic, with its tolerance of imprecision, will soon replace Aristotelian logic in a massive paradigm shift. "Nature," Zadeh is often quoted as saying, "writes with a spray can, not a ballpoint pen."

There is remarkable anticipation of fuzzy logic in H. G. Wells's philosophical work *First and Last Things* (1908). After describing a variety of objects called "chairs," he wrote: "In cooperation with an intelligent joiner I would undertake to defeat any definition of chair or chairishness that you gave me."

> Every species is vague, every term goes cloudy at its edges, and so in my way of thinking, relentless logic is only another name for stupidity—for a sort of intellectual pigheadedness. If you push a philosophical or metaphysical enquiry through a series of valid syllogisms—never committing any generally recognised fallacy—you nevertheless leave behind you at each step a certain rubbing and marginal loss of objective truth and you get deflections that are difficult to trace, at each phase in the process. Every species waggles about in its definition, every tool is a little loose in its handle, every scale has its individual.

Interest in fuzzy logic and fuzzy mathematics is now worldwide, but especially intense in China, Korea, and Japan. Fuzzy conferences are held regularly in the U.S., China, and Japan, where hundreds of fuzzy experts are publishing technical papers. Zadeh has become famous in Japan. More than a half-dozen introductory books on fuzzy logic are in Japanese. Technical books in English are finally being published, and several journals are devoted to this mushrooming field, the oldest being *Fuzzy Sets and Systems,* published in Amsterdam. The word *fuzzy* is on its cover in fuzzy red letters.

Every branch of applied mathematics has been fuzzified. Fuzzy arithmetic handles such fuzzy numbers as "almost 10" and "more than 50." Fuzzy geometry deals with almost straight lines, not quite round circles, and even vaguer concepts, such as ovals. Fuzzy graph theory draws graphs based on fuzzy points. There are fuzzy algebras, fuzzy topology, and fuzzy calculus. Work is being done on fuzzy artificial intelligence (AI), pattern recognition, and neural networks.

Fuzzy computer chips for handling fuzzy algorithms are rapidly being used in hundreds of control systems. In Japan, fuzzy silicon chips provide smooth stops and starts on Hitachi's subway in Sandai, Indonesia. The Japanese are fuzzifying elevators, cranes, washing machines, carburetors, showers, hair dryers, camcorders, electric razors, air conditioners, TV sets, ovens, vacuum cleaners, even entire chemical plants. "Expert systems," such as those used for medical diagnosis, mineral prospecting, and stock market analysis, are being fuzzified.

In 1989, the Japanese government funded the Laboratory for International Fuzzy Engineering Research with an advance of some $35 million and more than 40 member firms. Japanese cars are starting to use fuzzy transmissions. In 1989, Honda awarded its prestigious Honda prize to Zadeh for his contributions to Japanese technology. U.S. companies have been extremely reluctant to jump on the fuzzy bandwagon. Exceptions are Rockwell, which markets several fuzzy devices; Otis Elevator; and General Motors, which uses fuzzy logic in the transmission of its Saturn car.

Details of Zadeh's logic are technical, but let me convey some general features. A fuzzy set is one with fuzzy boundaries. Members are graded by a finite number of degrees, with incremental transitions between them. For example, heights of persons can be broken down into such fuzzy adjectives as very tall, tall, medium, short, and very short, each category defined by numerical intervals. A room's temperature is graded by numbers between hot and cold. True and false are replaced by degrees of truth and falseness. Although reasoning with fuzzy is precise, all its conclusions are fuzzy.

Many theorems in traditional logic carry over into fuzzy in modified ways. For example, on a scale of 0 to 1, assume that "Joe is short" has a fuzzy truth value of .2. Its complement, "Joe is not short," has a fuzzy value of 1 – .2 = .8. An "and" conjunction of "Joe is short" (value .2) with "Joe is handsome" (value .5) has a value of .5. "Joe is either short" or (in the exclusive sense) "Joe is handsome" has a value of .2. Implication: "If Joe is short then Joe is handsome" has a value equal to 1 – (.2 + .8), which is zero. Being short does not imply that one is handsome.

