Assignment

Designing and Tuning a Fuzzy Inference System

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INTRODUCTION

This report focuses on applying fuzzy logic to healthcare, by implementing a system that predicts medical urgency of patients based on temperature, age and headache. The system is designed to handle two different kinds of inputs i.e., crisp inputs and interval-based inputs. This allows handling of uncertainty in case the exact input values are not known. This report describes the fuzzy modelling process in detail.

MODEL DESIGN

Two types of models have been designed in order to handle different types of inputs.

- **Numeric Inputs**
  Type-1 singleton fuzzy logic is used to handle numeric inputs. We assume that the input does not have uncertainty and the user is sure about the input value. Therefore, singleton fuzzification can be used to convert the input into a fuzzy set. The numeric input takes the shape of a spike on the plot.

- **Interval-valued Inputs**
  Interval-valued input is represented by a non-singleton fuzzy set. Since the input is in the form of an interval, we are not certain about the exact value of the input. Therefore, it is converted into a non-singleton fuzzy set, to capture the uncertainty in the user input.

METHODOLOGY

The design of the fuzzy systems involved the following steps.

- Definition of the linguistic variables
- Design of the membership functions
- Definition of the fuzzy rules
- Determining the degree of truth for each antecedent
- Calculation of the firing strength for each rule
- Obtaining the output fuzzy set
- Defuzzification of the output

LINGUISTIC VARIABLES

The design of the fuzzy logic system involved four linguistic variables. Temperature, headache and age are the input variables used, whereas urgency is the output variable.

- **Temperature**
  Temperature is defined over the universe of discourse [34, 44] and represents the linguistic terms low, normal and high. It is recorded in degree Celsius.

- **Headache**
  Headache is defined over the universe of discourse [0, 10], where 0 represents no headache and 10 represents severe headache. The linguistic terms used are low, moderate and high.

- **Age**
  Age is defined over the universe of discourse [0, 130] and represents the linguistic terms young, middle-aged and old.

- **Urgency**
  Urgency is defined over the universe of discourse [0, 100], where 0 means not urgent and 100 represents extremely urgency. The linguistic terms used are not-urgent, less-urgent, urgent, extremely-urgent.

MEMBERSHIP FUNCTIONS

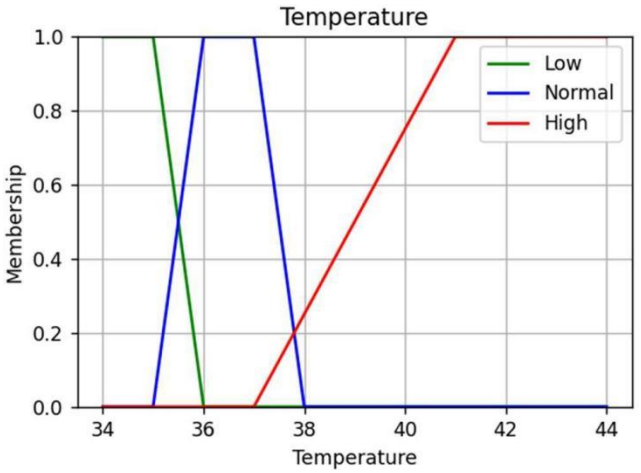
After some research on the normal and extreme values of each variable, the following membership functions were designed.

Temperature

Temperature is categorized into:

- Low
- Normal
- High

These terms are represented by trapezoidal functions having membership degree 1 at 34C-35C, 36C-37C and 41C- 44C respectively.

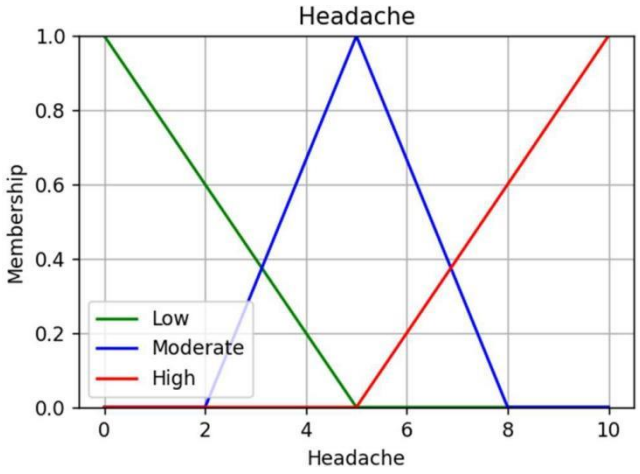


Headache

Headache is categorized into:

- Low
- Moderate
- High

These terms are represented by triangular functions having membership degree 1 at 0, 5 and 10 respectively.

