e-PGPathshala
Subject : Computer Science
Paper: Data Analytics
Module No 16: CS/DA/16 - Data Analysis Foundations – Fuzzy Logic
Quadrant 1 – e-text

1.1 Introduction

Fuzzy logic provides a simple way to arrive at a definite conclusion based upon vague, ambiguous, imprecise, noisy, or missing input information. Fuzzy logic is an extension of Boolean logic by Lotfi Zadeh in 1965 based on the mathematical theory of fuzzy sets, which is a generalization of the classical set theory. By introducing the notion of degree in the verification of a condition, thus enabling a condition to be in a state other than true or false, fuzzy logic provides a very valuable flexibility for reasoning, which makes it possible to take into account inaccuracies and uncertainties. One advantage of fuzzy logic in order to formalize human reasoning is that the rules are set in natural languageThis chapter gives an overview on fuzzy logic (FL), FL elements, FL representations, FL classification, fuzzy sets, and applications of FL in other fields etc.

1.2 Learning Outcomes

- **Learn the basics of Fuzzy logic**
- **Know applications of Fuzzy Logic**

1.3 What is fuzzy logic

Fuzzy logic(FL) is defined as a form of knowledge representation suitable for notions that cannot be defined precisely, but which depend upon their contexts. Fuzzy means "not clear, distinct, or precise; blurred".

Fuzzy Logic is a problem-solving control system methodology that lends itself to implementation in systems ranging from simple, small, embedded micro-controllers to large, networked, multi-channel PC or workstation-based data acquisition and control systems. It can be implemented in hardware, software, or a combination of both. FL provides a simple way to arrive at a definite conclusion based upon vague, ambiguous, imprecise, noisy, or missing input information. FL's approach to control problems mimics how a person would make decisions, only much faster.

FL requires some numerical parameters in order to operate such as what is considered significant error and significant rate-of-change-of-error, but exact values of these numbers are usually not critical unless very responsive performance is required in which case empirical tuning would determine them. For example, a simple temperature control system could use a single temperature feedback sensor whose data is subtracted from the command signal to compute "error" and then time-differentiated to yield the error slope or rate-of-change-of-error, hereafter called "error-dot". Error might have units of degs F and a small error considered to be 2F while a large error is 5F. The "error-dot" might then have units of degs/min with a small error-dot being 5F/min and a large one being 15F/min. These values don't have to be symmetrical and can be "tweaked" once the system is operating in order to optimize performance. Generally, FL is so forgiving that the system will probably work the first time without any tweaking.

1.4 Traditional representations of fuzzy logic

It is noted that one of the basic aims of fuzzy logic is to provide a computational framework for knowledge representation and inference in an environment of uncertainty and imprecision. In such environments, fuzzy logic is effective when the solutions need not be precise and/or it is acceptable for a conclusion to have a dispositional rather than categorical validity.

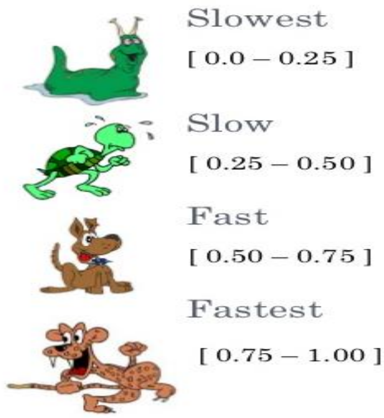
In fuzzy logic, unlike standard conditional logic, the truth of any statement is a matter of degree. For example, for the rule if (weather is cold) then (heat is on), both variables, cold and on, map to ranges of values. Fuzzy inference systems rely on membership functions to explain to the computer how to calculate the correct value between 0 and 1. The degree to which any fuzzy statement is true is denoted by a value between 0 and 1.

