



Introduction to Fuzzy Logic and How It Is Used to Solve Engineering Problems

An Online Continuing Education Course for Engineers

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Fuzzy Logic:

An Introduction to Fuzziness in Controllers and Decision Making for Engineers.

INTRODUCTION

Human beings have the ability to take in and evaluate all sorts of information from the physical world and mentally analyze, average and summarize all this input data into an optimum course of action. All living things do this, but humans do it more and do it better and have become the dominant species of the planet.

Computers, on the other hand, operate on a binary true or false basis. Unfortunately our world is not binary. The world we live in is full of ambiguities. The way a computer operates and how our world functions appear to be odds if we try to have computers mimic worldly events. "The temperature is pretty warm" cannot be evaluated as strictly true or false. We accept that this statement has certain ambiguities. As the complexity of a system increases, it becomes more difficult and eventually impossible to make a precise statement about its behavior, eventually arriving at a point of complexity where the fuzzy logic method born in humans is the only way to get at the problem.

Thus, the mathematical theory of fuzzy logic was developed. The theory of fuzzy logic states that rather than a statement being true or false, each statement has a certain confidence level. For example let us say a confidence value of 0.000 meant false and a confidence value 1.000 meant true, then the statement "this room is warm" might have a confidence value of .700 at 80 degrees. The idea of fuzzy logic has had a profound impact in many areas including decision making software in the control arena. Specifically, there are applications where "fuzziness" is utilized when human lives are at stake.

If you think about it, much of the information you take in is not very precisely defined, such as evaluation of the behavior of a vehicle entering from a side street and the likelihood of the vehicle pulling in front of you. This is called fuzzy input. However, some of your "input" is reasonably precise and non-fuzzy such as your speedometer reading. A human processing of all this information is not very precisely definable.

This is called fuzzy processing. Fuzzy logic theorists would call it using fuzzy algorithms (algorithm is another word for procedure or program, as in a computer program).

Fuzzy logic is the way the human brain works, and we can mimic this in machines so they will perform somewhat like humans, not to be confused with Artificial Intelligence, where the so far unattainable goal is for machines to perform EXACTLY like humans.

BASIC DEFINITIONS

Some preliminary definitions are provided here and utilized throughout this presentation. You will see that data may not be changed or altered but the processing of such data might be. Additionally, data is given the opportunity to participate in multiple “groupings” or “categories” or “sets”. It is this multiple sets which gives fuzzy processing its flexibility.

Define CRISP DATA as precisely defined input. Examples might be: 5.2 inches, 8 ft. in length, 45 m.p.h., 15 / 8 (Cartesian coordinates on an X-Y axis) . Each of these examples are defined as single data points.....so 5.2 inches is not the same as 5.25 inches or “>” (greater than) 5 inches or less than 6 inches.

Use the following crisp data for the following examples;

Sally (female)

Age: 14 (today is Sally’s birthday)

Height: 4’ 5”

Weight: 100 pounds

Hair color: Dark Blonde

Eye Color: Blue eyes

Fuzzy logic could tell that Sally is “not tall” compared to the entire population on earth or extremely tall compared to all members of her class in her current grade school. By defining set membership groups, we can categorize Sally as being part of every group

with some portion of participation. That is, Sally can be described as a member of the group called “female giants” but the confidence level applied is extremely low (say 0.015). These confidence levels are based on the ‘degree of truth’.

- Crisp Facts – distinct boundaries
- Fuzzy Facts – imprecise boundaries
- Probability - incomplete facts
- Example – Scout reporting an enemy
 - “Two to three tanks at grid NV 123456“ (Crisp)
 - “A few tanks at grid NV 123456” (Fuzzy)
 - “There might be 2 tanks at grid NV 54 (Probabilistic)

One further note, fuzzy analysis is not to be confused with reasoning or decision making under uncertainty. Crisp data, which can take on many forms, is required as for the fuzzy processing to be applied. Uncertainty generally refers to a probability of realizing some future data which may be drawn from a known or unknown probability distribution. The probability of a “noon rain shower tomorrow providing 1 inch of rain” might be drawn from a Gaussian, Normal or other distribution defining this event of uncertainty. On another hand, given a range of crisp data about a potential rain tomorrow, fuzzy logic can be applied to decisions surrounding the crisp data event (i.e., after the fact).

