Computational Intelligence

Chapter 5
Fuzzy Logic Systems

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Chapter 5: Fuzzy Logic Systems

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Overview

- ➜ **Fuzzy Logic Systems (FLS)** are a form of knowledge representation suitable for reasoning about vague, ambiguous, or imprecise information. Unlike traditional Boolean logic, which deals with binary true/false values, fuzzy logic allows for degrees of truth, making it especially useful in systems where a binary decision would be too rigid or insufficient.
- ➜ In this lecture, we will explore the basic concepts of fuzzy logic, how fuzzy sets work, how to design a fuzzy inference system, and various applications where fuzzy logic can be particularly effective.

1. Introduction to Fuzzy Logic

➜ **Fuzzy logic** was introduced by Lotfi Zadeh in 1965 as a mathematical way of representing uncertainty and reasoning with vague concepts. It is particularly useful when dealing with systems that require human-like reasoning or decision-making processes.

➜ **1.1. What is Fuzzy Logic?**

- Fuzzy logic deals with reasoning that is approximate rather than fixed and exact.
- Unlike classical logic where variables are either true (1) or false (0), fuzzy logic variables can take on a range of values between 0 and 1, representing degrees of truth.

1. Introduction to Fuzzy Logic

➜ 1.2. Fuzzy Set Theory

- **Fuzzy sets** generalize classical sets. In a classical set, an element either belongs to the set or does not. In a fuzzy set, each element has a degree of membership ranging from 0 to 1.

➜ Example:

- Consider the set of **"tall people"**. In classical logic, you might define a tall person as someone taller than 6 feet. In fuzzy logic, however, you would assign a degree of "tallness" to people based on their height. A person who is 5'11" might be 0.8 tall, while someone 6'2" might be 0.95 tall.

2. Fuzzy Sets and Membership Functions

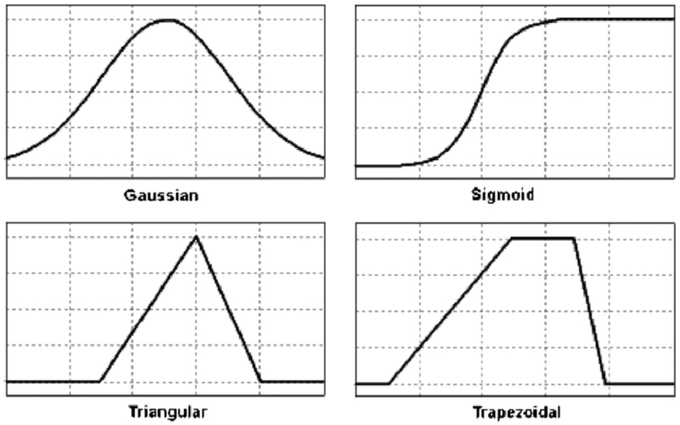
➜ 2.1. Fuzzy Sets

- A **fuzzy set** is a set where each element has a degree of membership. The membership function (MF) assigns a value between 0 and 1 to represent the degree of membership.

➜ 2.2. Membership Functions

- A **membership function** defines how each point in the input space is mapped to a membership value (or degree of truth). Common types of membership functions include:

  - **Triangular Membership Function**
  - **Trapezoidal Membership Function**
  - **Gaussian Membership Function**
  - **Sigmoid Membership Function**



3. Fuzzy Logic Operators

Fuzzy logic uses modified versions of classical logic operators such as AND, OR, and NOT. These operators work on degrees of truth, rather than binary values.

➜ **3.1. Fuzzy AND (Minimum Operator)**

$$A \text{ AND } B = \min(\mu_A(x), \mu_B(x))$$

Where $\mu_A(x)$ and $\mu_B(x)$ are the membership values of fuzzy sets A and B, respectively.