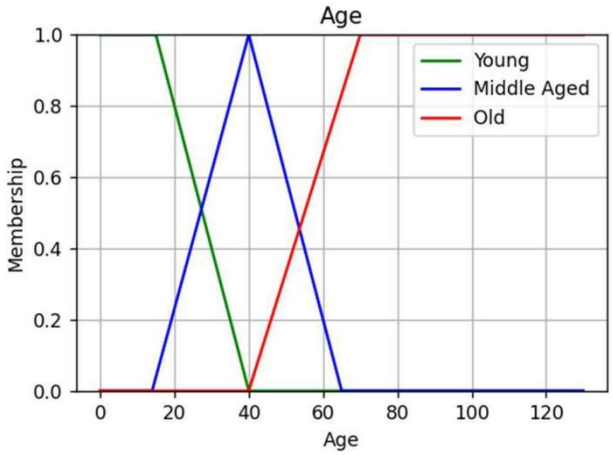


Age

Based on age, people are categorized as:

- Young
- Middle-aged
- Old

Young and Old are represented by trapezoidal functions having membership degree 1 at 0-15 and 70-130 respectively. A triangular function having a peak at average age 40 is used for middle-age.

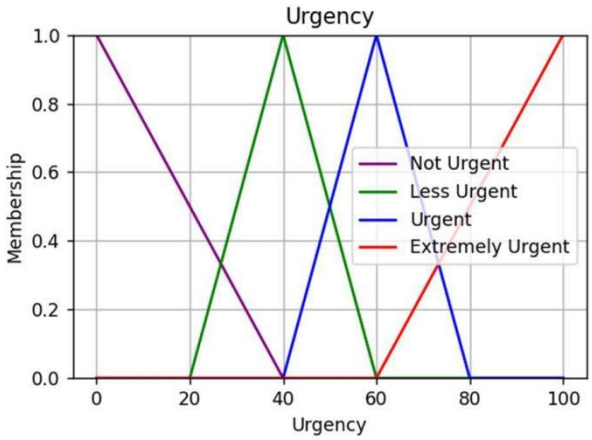


Urgency

Urgency is divided into four categories.

- Not Urgent
- Less Urgent
- Urgent
- Extremely-urgent

All these terms are represented by triangular functions having peaks at 0, 40, 60 and 100 respectively.



FUZZY RULES

A set of fuzzy rules was established to map the combinations of the linguistic variables to the urgency levels. These rules were formulated after discussion with a medical practitioner.

1. If temperature is **low** and headache is **low,** and age is **young** then **not-urgent.**
2. If temperature is **low** and headache is **moderate,** and age is **young** then **less-urgent.**
3. If temperature is **low** and headache is **high,** and age is **young** then **urgent.**
4. If temperature is **normal** and headache is **low,** and age is **young** then **not-urgent.**
5. If temperature is **normal** and headache is **moderate,** and age is **young** then **not-urgent.**
6. If temperature is **normal** and headache is **high,** and age is **young** then **less-urgent.**
7. If temperature is **high** and headache is **low,** and age is **young** then **less-urgent.**
8. If temperature is **high** and headache is **moderate,** and age is **young** then **urgent.**
9. If temperature is **high** and headache is **high,** and age is **young** then **urgent.**

10. If temperature is **low** and headache is **low,** and age is **middle-aged** then **not-urgent.**
11. If temperature is **low** and headache is **moderate,** and age is **middle-aged** then **less-urgent.**
12. If temperature is **low** and headache is **high,** and age is **middle-aged** then **urgent.**

13. If temperature is **normal** and headache is **low,** and age is **middle-aged** then **not-urgent.**
14. If temperature is **normal** and headache is **moderate,** and age is **middle-aged** then **less-urgent.**
15. If temperature is **normal** and headache is **high,** and age is **middle-aged** then **urgent.**
16. If temperature is **high** and headache is **low,** and age is **middle-aged** then **less-urgent.**
17. If temperature is **high** and headache is **moderate,** and age is **middle-aged** then **urgent.**
18. If temperature is **high** and headache is **high,** and age is **middle-aged** then **extremely-urgent.**