Consider a scenario where you want to indicate speed of an animal. We may start with two values: fast and slow indicated using values 1 and 0 respectively, which may be logically represented using the following pseudo code:

```
bool speed;
get the speed
if ( speed == 0) {
        //  speed is slow
}
else {
        //  speed is fast
}
```

But in fuzzy logic, the variable speed can be mapped to a set of or range of values like: slowest, slow, fast and fastest mapped to [0 – 0.25], [0.25 – 0.50], [0.5 – 0.75] and [0.75 – 1] respectively as represented using pseudo code:

```
float speed;
get the speed
if ((speed >= 0.0)&&(speed < 0.25)) {
        //  speed is slowest
}
else  if  ((speed  >=  0.25)&&(speed  <  0.5))
{
        //  speed is slow
}
else if ((speed >= 0.5)&&(speed < 0.75))
{
        //  speed is fast
}
else // speed >= 0.75 && speed < 1.0
{
        //  speed is fastest
}
```



1.5 Fuzzy sets

Fuzzy Set Theory was formalised by Professor Lofti Zadeh at the University of California in 1965. What Zadeh proposed is very much a paradigm shift that first gained acceptance in the Far East and its successful application has ensured its adoption around the world.

A paradigm is a set of rules and regulations which defines boundaries and tells us what to do to be successful in solving problems within these boundaries. For example the use of transistors instead of vacuum tubes is a paradigm shift - likewise the development of Fuzzy Set Theory from conventional bivalent set theory is a paradigm shift.

Bivalent Set Theory can be somewhat limiting if we wish to describe a 'humanistic' problem mathematically. For example, Fig 1 below illustrates bivalent sets to characterise the temperature of a room.

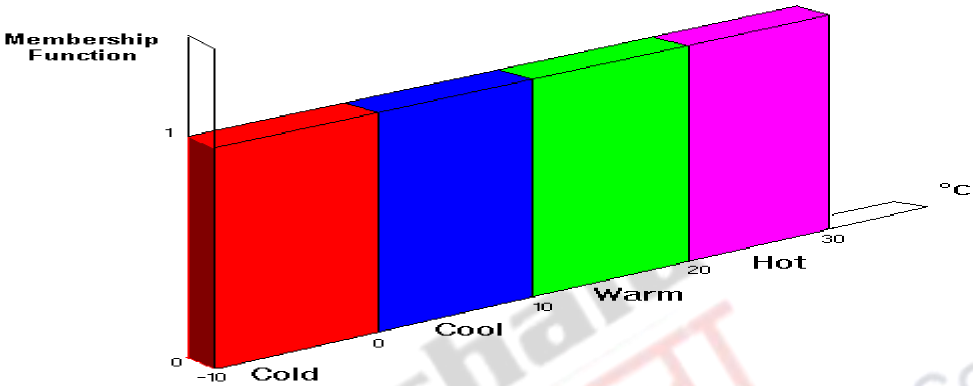


Figure 1. Bivalent sets to characterize the temperature of a room

The most obvious limiting feature of bivalent sets that can be seen clearly from the diagram is that they are mutually exclusive - it is not possible to have membership of more than one set (opinion would widely vary as to whether 50 degrees Fahrenheit is 'cold' or 'cool' hence the expert knowledge we need to define our system is mathematically at odds with the humanistic world). Clearly, it is not accurate to define a transiton from a quantity such as 'warm' to 'hot' by the application of one degree Fahrenheit of heat. In the real world a smooth (unnoticeable) drift from warm to hot would occur.

This natural phenomenon can be described more accurately by Fuzzy Set Theory. Fig.2 below shows how fuzzy sets quantifying the same information can describe this natural drift.

