Only rules dictate results, come what may. When a contrary result has been reached, the rule has been abandoned or changed. Principles do not work that way; they incline a decision one way, though not conclusively, and they survive intact when they do not prevail.*

On the principles view a judge must first weight all principles and then add them up to decide the case. All the principles "hang together" as Dworkin says. The judge may work with some clear rules but this is rare. The hard part is matching fuzzy facts to all "relevant" principles. You contest a verbal contract with your boss or car dealer or landlord. The case comes to court. The judge matches your facts to the principles of freedom of contract, full disclosure, buyer beware, seller beware, and acquiescence. You were free to large degree when you struck the deal. You were to large degree open and clear on the terms. You acted on it to some degree. The judge weights the principles and cites case precedents to back up the weights. The judge does not give the weights as numbers—at least today a judge does not—but they are a matter of degree. Some weights rank more important than others. Some judges know more law and see more connections and cite more cases than others do. The judge cites these cases to justify her ruling. She does not point out an audit trail in a rule book. She gives what looks a lot like a fuzzy weighted average.

The FAM analogy to a law judge is only an analogy. But the FAM model comes closer to how we judge things than the decision tree model comes. It gives a new way to think about how we reason. And law principles look a lot like fuzzy rules.

We now drop the analogy and turn to where we have built systems in the FAM image.

FAMS IN PRACTICE: FUZZY PRODUCTS

How does a fuzzy washing machine work? At the math level it acts as a FAM. Rules pick out patches and the patches add up to cover the system. Most new machines have a small chip or microprocessor in them. You program the chip to store the FAM rules and make decisions as fuzzy weighted averages.

*Dworkin, R. M., *Taking Rights Seriously*, Harvard University Press, Cambridge, MA, 1977.

At the user level you drop clothes in the washer and press Start. In some models once a week or so you also load the machine with detergent. The smart washer adjusts the wash cycle to the type of clothes and their dirt status. Some stains take longer to dissolve than do others. Oil stains break down slowly. Mud and dirt break down quickly. The agitator acts as a load sensor as it turns the clothes. The agitator feels the load size and guesses at the clothing type as it knocks off dirt. It sends this data to the microprocessor. As the machine continues to wash, an optical sensor pulses a light beam through the pipe of waste water. The wash murk clouds the light pulse and tells the sensor, which tells the microprocessor, the dirt level, and the detergent level. Some new machines shoot bubbles into the wash water to help break up dirt and detergent. All fuzzy washing machines help prevent cloth damage and underwashing and overwashing.

The fuzzy system sits in the microprocessor. That is where fuzzy systems sit in all smart products. The fuzzy system turns sensor data into wash commands. There are 600 or so commands it can give. Fuzzy weighted averages pick the commands. Each second or each fraction of a second the FAM system tells the agitator how to turn and whether to let in more or less water and how to change the wash or spin or rinse cycles or whether to repeat them. The engineers at Hitachi and Matsushita (Panasonic) and South Korea's Samsung drew the fuzzy-set triangles for the load size and water clarity and water flow and then related them with 30 or so rules. The load is small, medium, large, or very large. The water is very dirty, dirty, medium, clean, or very clean. Let in no water, a little, medium, or a lot of water. If the load is heavy and dirty, use a lot of water and repeat the cycles. If the load is light and clean, use a little water and do not repeat a cycle.

In the same way, a fuzzy dryer turns the flow of hot air, load size, and fabric type into drying times and drying strategies. Fuzzy microwave ovens measure temperature, humidity, infrared light patterns, and change in food shape and then map these to cooking times and patterns of hot-air blowing.