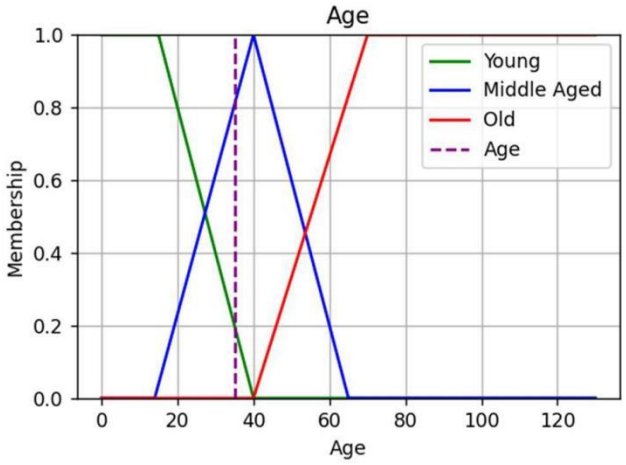
19. If temperature is **low** and headache is **low,** and age is **old** then **not-urgent.**
20. If temperature is **low** and headache is **moderate,** and age is **old** then **less-urgent.**
21. If temperature is **low** and headache is **high,** and age is **old** then **urgent.**
22. If temperature is **normal** and headache is **low,** and age is **old** then **not-urgent.**
23. If temperature is **normal** and headache is **moderate,** and age is **old** then **less-urgent.**
24. If temperature is **normal** and headache is **high,** and age is **old** then **urgent.**
25. If temperature is **high** and headache is **low,** and age is **old** then **urgent.**
26. If temperature is **high** and headache is **moderate,** and age is **old** then **extremely-urgent.**
27. If temperature is **high** and headache is **high,** and age is **old** then e**xtremely-urgent.**

DEGREE OF TRUTH OF AN ANTECEDENT

The degree of truth for each antecedent is calculated, based on the type of the input:

- **Numeric Input**

  In case of a numeric input, the number is converted into a singleton fuzzy set, which is represented by a spike on the graph. The degree of truth is calculated by computing the intersection of this set and the antecedent fuzzy set. The maximum degree of membership in this intersection is used as the degree of truth.



  For Example, the degree of truth for young, middle-aged and old is 0.2, 0.8 and 0 respectively for the input age 35.

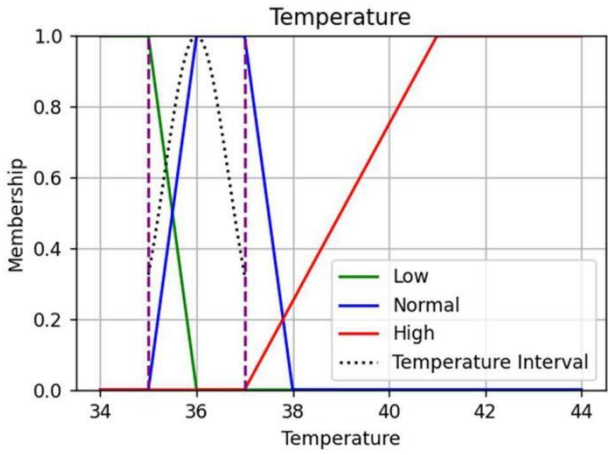
- **Interval-valued input**

  In case of an interval-valued input, the interval is converted into a non-singleton fuzzy set, represented by a gaussian function. This gaussian function helps in handling the uncertainty in the input. The subsethood method is used to calculate the degree of truth for each antecedent. This method is preferred because it handles uncertainty over large intervals better than the centroid method.

Let X be the interval fuzzy set and A be the antecedent fuzzy set. The degree of truth for the antecedent is calculated as follows:

$$\frac{|X \cap A|}{|A|}$$

For Example, the degree of truth for low, normal and high is calculated as 0.26, 0.85 and 0 respectively for the interval 35-37, based on their intersection with the input fuzzy set.



FIRING STRENGTH FOR EACH RULE

The firing strength for each rule is calculated by combining the degrees of membership for each antecedent of the rule using a t-norm operator. In this system, the minimum of the membership degrees is used as the firing strength of the rule.

