A Powerful way to analyze and control a complex system
INTRODUCTION

What is Fuzzy Logic?

Fuzzy logic is a form of multi-valued logic derived from fuzzy set theory to deal with reasoning that is approximate rather than precise. The degree of truth of a statement can range between 0 and 1 and is not constrained to the two truth-values of classic propositional logic.

From the set theory point of view, it is a superset of conventional (Boolean) logic that has been extended to handle the concept of partial truth values between "completely true" and "completely false". As its name suggests,
BACKGROUND AND EVOLUTION OF FUZZY LOGIC

In the early 1900s, Lukasiewicz came and proposed a systematic alternative to the bi-valued logic (*bivalence*) of Aristotle. Knuth, a former student of Lukasiewicz proposed a three-valued logic apparently missed by Lukasiewicz, which used an integral range \([-1, 0 +1]\) rather than \([0, 1, 2]\). Nonetheless, this alternative failed to gain acceptance.

**Lotfi A. Zadeh**, a professor of UC Berkeley in California, published his seminal work "Fuzzy Sets" which described the mathematics of fuzzy set logic. This theory proposed making the membership function (or the values False and True) operate over the range of real numbers \([0.0, 1.0]\).
How fuzzy is different from conventional control system model

FL incorporates a simple, rule-based IF X AND Y THEN Z approach to solving control problems rather than attempting to model a system mathematically. Rather than dealing with temperature control in terms such as "SP = 500°F", "T < 1000°F", or "210°C < TEMP < 220°C", terms like "IF (process is too cool) AND (process is getting colder) THEN (add heat to the process)" or "IF (process is too hot) AND (process is heating rapidly) THEN (cool the process quickly)" are used. These terms are imprecise and yet very descriptive of what must actually happen. Thus FL is capable of mimicking human behavior but at a very high rate.
Precision and Significance in the Real World

A 1500 kg mass is approaching your head at 45.3 m/s

Precision

Normal control system logic

Significance

Control system based on Fuzzy logic

LOOK OUT!!
Characteristics of FUZZY Logic

The essential characteristics of fuzzy logic as founded by Zader Lotfi are as follows.

1. In fuzzy logic, exact reasoning is viewed as a limiting case of approximate reasoning.
2. In fuzzy logic everything is a matter of degree.
3. Any logical system can be fuzzified
4. In fuzzy logic, knowledge is interpreted as a collection of elastic or, equivalently, fuzzy constraint on a collection of variables
5. Inference is viewed as a process of propagation of elastic constraints.

The third statement hence, define Boolean logic as a subset of Fuzzy logic.
Basic Parameters

Linguistic Variable:. They are objects or words, rather than numbers. The sensor input is a noun, e.g. "temperature", "displacement etc. Since error is just the difference, it can be thought of the same way (e.g. "large positive" error, "small positive" error ,"zero" error)

Fuzzy Sets - A fuzzy set is almost any condition for which we have words. Example: A woman is 6 feet, 3 inches tall. She is one of the tallest women, so her height may be rated .98

Fuzzy Algorithm - A fuzzy algorithm, then, is a procedure, usually a computer program, made up of statements relating linguistic variables and control actions.

Defuzzify – Evaluation of several sub-sets established by the designer for a fuzzy logic based control system, such as "speed too fast," "speed too slow" and "speed about right" at a specific input value (Example: 2,390 RPM) to determine a crisp output which will be the input for the system being controlled.
Designing a control system using Fuzzy Logic

The System:

We want to design a simple proportional temperature controller with an electric heating element and a variable-speed cooling fan. A positive signal output calls for 0-100 percent heat while a negative signal output calls for 0-100 percent cooling.
Specification:

"N" = "negative" error or error-dot input level
"Z" = "zero" error or error-dot input level
"P" = "positive" error or error-dot input level
"H" = "Heat" output response
"-" = "No Change" to current output
"C" = "Cool" output response

Definition:

INPUT#1: ("Error", positive (P), zero (Z), negative (N))
INPUT#2: ("Error-dot", positive (P), zero (Z), negative (N))
CONCLUSION: ("Output", Heat (H), No Change (-), Cool (C))

INPUT#1 System Status
Error = Command-Feedback
P=Too cold, Z=Just right, N=Too hot

INPUT#2 System Status
Error-dot = d(Error)/dt
P=Getting hotter Z=Not changing N=Getting colder

OUTPUT Conclusion & System Response
Output H = Call for heating - = Don't change anything C = Call for cooling
Rule Structure & Rule Matrix:

- IF Cmd-Temp=N AND d(Cmd-Temp)/dt=N THEN Output=C
- IF Cmd-Temp=Z AND d(Cmd-Temp)/dt=N THEN Output=H
- IF Cmd-Temp=P AND d(Cmd-Temp)/dt=N THEN Output=H
- IF Cmd-Temp=N AND d(Cmd-Temp)/dt=Z THEN Output=C
- IF Cmd-Temp=Z AND d(Cmd-Temp)/dt=Z THEN Output=NC
- IF Cmd-Temp=P AND d(Cmd-Temp)/dt=Z THEN Output=H
- IF Cmd-Temp=N AND d(Cmd-Temp)/dt=P THEN Output=C
- IF Cmd-Temp=Z AND d(Cmd-Temp)/dt=P THEN Output=C
- IF Cmd-Temp=P AND d(Cmd-Temp)/dt=P THEN Output=H

<table>
<thead>
<tr>
<th>RULE MATRIX</th>
<th>N</th>
<th>Z</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>C</td>
<td>H</td>
<td>H</td>
</tr>
<tr>
<td>Z</td>
<td>C</td>
<td>NC</td>
<td>H</td>
</tr>
<tr>
<td>P</td>
<td>C</td>
<td>C</td>
<td>H</td>
</tr>
</tbody>
</table>
MEMBERSHIP FUNCTION:
The membership function is a graphical representation of the magnitude of participation of each input. It associates a weighting with each of the inputs that are processed, define functional overlap between inputs, and ultimately determines an output response. The rules use the input membership values as weighting factors to determine their influence on the fuzzy output sets of the final output conclusion. Once the functions are inferred, scaled, and combined, they are defuzzified into a crisp output which drives the system.
The degree of membership for an "error" of -1.0 projects up to the middle of the overlapping part of the "negative" and "zero" function so the result is "negative" membership = 0.5 and "zero" membership = 0.5. This selects only the left and middle columns of the rule matrix.

For an "error-dot" of +2.5, a "zero" and "positive" membership of 0.5 is indicated. This selects the middle and bottom rows of the rule matrix. By overlaying the two regions of the rule matrix, it can be seen that only the rules in the 2-by-2 square in the lower left corner (rules 4,5,7,8) of the rules matrix will generate non-zero output conclusions. The others have a zero weighting due to the logical AND in the rules.
Defuzzification:

It involves following steps.

1) The Calculation of function strength—
   "negative" = (R1^2 + R4^2 + R7^2 + R8^2) (Cooling) = (0.00^2 + 0.50^2 + 0.50^2 + 0.50^2)^.5 = 0.866
   "zero" = (R5^2)^.5 = (0.50^2)^.5 (No Change) = 0.500
   "positive" = (R2^2 + R3^2 + R6^2 + R9^2) (Heating) = (0.00^2 + 0.00^2 + 0.00^2 + 0.00^2)^.5 = 0.000

2) Calculation of Output Membership function

\[
\frac{\text{neg}_\text{center} \times \text{neg}_\text{strength} + \text{zero}_\text{center} \times \text{zero}_\text{strength} + \text{pos}_\text{center} \times \text{pos}_\text{strength}}{\text{neg}_\text{strength} + \text{zero}_\text{strength}} = \text{OUTPUT}
\]

\[
\frac{(-100 \times 0.866 + 0 \times 0.500 + 100 \times 0.000)}{(0.866 + 0.500 + 0.000)}
\]
Advantages

FL offers several unique features that make it a particularly good choice for many control problems.

1) It is inherently robust since it does not require precise, noise-free inputs and can be programmed to fail safely if a feedback sensor quits or is destroyed. The output control is a smooth control function despite a wide range of input variations.

2) Since the FL controller processes user-defined rules governing the target control system, it can be modified and tweaked easily to improve or drastically alter system performance.

3) FL is not limited to a few feedback inputs and one or two control outputs, nor is it necessary to measure or compute rate-of-change parameters in order for it to be implemented. Any sensor data that provides some indication of a system's actions and reactions is sufficient.

4) FL can control nonlinear systems that would be difficult or impossible to model mathematically. This opens doors for control systems that would normally be deemed unfeasible for
1) Fuzzy Logic has huge application on Control System Design and in Automation.

2) With the help of Fuzzy Logic, we can design artificial neural network which mimics our human neural system.

3) Vast expert decision makers, theoretically able to distill the wisdom of every document ever written.

4) Computers that understand and respond to normal human language.

5) Machines that write interesting novels and screenplays in a selected style, such as Hemingway's.

6) Molecule-sized soldiers of health that will roam the blood-stream, killing cancer cells and slowing the aging process.
Thank you!