New sensors help the washing machine and help all smart machines. Critics point to the new sensors when they want to

A fuzzy vacuum sweeper only improves the taste. As always the fuzzy system sits in a small chip. Infra-red sensors detect the carpet or floor type and measure the amount of sucked dirt. The dirt and floor data fire the fuzzy rules. If the floor is shag carpet, suck hard. If the floor is tile, suck little. If the carpet is very dirty, suck very hard. Out comes a weighted fuzzy average that gives the suction motor's power in watts. The fuzzy control is elegant and saves watts but here that may not be too big a deal. It may save only a few cents per room. Fuzzy air conditioners save still more watts. Mitsubishi and Korea's Samsung report 40% to 100% energy saving with their fuzzy models.

Fuzzy car systems do more than improve the taste. The major Japanese and Korean car firms have built and patented many car systems. Nissan holds patents on fuzzy systems for antiskid brakes that pump the brakes in some optimal way and on automatic transmissions that shift gears based on road and car conditions as the best human drivers do with a stick. The firms will not reveal the exact type or number of fuzzy rules. Nissan uses a set of rules to control fuel injection in engine cylinders. Sensors measure the manifold pressure, throttle setting, water temperature, and r.p.m., and feed this data to a small onboard microprocessor. There a FAM system converts it to a fuel flow. A second FAM system combines data on r.p.m., water temperature, and oxygen concentration to time the ignition. Mitsubishi uses fuzzy systems to control suspension, air conditioning, transmission, and four-wheel drive.

Here is a 1992 list of fielded fuzzy products in Japan and South Korea:

PRODUCT	COMPANY	FUZZY LOGIC ROLE
Air Conditioner	Hitachi, Matsushita, Mitsubishi, Sharp	Prevents overshoot-undershoot temperature oscillation and consumes less on-off power
Anti-lock brakes	Nissan	Controls brakes in hazardous cases based on car speed and acceleration and on wheel speed and acceleration

PRODUCT	COMPANY	FUZZY LOGIC ROLE
Auto engine	NOK/ Nissan	Controls fuel injection and ignition based on throttle setting, oxygen content, cooling water temperature, RPM, fuel volume, crank angle, knocking, and manifold pressure
Auto transimssion	Honda, Nissan, Subaru	Selects gear ratio based on engine load, driving style, and road conditions
Chemical mixer	Fuji Electric	Mixes chemicals based on plant conditions
Copy machine	Canon	Adjusts drum voltage based on picture density, temperature, and humidity
Cruise Control	Isuzu, Nissan, Mitsubishi	Adjusts throttle setting to set speed based on car speed and acceleration
Dishwasher	Matsushita	Adjusts cleaning cycle and rinse and wash strategies based on the number of dishes and on the type and amount of food encrusted on the dishes
Dryer	Matsushita	Converts load size, fabric type, and flow of hot air to drying times and strategies
Elevator control	Fujitec, Mitsubishi Electric, Toshiba	Reduces waiting time based on passenger traffic
Factory control	Omron	Schedules tasks and assembly line strategies
Golf diagnostic system	Maruman Golf	Selects golf club based on golfer's physique and swing

Product	Company	Fuzzy Logic Role
Health management system	Omron	Over 500 fuzzy rules track and evaluate an employee's health and fitness
Humidifier	Casio	Adjusts moisture content to room conditions
Iron mill control	Nippon Steel	Mixes inputs and sets temperatures and times
Kiln control	Mitsubishi Chemical	Mixes cement
Microwave oven	Hitachi, Sanyo, Sharp, Toshiba	Sets and tunes power and cooking strategy
Palmtop computer	Sony	Recognizes handwritten Kanji characters
Plasma etching	Mitsubishi Electric	Sets etch time and stategy
Refrigerator	Sharp	Sets defrosting times and cooling times based on usage. A neural network learns the user's usage habits and tunes the fuzzy rules accordingly.
Rice cooker	Matsushita, Sanyo	Sets cooking time and method based on steam, temperature, and rice volume
Shower system	Matsushita (Panasonic)	Suppresses variations in water temperature
Still camera	Canon, Minolta	Finds subject anywhere in frame, adjusts autofocus
Stock trading	Yamaichi	Manages portfolio of Japanese stocks based on macroeconomic and microeconomic data
Television	Goldstar (Korea), Hitachi, Samsung (Korea), Sony	Adjusts screen color and texture for each frame and stabilizes volume based on viewer's room location
Translator	Epson	Recognizes, translates words in pencil-size unit
Toaster	Sony	Sets toasting time and heat strategy for each bread type
Vacuum cleaner	Hitachi, Matsushita, Toshiba	Sets motor-suction strategy based on dust quantity and floor type
Video camcorder	Canon, Sanyo	Adjusts autofocus and lighting
Video camcorder	Matsushita (Panasonic)	Cancels handheld jittering and adjusts autofocus
Washing machine	Daewoo (Korea), Goldstar (Korea), Hitachi, Matsushita, Samsung (Korea), Sanyo, Sharp	Adjusts washing strategy based on sensed dirt level, fabric type, load size, and water level. Some models use neural networks to tune rules to user's tastes.