Instead of precise fuzzy values one might use what is called a "fuzzy fuzzy" value of, say, "almost .2." Zadeh calls such values a "second order of fuzziness."

"Fuzziness" is distinguished from "vagueness" in terms of (what else?) degree. "Jesus will return in a few years" is fuzzy. "Jesus will return eventually" is so extremely fuzzy that Zadeh calls it vague. He also distinguishes fuzzy from "probability" statements. "The chance it will rain tomorrow is .5" is a probability forecast. The fuzzy equivalent is, "The degree of truth that it will rain tomorrow is .5." The distinctions are subtle. Thus even the term *fuzzy* is "fuzzy."

Fuzzy logic, especially among artificial intelligence specialists in the U.S., has persistent detractors. They claim that fuzzy logic is overhyped, seeing it as a momentary fad similar to the "catastrophe theory" craze that befuddled mathematicians in the late 1970s. It has been called a "cult," with Zadeh as its founder and guru. Some have even called it "content free" and "the cocaine of science." Douglas Hofstadter thinks the idea of reasoning precisely about blurry concepts is "rather comical." Michael Arbib suggests that the cult would never have arisen if Zadeh had named his logic "set theory with degrees of membership."

Arguments between promoters and opponents of fuzzy have become acrimonious. In a 1994 conference on fuzzy in San Diego sponsored by *Computer Design* magazine, the main event was supposed to be a debate between fuzzian Earl Cox and anti-fuzzian Bob Pease. An announcement said the debate would be carefully monitored by the magazine's editor "to keep the contenders from doing each other actual harm." I am told the debate did not take place.

Opponents maintain that algorithms and chips based on probability theory and familiar multi-valued logics can do just as well as fuzzy in controlling machinery. After all, probability controls put astronauts on the moon, and guide intercontinental missiles and solar system probes. The line between fuzzy logic and probability logics is blurry. To assign "very tall" a fuzzy value of *n* is the same as saying that, in a given culture, a person over six feet will be called tall with a probability of *n*. Is fuzzy, detractors ask, merely probability theory in disguise?

To a large extent disagreements may be verbal. A computer program based on an analog algorithm with digital components would be called fuzzy by fuzzians, but not by others. Fuzzy chips, using sieves instead of on-off switches, would be called an analog program by the anti-fuzzians. Zadeh likes to point out that chess players have fuzzy intermediate goals, and when you park a car you maneuver it into fuzzy positions. Detractors would say that chess players and car parkers are simply making probability estimates.

In many cases, say the probabilists, a simple feedback mechanism, such as a flywheel or a thermostat, can serve adequately as a control mechanism. Fuzzy experts are proud of the fact that the Japanese have a fuzzy stability program that balances a pole on one end. Detractors say the same thing can be done with nonfuzzy programs. Fuzzians insist that fuzzy chips balance the pole, as well as handle other control systems, more efficiently with simpler rules and lower costs.

In 1993 two popular books on fuzzy logic were published in the U.S.: *Fuzzy Logic* (Simon and Schuster), by Daniel McNeil and Paul Freiberger, and *Fuzzy Thinking* (Hyperion) by Bart Kosko. Both books are breathless paeans to fuzzy, hailing it as a revolution of monumental proportions in computer technology—a revolution destined to transform the world.

Fuzzy Logic is the more restrained of the two. The authors give space to detractors, but argue that their opposition springs from a failure to understand fuzzy logic and from the slowness of a stubborn establishment to recognize a new paradigm shift. They agree with Zadeh that it will be many years until the U.S. catches up with Japanese technology in fuzzifying control systems. Although they are convinced that fuzziness will soon invade world technology, they grant the possibility that this prediction may "harden into garish embarrassments like the predictions of A.I. (artificial intelligence) and neural networks."

"Fuzzy arithmetic handles such fuzzy numbers as 'almost 10' and 'more than 50.'"