➜ **3.2. Fuzzy OR (Maximum Operator)**

$$A \text{ OR } B = \max(\mu_A(x), \mu_B(x))$$

➜ **3.3. Fuzzy NOT (Complement)**

$$\text{NOT } A = 1 - \mu_A(x)$$

➜ **Example:**

For a fuzzy set of temperatures, "hot" might have a membership value of 0.7 at 75°F, and "cold" might have a membership of 0.3 at the same temperature. Using fuzzy AND:

- Hot AND Cold=min(0.7,0.3)=0.3

4. Fuzzy Inference System (FIS)

➜ A **Fuzzy Inference System (FIS)** is the process of formulating the mapping from a given input to an output using fuzzy logic. It involves several steps:

➜ **4.1. Components of a Fuzzy Inference System**

- **Fuzzification**: Converting crisp inputs (real-world values) into fuzzy values using membership functions.
- **Inference Engine**: Applying fuzzy logic rules to the fuzzified inputs to generate fuzzy outputs.
- **Rule Base**: A collection of if-then rules that define how to make decisions based on fuzzy inputs.
- **Defuzzification**: Converting the fuzzy output back into a crisp value.

➜ **4.2. Example of Fuzzy Rules**

Consider a fuzzy system designed to control the temperature of an air conditioner:

- **If temperature is hot, then fan speed is high.**
- **If temperature is warm, then fan speed is medium.**
- **If temperature is cold, then fan speed is low.**

5. Types of Fuzzy Inference Systems

There are two common types of fuzzy inference systems:

➜ **5.1. Mamdani Fuzzy Model**

- Developed by Ebrahim Mamdani in 1975.
- Uses fuzzy sets for both the input and the output variables.
- Relies on max-min composition for inference.
- **Defuzzification**: Typically performed using the centroid method.

➜ **5.2. Sugeno Fuzzy Model**

- Developed by Takagi, Sugeno, and Kang.
- Uses fuzzy sets for the input variables, but the output is a crisp function of the input variables (e.g., linear or constant functions).
- Often used in control systems because it is computationally efficient.

6. Defuzzification Methods

Once a fuzzy output is generated, the process of **defuzzification** converts this fuzzy output back into a single crisp value that can be used in the real world. There are several methods for defuzzification:

➜ 6.1. Centroid Method

- The most common method of defuzzification.

- Finds the center of gravity of the area under the membership function curve.

$$y = \frac{\int_{\text{all } x} \mu(x) \cdot x \, dx}{\int_{\text{all } x} \mu(x) \, dx}$$

➜ 6.2. Maximum Membership Principle

- Chooses the output value that corresponds to the highest degree of membership.

➜ 6.3. Weighted Average Method

- Assigns weights to different membership values and computes the weighted average to produce a crisp output.

7. Applications of Fuzzy Logic Systems

➜ Fuzzy logic has been applied across various domains where precise models are difficult to develop due to uncertainty, vagueness, or human reasoning:

➜ **7.1. Control Systems**

- **Washing machines**: Fuzzy logic is used to adjust the washing cycle based on load size, dirtiness, and fabric type.
- **Cameras**: Focus and exposure control in automatic cameras are often managed by fuzzy logic.
- **Air conditioning**: Fuzzy logic systems regulate temperature based on fuzzy inputs like outside temperature and humidity.

7. Applications of Fuzzy Logic Systems

➜ **7.2. Decision-Making Systems**

- **Medical diagnosis**: Fuzzy systems help in diagnosing diseases by reasoning with uncertain or imprecise symptoms.
- **Expert systems**: In situations where human expertise is required but formal mathematical models are unavailable.

➜ **7.3. Image Processing**

- **Edge detection**: Fuzzy logic can detect edges in images where traditional methods may fail due to noise or low contrast.

8. Advantages and Limitations of Fuzzy Logic Systems

➜ **Advantages:**

- **Handling of Uncertainty**: Fuzzy logic excels in scenarios where data is imprecise or uncertain.
- **Simplicity**: It is relatively easy to implement and understand, especially in systems that mimic human decision-making.
- **Flexibility**: Fuzzy systems can be adapted or tuned by adjusting membership functions or rules.

➜ **Limitations:**

- **Not Universally Applicable**: Fuzzy logic may not perform well in situations where precise or crisp boundaries are needed.
- **Design Complexity**: Developing an effective fuzzy rule base and membership functions can be challenging and subjective.
- **Defuzzification**: Choosing the correct defuzzification method can significantly impact system performance.

Thanks!

Any questions?