THE OUTPUT FUZZY SET

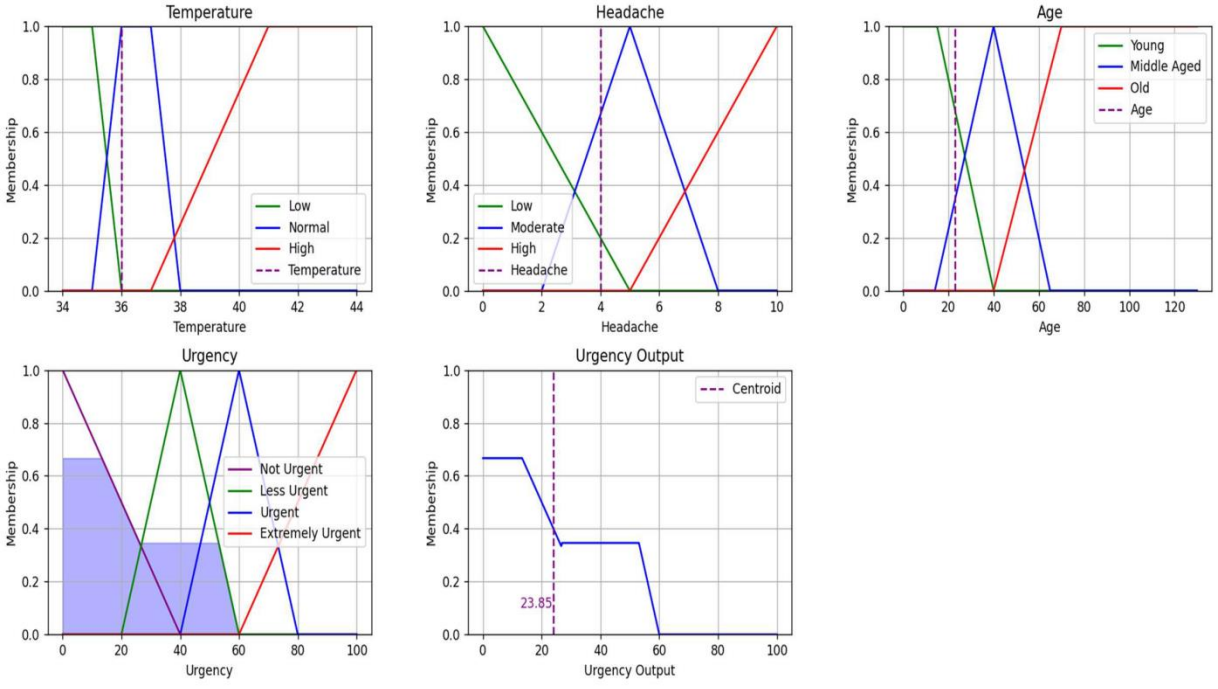
The firing strength is modelled as a cylindrical extension and its intersection with the consequent fuzzy set is computed as the output. Outputs from individual rules are then combined using a t-conorm operator (maximum).

DEFUZZIFICATION OF THE OUTPUT

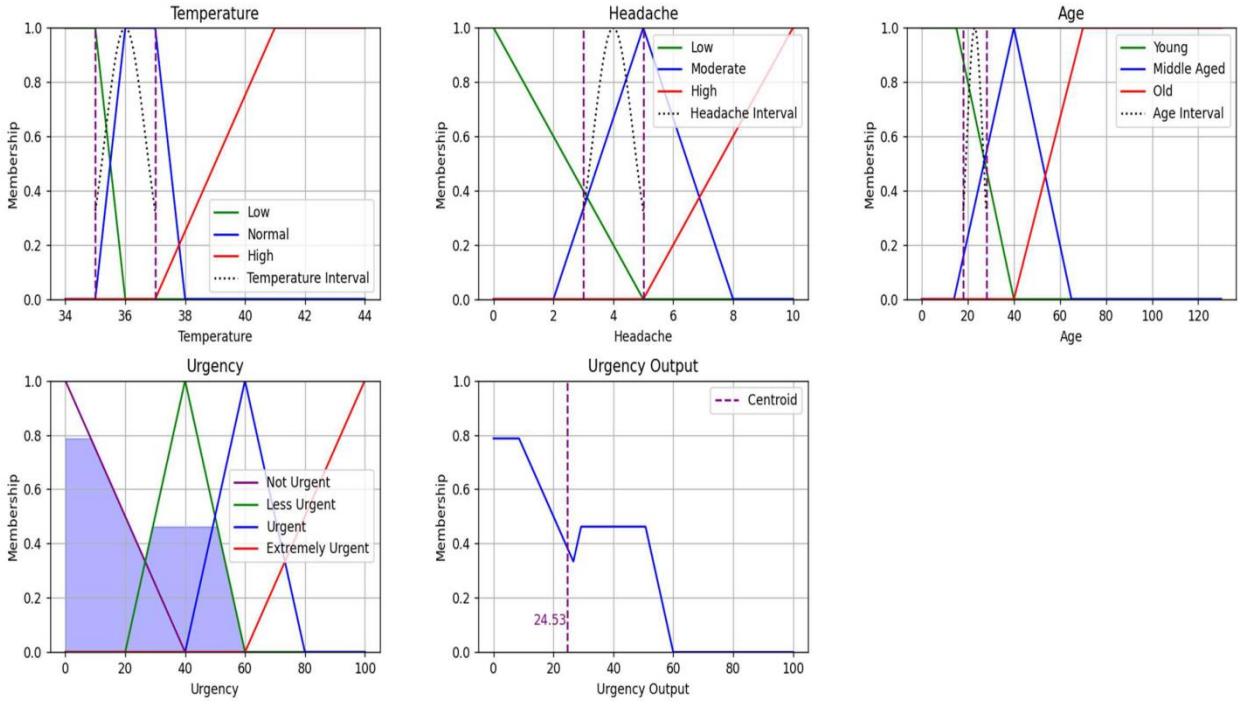
Centroid defuzzification is used to convert the output into a numeric value.