There are many more applications. And behind them all is a legal thicket of patents.

How do you patent a fuzzy system? They all use the same FAM architecture or some small variation of it. You can't patent that because you can't patent math. I did not patent the FAT theorem and could not have if I had wanted to. Do you patent the fuzzy rules? Some firms try to do that. But most systems use the same kind of rules. Most control systems are "error nulling" systems that turn left when something turns right or that go down when something goes up. They try to reduce or

null the error or gap between where the system is and where you want it to go. That leads to similar rules and most of these rules are just a short list of software. You may be able to patent the box that houses and implements a fuzzy system. This breaks down for fuzzy chips since they use the same logic components. Then it reduces to chip design or software instructions and again these tend to be very similar. Lawyers have asked me to play expert witness in Japanese patent disputes. That honor I decline.

Japanese firms hold over a thousand fuzzy patents in Japan. As of December 1990 they also held 30 of the 38 fuzzy patents, many sweeping in scope, that the U.S. government had given out*:

JAPANESE FIRM	U.S. PATENT DESCRIPTION
1. Fuji Photo Film	Liquid and powder measuring device
2. Fuji Photo Film	Powder measuring device
3. Fuji Photo Film	Method of measuring liquid
4. Fuji Photo Film	Control method and measuring method for liquids and powders
5. Mitsubishi	Power system stabilizer
6. Mitsubishi	Auto-tuning controller
7. Hitachi	Fuel-injection controller for internal combustion engine
8. Hitachi	Device for stopping vehicle at predetermined position
9. Hitachi	Analogical inference method and apparatus control system
10. Hitachi	PID controller
11. Omron Electronics	Fuzzy data communications system
12. Omron Electronics	Fuzzy semifinished integrated circuit
13. Omron Electronics	Fuzzy function circuit
14. Omron Electronics	Fuzzy logic computers and circuits

*Source: U.S. Patent and Trademark Office, U.S. Department of Commerce.

JAPANESE FIRM	U.S. PATENT DESCRIPTION
15. Omron Electronics	Fuzzy logic basic circuit and integrated circuit operable in current mode
16. Omron Electronics	Fuzzy membership function circuit
17. Honda	Vehicle control system A
18. Honda	Vehicle control system B
19. Japan Electronic Control Systems	Electric air-fuel ratio controller
20. Japan Electronic Control Systems	Air-fuel mixture ratio controller for internal-combustion engine
21. Japan Electronic Control Systems	Electronic learning control apparatus for internal-combustion engine
22. Toshiba	Adaptive process controller
23. Toshiba	Apparatus for performing group control on elevators
24. Toshiba	Automatic trouble analyzer
25. Matsushita Electric	Temperature-adjustable water-supply system
26. Mazda	Control system for vehicle engines
27. Nissan	Fuzzy control system for automatic transmission
28. Nissan	Vehicle air-conditioning system based on fuzzy inference
29. Nissan	Antiskid braking control system based on fuzzy inference
30. Agency of Industrial Science and Technology	Method and apparatus for recognizing colored patterns