# FUZZY SETS

*Everything is vague to a degree you do not realize till you have tried to make it precise.*

BERTRAND RUSSELL
THE PHILOSOPHY OF LOGICAL ATOMISM

*Think of arm chairs and reading chairs and dining-room chairs, and kitchen chairs, chairs that pass into benches, chairs that cross the boundary and become settees, dentist's chairs, thrones, opera stalls, seats of all sorts, those miraculous fungoid growths that cumber the floor of the arts and crafts exhibitions, and you will see what a lax bundle in fact is this simple straightforward term. I would undertake to defeat any definition of chair or chairishness that you gave me.*

CHARLES PIERCE
DICTIONARY OF PHILOSOPHY AND PSYCHOLOGY,
VOLUME 2, 1902

*The vagueness of the world chair is typical of all terms whose application involves the use of the senses. In all such cases "borderline cases" or "doubtful objects" are easily found to which we are unable to say either that the class name does or does not apply.*

MAX BLACK
"VAGUENESS: AN EXERCISE IN LOGICAL ANALYSIS,"
PHILOSOPHY OF SCIENCE, VOLUME 4, 1937

# THE FUZZY PRINCIPLE

*Shuzan (926-992 A.D.) once held up his bamboo stick to an assembly of his disciples and declared:"Call this a stick and you assert. Call it not a stick and you negate. Now, do not assert or negate, and what would you call it? Speak! Speak!" One of the disciples came out of the ranks, took the stick away from the master, and breaking it in two, exclaimed, "What is this?"*

DAISETZ TEITARO SUZUKI
AN INTRODUCTION TO ZEN BUDDHISM

*Everything is a matter of degree.*
ANONYMOUS

# ARISTOTLE VS. THE BUDDHA

*Everything must either be or not be, whether in the present or in the future.*

ARISTOTLE
DE INTERPRETATIONE

*I have not explained that the world is eternal or not eternal. I have not explained that the world is finite or infinite.*

THE BUDDHA
MAJJHIMA-NIKAYA

*The fundamental idea of Buddhism is to pass beyond the world of opposites, a world built up by intellectual distinctions and emotional defilements.*

D.T. SUZUKI
THE ESSENCE OF BUDDHISM

| BIVALENCE | MULTIVALENCE |
|---|---|
| Aristotle | Buddha |
| A OR not-A | A AND not-A |
| exact | partial |
| all or none | some degree |
| 0 or 1 | continuum between 0 and 1 |
| digital computer | neural network (brain) |
| Fortran | English (natural language) |
| bits | fits |

# I. Introduction

History of Development

- 1962, Lotfi A. Zadeh

"From circuit theory to system theory", IRE Proc. 50, pp. 856-865.

- 1965, L.A. Zadeh

"Fuzzy Sets", Information and Control, 8, pp.338-353. "Fuzzy Sets and Systems", in *System Theory* (ed. J. Fox), Polytechnic Press, pp. 29-37.

- 1937, Max Black

"Vagueness : an exercise in logical analysis", Philosophy and Science, 4, 427-455.

- Papers on Fuzzy Sets

1965-2
1966-4
1967-12
1968-22
1970-25
:
1975-227
:
1979-over 1500

- First Conference-

International Automatic Control Conference -1973 Parameter Control and Pattern Recognition, Delft, Netherland.

- First Journal-

Fuzzy Sets and Systems -1978 North Holland

# List of Journals

1. Automata
2. Colloquia Mathematica Societatis Janos Bolyai
3. Computers and Mathematics with Applications
4. Computers and Operations Research
5. *Control and Cybernetics
6. Decision Sciences
7. Decision Support Systems
8. Economic Computer and Economic Cybernetic Studies and Researches
9. Environment and Planning A
10. *European Journal of Operational Research
11. *Fuzzy Sets and Systems
12. *IEEE Transactions on Fuzzy Systems
13. Human Systems Management
14. *IEEE Transactions on Systems, Man, and Cybernetics
15. Information and Control
16. Information Science
17. International Journal of General System
18. International Journal of Intelligent System
19. International Journal of Man-Machine Studies
20. International Journal of Production Research
21. *International Journal of System Science
22. Journal of Cybernetics
23. Journal of Experimental Psychology: General
24. Journal of Experimental Psychology: Human Perception and performance
25. Journal of Mathematical Analysis and Its Applications
26. Journal of Operational Research Society
27. Kybernetika
28. Kybernetes
29. Large Scale System
30. Literary and Linguistic Computing
31. Machine Intelligence
32. Management Sciences
33. Mathematical Analysis and Applications
34. Mathematical Modelling
35. Naval Research Logistics
36. ORSA Journal on Computing
37. Tekhnicheskaya Kibernetika

*indicates that articles of fuzzy mathematical programming and fuzzy multiple objective decision-making appear frequently in this journal.