OUTPUT EXAMPLES

In the following example, we get urgency = 23.85 for temperature 36C, headache 4 and age 23.



For the interval values temperature = 35-37, headache = 3-5 and age = 18-28, we get urgency = 24.53.



RESULTS AND DISCUSSION

In order to evaluate the performance of the system, a comparison of different scenarios and their corresponding urgency outputs was conducted for both numeric and interval-valued inputs.

Numeric Input			
Temperature	**Headache**	**Age**	**Urgency**
36	1	15	13.75
37	5	40	40.00
36.5	3.5	28	27.88
38.5	5.5	35	64.35
35	1.5	42	14.23
39.25	6.9	50	72.07
38.5	7.8	55	80.19
38.5	8.5	60	83.49
35.75	3.8	32	31.3
34.5	6.5	48	47.7

Interval-Valued Input			
Temperature	**Headache**	**Age**	**Urgency**
35-37	0-2	12-18	13.58
36-38	4-6	39-41	43.27
35-38	3-4	25-31	28.70
38-39	4-7	30-40	64.43
34-36	0-3	40-44	16.32
39-39.5	6.8-7	45-55	72.63
38-39	7.5-8.1	54-56	80.64
37-40	8-9	58-62	77.98
35-36.5	3.5-4.1	30-34	29.90
34-35	5.5-7.5	45-51	48.35

We observe that the output for the interval inputs is similar to the output for their corresponding midpoints. However, there is a slight difference in the urgency values due to the uncertainty captured in case of interval input. The interval-valued inputs encompass a range of values,

capturing a broader spectrum of possibilities. This allows better prediction, accounting for the uncertainties in real-world scenarios.

NUMERIC INPUT VS INTERVAL-VALUED INPUT

Fuzzy System for Numeric Input

This system is used when the user is certain about the input values. It receives a crisp input from the user and returns a numeric value of urgency.

Strengths

1. Provides a precise output based on the exact input values, allowing for specific urgency determination.
2. Offers straightforward and direct interpretations of the input-output relationships, due to the specific numeric values used in the rules.
3. Easily interpretable graphs.

Drawbacks

1. Does not handle uncertainty, limiting its adaptability to real-world imprecisions.
2. Vulnerable to input variations, leading to drastic changes in the output.
3. Oversimplifies complex scenarios due to the reliance on precise numeric inputs. E.g., severity of headache cannot be precisely represented by a number.

Fuzzy System for Interval-Valued Input

This system is used when the user is not certain about the input values. The input is provided in the form of an interval. The system handles the input certainty by using a gaussian function to represent the input.

Strengths

1. Handles Uncertainty and provides a more robust interpretation.
2. Better results in real-world scenarios where exact measurements are not always known.
3. Less affected by minor input inaccuracies.

Drawbacks

1. Increased interpretation complexity.
2. Computationally expensive compared to the numeric valued system.
3. Overlapping intervals might complicate the rule interpretation and create ambiguity.
4. The results are not very useful in case of very large intervals.

SELF-REFLECTION

This assignment was a great learning experience for me. I got a clearer understanding of how fuzzy logic is implemented in uncertain environments. I read several research papers to figure out how interval input is handled and how the firing strength can be calculated in case of intervals. Me and my group member had detailed discussions about the approach to be used. We designed the membership functions and the rules individually and then compared our work to come up with the final design of the system. Both of us explored several different approaches and fuzzy libraries before finalizing our work.

REFERENCES

D. Pekaslan, J. M. Garibaldi and C. Wagner, "Exploring Subsethood to Determine Firing Strength in Non-Singleton Fuzzy Logic Systems," 2018 IEEE International Conference on Fuzzy Systems (FUZZ-IEEE), Rio de Janeiro, Brazil, 2018, pp. 1-8, doi: 10.1109/FUZZ-IEEE.2018.8491614.