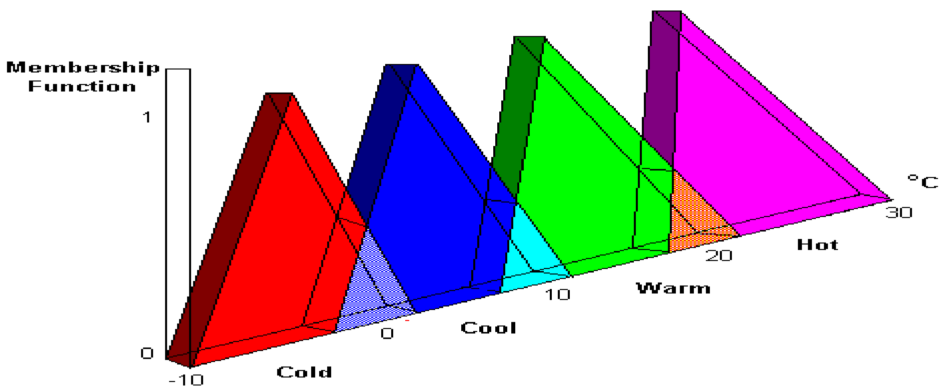


Figure 2. Fuzzy sets quantifying the temperature of the room

1.6 Origin of fussy logic

Fuzzy Logic was initiated in 1965, by Dr. Lotfi A. Zadeh, professor for computer science at the university of California in Berkley. Basically, Fuzzy Logic is a multivalued logic, that allows intermediate values to be defined between conventional evaluations like true/false, yes/no, high/low, etc. Fuzzy Logic starts with and builds on a set of user–supplied human language rules. Fuzzy Systems convert these rules to their mathematical equivalents.

The history of fuzzy logic can be brief as 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.

1.7 Basic elements of fuzzy logic system

The architecture of the fuzzy logic controller shown in figure 3 includes four components: Fuzzifier, Rule Base, Fuzzy Inference Engine, and Defuzzifier.

Fuzzifier: The fuzzifier is the input interface which maps a numeric input to a fuzzy set so that it can be matched with the premises of the fuzzy rules defined in the application-specific rule base.

Rule Base: The rule base contains a set of fuzzy if-then rules which defines the actions of the controller in terms of linguistic variables and membership functions of linguistic terms.

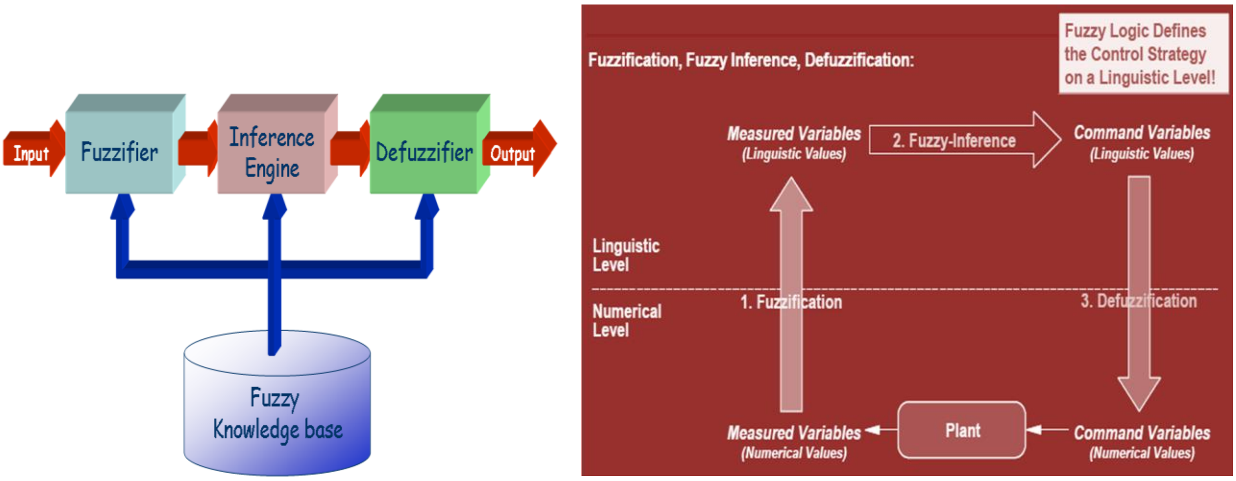


Figure 3. Basic configuration of a fuzzy logic controller

Fuzzy Inference Engine: The fuzzy inference engine applies the inference mechanism to the set of rules in the fuzzy rule base to produce a fuzzy output set. This involves matching the input fuzzy set with the premises of the rules, activation of the rules to deduce the conclusion of each rule that is fired, and combination of all activated conclusions using fuzzy set union to generate fuzzy set output.