Background and some History

The concept of Fuzzy Logic (FL) was conceived by Lotfi Zadeh, a professor at the University of California at Berkley. Fuzzy logic was developed in the 1960's in order to provide mathematical rules and functions which permitted natural language queries. Fuzzy logic provides a means of calculating intermediate values between absolute true and absolute false with resulting values ranging between 0.0 and 1.0. With fuzzy logic, it is possible to calculate the degree to which an item is a member. For example, if a person is .83 of tallness, they are "rather tall." Fuzzy logic calculates the shades of gray between black/white and true/false.

In 1965 Dr. Zadeh published a paper "Fuzzy Sets" that formally developed multi-valued set theory and introduced the term fuzzy into technical literature.

E.H. Mamdani is credited with building the world's first fuzzy logic controller, after reading Dr. Zadeh's paper on the subject. Dr. Mamdani, London University, U.K., stated firmly and unequivocally that utilizing a fuzzy logic controller for speed control of a steam engine was much superior to controlling the engine by conventional mathematically based control systems and logic control hardware. Dr. Mamdani found that, using the conventional approach, extensive trial and error work was necessary to arrive at successful control for a specific speed set-point. Further, due to the non-linearity of the steam engine operating characteristics, as soon as the speed set-point was changed, the trial and error effort had to be done all over again to arrive at effective control. This did not occur with the fuzzy logic controller, which adapted much better to changes, variations and non-linearity in the system.

Dr. Zadeh, as the principal founder of the fuzzy logic theory has earned numerous Awards, Fellowships and Honors and has contributed a large amount of research and publications to the field of knowledge representation. A brief summary of historical steps follows:

- 1965 Seminal Paper “Fuzzy Logic” by Prof. Lotfi Zadeh, Faculty in Electrical Engineering, U.C. Berkeley, Sets the Foundation of the “Fuzzy Set Theory”
- 1970 First Application of Fuzzy Logic in Control Engineering (Europe)
- 1975 Introduction of Fuzzy Logic in Japan
- 1980 Empirical Verification of Fuzzy Logic in Europe
- 1985 Broad Application of Fuzzy Logic in Japan
- 1990 Broad Application of Fuzzy Logic in Europe
- 1995 Broad Application of Fuzzy Logic in the U.S.
- 2000 Fuzzy Logic Becomes a Standard Technology and Is Also Applied in Data and Sensor Signal Analysis. Application of Fuzzy Logic in Business and **Finance**.

Interesting “historical” side notes:

Before getting to the heart of fuzzy logic applied to basic control applications, it may be very informative to the reader to explain some of the nuances of “fuzz” and why many scientists and developers in OTHER countries embraced this faster than those based in the United States.

- The word “fuzzy” has an negative connotation in the US
 - Fuzzy thinking, fuzzballs, fuzzy haircuts, uphill battle with first impression
- “Fuzzy” phonetically translates to “smart” in Japanese

Not that the above ideas are the absolute reasons, but this has helped to contribute to the fact that Japan & Asian & Pacific Rim countries have 80% of the patents of Fuzzy related inventions

What is Fuzzy anything and Why do we care?

Artificial Intelligence

Artificial Intelligence (AI) is a form of computer reasoning designed to mimic that of the human reasoning process. Artificial intelligence may be thought of as the umbrella term for many forms of evolving technology (expert systems, neural networks) that in some manner attempt to emulate human capabilities be they thinking, seeing, or hearing. Traditional (Boolean) logic that has been extensively used in computers has values between "completely true" and "completely false".

Fuzzy logic is the characteristic of the approximation. Fuzzy logic has been used in applications such as sales forecasting, control systems, pricing models, and image processing.

Fuzzy logic is used in engineering development. It shortens the time for complex systems, is the only way to solve the problem.

Fuzziness describes an event occurs, not whether it occurs. It allows for partial membership requirements that allow for partial membership. The membership degree which an object is a member of a fuzzy set can be any value from 0 to 1, rather than strictly 0 or 1 as in a traditional set. Structured properly, a fuzzy set allows a gradual transition from membership to non-membership.

For example, a man 6 feet tall may be a member of the fuzzy set TALL to degree 0.5. A man 5 feet 6 inches tall is TALL to degree 0.25, and a man 6 feet 6 inches tall is TALL to degree 0.75. In this example, the membership degree (0.25, 0.50, and 0.75) are assigned by the developer; therefore, there is great flexibility in setting up the fuzzy logic system.

Fuzzy sets, which allow partial membership, provide a way for a computer to deal with this ambiguity by classifying the man as partially SHORT and partially TALL at the same time.