# Why Study Fuzzy Sets

- Fuzzy logic is going to make the future perfectly clear.

- The theory of fuzzy sets enables us to structure and describe activities and observations which differ from each other only vaguely, to formulate them in models and to use these models for various purposes - such as problem-solving and decision-making. This is an ability we already have as human beings, but which is not present in classical mathematics and not -as a consequence- in any science-oriented methodology.

- The human brain is said to think and reason in imprecise, non-quantitative, vague terms, and it is said that this gives us (1) the ability to decipher sloppy handwriting and understand distorted speech; but it also gives us (2) the ability to summarize information, (3) to focus on relevant information and (4) to concentrate upon essential aspects when making decisions under uncertainty. The last-mentioned three abilities are often cited as "essential" for managers-to-be.

## DOUBTS

*So far as the lows of mathematics refer to reality, they are not certain. And so far as they are certain, they do not refer to reality.*

ALBERT EINSTEIN
GEOMETRY AND EXPERIENCE

*Fuzzy theory is wrong, wrong, and pernicious. What we need is more logical thinking, not less. The danger of fuzzy logic is that it will encourage the sort of imprecise thinking that has brought us so much trouble. Fuzzy logic is the cocaine of science.*

PROFESSOR WILLIAM KAHAN
UNIVERSITY OF CALIFORNIA AT BERKELEY

*"Fuzzification" is a kind of scientific permissiveness. It tends to result in socially appealing slogans unaccompanied by the discipline of hard scientific work and patient observation.*

PROFESSOR RUDOLF KALMAN
UNIVERSITY OF FLORIDA AT GAINESVILLE

*Fuzziness is probability in disguise. I can design a controller with probability that could do the same thing that you could do with fuzzy logic.*

PROFESSOR MYRON TRIBUS, ON HEARING OF THE
FUZZY-LOGIC CONTROL OF THE
SENDAI SUBWAY SYSTEM
IEEE INSTITUTE, MAY 1988

## DOUBTS (continued)

The November 1991 *Fuzzy logic* report of the U.S. Commerce Department calls out this new blend of Zen and money:

> From a philosophical viewpoint, the fuzzy logic concept is attuned to the fundamental teachings of Zen Buddhism, which perhaps contributed to the Japanese acceptance of this concept. There are others who believe that the fuzzy logic success in Japan is a result of that country's perceived need to become competitive in advanced technologies such as artificial intelligence, biotechnology, and optical computing.

## FACTS

• In most cases Japanese, Korean, and Taiwanese firms have tried many types of control systems tuned in many ways. They have compared each system with the others. And each system uses all the data the new sensors give it. In most machines that use fuzzy logic the fuzzy system has beaten its nonfuzzy competitors. That's why it's there–performance.

• By the time we fuzzy theorists threw the first U.S. fuzzy conference in Austin, Texas, in June 1991 (at MCC or the Microelectronics and Computer Technology Corporation), the Japanese had already passed the $1 billion mark in annual sales of fuzzy products and taken another leap forward in their world leadership of consumer electronics and high-tech engineering and manufacturing. Cultural preferences come with costs.

• Fuzzy cameras and camcorders are a case in point. The Canon hand-held H800 cameras use only 13 rules to tune the autofocus on the lens. The fuzzy system takes up a tiny bit of memory, only 1.1 kilobytes, a small part of even an old big floppy disk. Small electrical sensors measure the image clarity and the change in image clarity in six parts of the image. That gives 12 types of sensor data. The 13 rules turn these 12 data into new lens settings. Canon tests its cameras on a large set of images. Canon claims the fuzzy system focuses twice as well as did the other controllers they tested and used to use.

*Japanese government, industrial, commercial, and academic institutions are busily studying fuzzy-logic theory and using fuzzy logic in a variety of applications. The government research project is led by the Science and Technology Agency's five-year research project consisting of nineteen separate programs (e.g., simulating global air pollution, predicting earthquakes, modeling plant growth). The Japanese industrial effort is showcased by the MITI-authorized Laboratory for International Fuzzy Engineering (LIFE), established by 48 Japanese companies to strengthen academic-industrial ties. Some of the applications which LIFE is working toward are a nuclear-power-plant control system and a prototype fuzzy computer....Japanese fuzzy-system researchers expect that fuzzy logic will enable the development of computer systems which adjust to people, rather than the reverse.*

MEMORANDUM R-I20608Z
MARCH 1990

If our reasoning has logic, it's fuzzy at best. We have only one decision rule: *I'll do it if it feels right*. The formal logic we first learn in tenth-grade geometry class has little to do with it. That's why we made it to tenth grade.