Defuzzifier: The defuzzifier is an output mapping which converts fuzzy set output to a crisp output. Based on the crisp output, the fuzzy logic controller can drive the system under control.

The fuzzy rule base contains a set of linguistic rules. These linguistic rules are expressed using linguistic values and linguistic variables. Different linguistic values can be assigned to a linguistic variable. These linguistic values are modeled as fuzzy sets. Based on the linguistic values, their corresponding membership functions can be expressed based on application requirements. So, we can say that the job of a fuzzy logic controller is to carry out the following three steps.

1. To receive one or a large number, of measurement or other assessment of conditions existing in some system we wish to analyze or control.

2. Processing all these inputs according to human based, fuzzy "If-Then" rules, which can be expressed in plain language words.

3. Averaging and weighting the resulting outputs from all the individual rules into one single output decision or signal which decides what to do or tells a controlled system what to do. The output signal eventually arrived at is a precise appearing, defuzzified, value.

1.8 Fuzzy Logic In Control Systems

Fuzzy Logic provides a more efficient and resourceful way to solve Control Systems. Some Examples:

- Temperature Controller
- Anti – Lock Break System (ABS)

1.8.1 Temperature Controller:

- The problem - Change the speed of a heater fan, based off the room temperature and humidity as given in figure 4
- A temperature control system has four settings - Cold, Cool, Warm, and Hot
- Humidity can be defined by - Low, Medium, and High
- Using this we can define - the fuzzy set

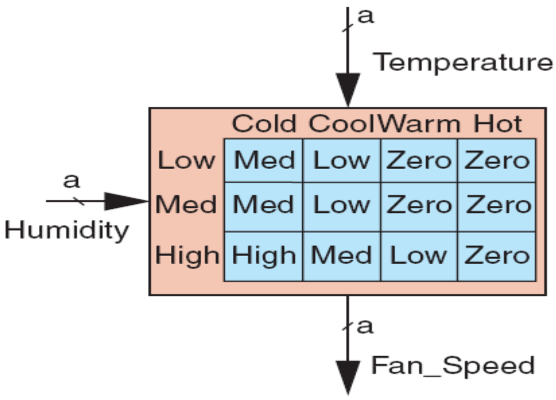


Figure 4. Temperature control system

1.8.2 Anti – Lock Break System (ABS)

ABS is nonlinear and dynamic in nature with inputs for Intel Fuzzy ABS which are derived from:

- Brake
- 4 WD
- Feedback
- Wheel speed
- Ignition

The outputs are pulsewidth and error lamp.