Bart Kosko, author of *Fuzzy Thinking*, is the movement's most controversial and combative promoter. He is the hero of the McNeil-Freiberger book, which devotes an entire chapter to him. Born in 1960 in Kansas City, Kansas, Kosko obtained his Ph.D. in 1987 from the University of California, San Diego, with a thesis on

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fuzzy systems. He now teaches electrical engineering at the University of Southern California, Los Angeles.

Kosko is also a karate expert, body builder, music composer, and fiction writer. Politically he is a libertarian. A believer in the future of cryonics—freezing human bodies to resuscitate them later when medical science is more advanced—he made this the basis of his science fiction novella, *Wake Me When I Die.* He was an ardent logical positivist, steeped in the binary thinking of Carnap and Quine, before Zadeh's work overwhelmed him and Kosko moved from black and white to gray. Since then his contributions to fuzzy have been immense, notably his recent work on "fuzzy entropy" and "fuzzy systems."

Kosko is also into Zen meditation. He believes U.S. logicians and manufacturers are still mired in the binary either/or thinking of Western philosophy. By contrast, Southeast Asia, with its Buddhist background, is more tolerant of continuity and vagueness. True, the yin/yang symbol is binary, but each half contains a spot of the other, suggesting the fuzziness of both sides. Perhaps Japanese fuzzians will fuzzify the symbol by fading the white and black sides through a continuum of grays.

Kosko is good at inventing fuzzy phrases, such as "fuzz-up" and "fits" (fuzzy units to replace fuzzy bits, or binary units). Rubik's cube suggested to him a clever way to model fuzzy values as fuzzy points within cubes and hypercubes. He likes to speak of the day he learned that "science is not true"—that is, all its laws are fuzzy.

Fuzzy Thinking is an entertaining tour de force that ranges widely and smoothly over such topics as relativity theory, quantum mechanics, psychology, ethics, philosophy, and even theology. Everything is, of course, fuzzified. "God," Kosko writes in his last chapter, "is He who wrote the math. Or She who wrote the math. Or It that wrote the math. Or the Nothingness that wrote the math.The Mathmaker."

Is fuzzy logic as revolutionary as Kosko and his mentor Zadeh believe? Maybe. □

Consciousness *from page 26*

tremendous advantages for social interactions. The individual can form a model of what it is like to be another person. Such models can be used with great advantage to predict the desires and behaviors of others.

It is not known at this time how consciousness is bound into a field, although there are speculations beyond the scope of this article. Any artifact that can behave like a conscious entity must have some physical operation equivalent to the brain's binding process. Short-term memory is also necessary to sustain the field of consciousness. A moment-to-moment field is equivalent to no consciousness. Memory can hold both noticed and unnoticed parts of the field. We have seen that we cannot have an awareness of an observation until it is remembered. We could have no knowledge of the witness without memory.

Even if we should find the operations that generate the qualitative content of consciousness, the outer, or objective, view of those operations would look quite different. Consider a camera and its shutter action. The shutter action can be photographed in all its stages by another camera, but if the camera photographs its own shutter action by means of a mirror, that action will appear as a blur. Observing the neural action that supports the experience of blueness is not the same as observing blueness. It may not be possible to explain the final nature of conscious experience. We do not expect to explain the final nature of matter and energy. We finally come to the mystery of existence itself.

If we should succeed in constructing an artifact that does have consciousness, we would be faced by some extremely difficult moral problems. Our own system of morals would be meaningless if people had no consciousness. Furthermore, we might find it quite a task to nourish a healthy, balanced psyche in an artifact. The artifact could not have an ongoing viable mentality without constant massive interaction with its external world. Experiments have shown that people's minds begin to show symptoms of extreme disorientation after only a few hours in isolation tanks. The task of creating more than a rudimentary consciousness in an artifact seems very daunting indeed when we consider all the skill, wisdom, and sacrifice necessary to produce a viable psyche in a human creature.

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