# Fuzzy Patents

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 |
| 15. Omron Electronics | Fuzzy logic basic circuit and integrated circuit operable in current mode |

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

| JAPANESE FIRM | U.S. PATENT DESCRIPTION |
|---|---|
| 16. Omron Electronics | Fuzzy membership function circuit |
| 17. Honda | Vehicle control system A |
| 18. Honda | Vehicle control systemB |
| 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 |

# Fuzzy Products

| 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 |
| 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 transmission | 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 |

| PRODUCT | COMPANY | FUZZY LOGIC ROLE |
|---|---|---|
| Golf diagnostic system | Maruman Golf | Selects golf club based on golfer's physique and swing |
| 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 strategy |
| 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), | Adjusts screen color and texture for each frame and stabilizes |

| PRODUCT | COMPANY | FUZZY LOGIC ROLE |
|---|---|---|
| | Hitachi, Samsung (Korea), Sony | 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. |

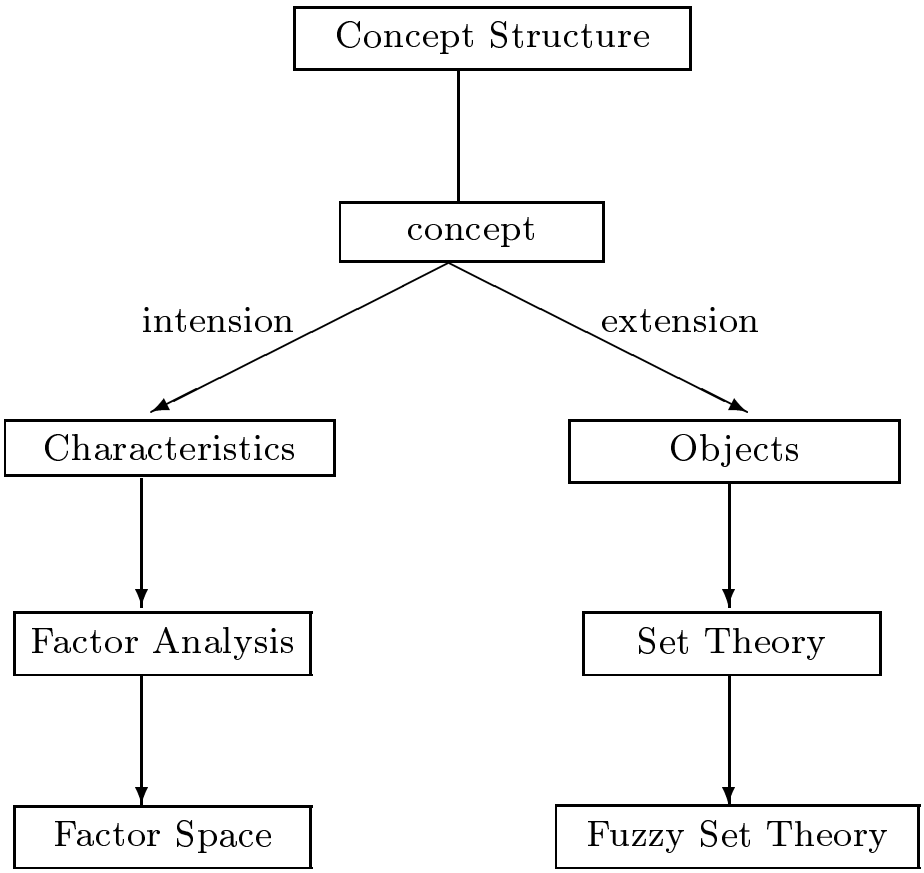
# FUZZY SYSTEMS

*Classical logic is like a person who comes to a party dressed in a black suit, a white, starched shirt, a black tie, shiny shoes, and so forth. And fuzzy logic is a little bit like a person dressed informally, in jeans, tee shirt, and sneakers. In the past, this informal dress wouldn't have been acceptable. Today, it's the other way around.*

LOTFI A. ZADEH
COMMUNICATIONS OF THE ASSOCIATION FOR COMPUTING MACHINERY, VOLUME 27, 1984

*Fuzzy logic is a concept derived from the branch of mathematical theory of fuzzy sets. Unlike the basic Aristotelian theory that recognizes statements as only "true" or "false," or "1" or "0" as represented in digital computers, fuzzy logic is capable of expressing linguistic terms such as "maybe false" or "sort of true." In general, fuzzy logic, when applied to computers, allows them to emulate the human reasoning process, quantify imprecise information, make decisions based on vague and incomplete data, yet by applying a "defuzzification" process, arrive at definite conclusions.*

FUZZY LOGIC: A KEY TECHNOLOGY FOR FUTURE COMPETITIVENESS
U.S. DEPARTMENT OF COMMERCE, NOVEMBER 1991


Concept Structure
concept
intension
extension
Characteristics
Objects
Factor Analysis
Set Theory
Factor Space
Fuzzy Set Theory