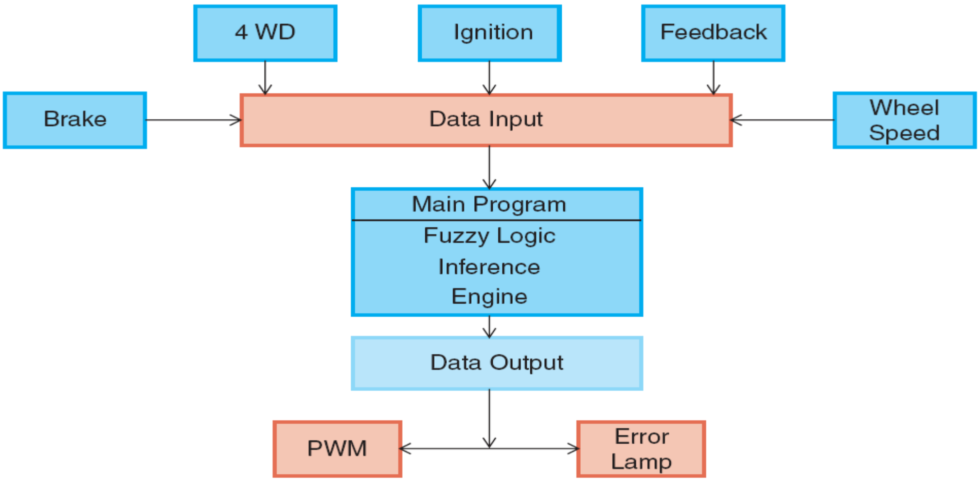


Figure 5. Anti – Lock Break System

1.9 Fuzzy classification

Fuzzy classification is the process of grouping elements into a fuzzy set whose membership function is defined by the truth value of a fuzzy propositional function. Goal of fuzzy classification is create fuzzy "category memberships" function ,to convert objectively measurable parameters to "category memberships" and which are then used for classification

- In fuzzy classification, a sample can have membership in many different classes to different degrees. Typically, the membership values are constrained so that all of the membership values for a particular sample sum to 1.
- Now the *expert knowledge* for this variable can be formulated as a rule like
- **IF** Entropy *high* **AND** α *high* **THEN** Class = class 4
- The rules can be combined in a table, called as rule base.

Entropy	α	Class
Very low	Low	Class A
Low	Medium	Class B
Medium	High	Class C
High	High	ClassD

1.10 Fuzzy logic in other fields

- **Aerospace**
  - Altitude control of spacecraft, satellite altitude control, flow and mixture regulation in aircraft deicing vehicles.
- **Automotive**
  - Trainable fuzzy systems for idle speed control, shift scheduling method for automatic transmission, intelligent highway systems, traffic control, improving efficiency of automatic transmissions
- **Business**
  - Decision-making support systems, personnel evaluation in a large company
- **Chemical Industry**
  - Control of pH, drying, chemical distillation processes, polymer extrusion production, gas cooling plant
- **Defense**
  - Underwater target recognition, automatic target recognition of thermal infrared images, naval decision support aids, control of a hypervelocity interceptor
- **Electronics**
  - Control of automatic exposure in video cameras, humidity in a clean room, air conditioning systems, washing machine timing, microwave ovens, vacuum cleaners
- **Financial**
  - Banknote transfer control, fund management, stock market predictions.
- **Industrial**
  - Cement kiln controls, heat exchanger control, activated sludge wastewater treatment process control, water purification plant control, quantitative pattern analysis for industrial quality assurance, control of constraint satisfaction problems in structural design, control of water purification plants
- **Manufacturing**
  - Optimization of cheese production.

- **Marine**
  - Autopilot for ships, optimal route selection, control of autonomous underwater vehicles, ship steering.
- **Medical**
  - Medical diagnostic support system, control of arterial pressure during anesthesia, multivariable control of anesthesia, modeling of neuropathological findings in Alzheimer's patients, radiology diagnoses, fuzzy inference diagnosis of diabetes and prostate cancer.
- **Mining and Metal Processing**
  - Sinter plant control, decision making in metal forming.
- **Robotics**
  - Fuzzy control for flexible-link manipulators, robot arm control.
- **Securities**
  - Decision systems for securities trading.
- **Signal Processing and Telecommunications**
  - Adaptive filter for nonlinear channel equalization control of broadband noise
- **Transportation**
  - Automatic underground train operation, train schedule control, railway acceleration, braking, and stopping

<table>
<tr><td></td><td>Case Studies</td></tr>
<tr><td colspan="2">A) https://www.doc.ic.ac.uk/~nd/surprise_96/journal/vol4/sbaa/report.traff.html</td></tr>
<tr><td colspan="2">Case Study: Fuzzy Traffic Light Controller

Describes the design procedures of a real life application of fuzzy logic: A Smart Traffic Light Controller. The controller is suppose to change the cycle time depending upon the densities of cars behind green and red lights and the current cycle time</td></tr>
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Summary

- Fuzzy logic provides an alternative way to represent linguistic and subjective attributes of the real world in computing.
- Can be applied to control systems and other applications in order to improve the efficiency and simplicity of the design process.