COMP4033

Using Fuzzy Inference Systems to Aid Doctors Diagnose the Severity of an Illness

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1 Introduction

Referring patients from the doctor’s office to the hospital or recommending treatments can often be complex and time-consuming tasks for doctors. By using a fuzzy inference system, the doctor would be able to save time by entering the patients' medical information and receiving a recommended outcome.

The fuzzy system requires three inputs: patient age to predict the efficiency of the patient's immune system, patient temperature to predict the severity of the patient’s symptoms, and finally, the severity of the patient’s headache as an addition to temperature to indicate the severity of the symptoms the patient is suffering.

2 Model Design

2.1 Overview of the Fuzzy System

Input Sets:

The first input used is patient age, which has been divided into three sets: child, adult, and elderly. Each set uses a trapezoidal membership function to predict when the patient is most or least at risk from an illness by estimating the efficiency of their immune system, as the immune system of children is still developing ([1]) while that of the elderly is degrading ([3]) - this timeline for the immune system can be derived from scheduled vaccination dates ([2]).

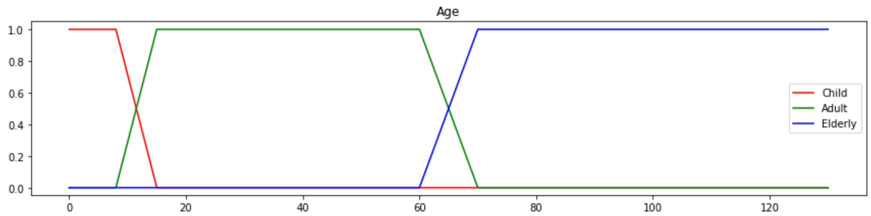


Illustration of the input sets and set ranges used for age.

The second input set; temperature is divided into three membership sets: hypothermic, average, and fever. Average is used to indicate the normal ranges wherein the patient’s temperature is healthy and utilises a triangular membership function as any deviation from average can be indicative of a problem. Hypothermic indicates where the patient’s temperature has fallen to the point where they need immediate attention ([8]), therefore using a trapezoidal membership function is necessary to maintain consistent outputs. Fever covers higher temperatures which usually serves as an indicator of an underlying issue which could be harmful, therefore also using a trapezoidal membership function to maintain consistent outputs.

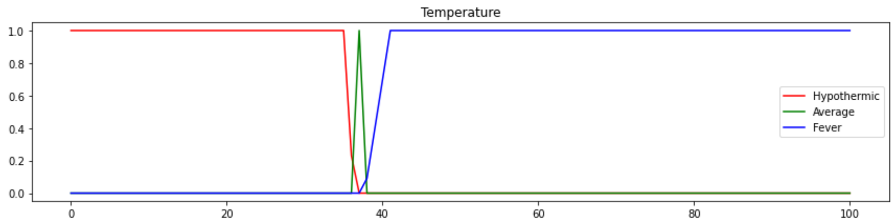


Illustration of the input sets and set ranges used for temperature.

The final input set of headache severity consists of three membership sets: normal, benign, and malign. Since a scale of zero to ten based on how the patient feels is not objective or consistent, the membership functions must account for patient uncertainty. Normal uses a triangular membership function as any deviation from zero is abnormal, however not inherently harmful. Meanwhile benign and malign headaches utilise trapezoidal membership functions to accommodate for user uncertainty when designating a value for their headache, as users would be required to refer to medical documents/accounts as comparison ([4]) for their experience.

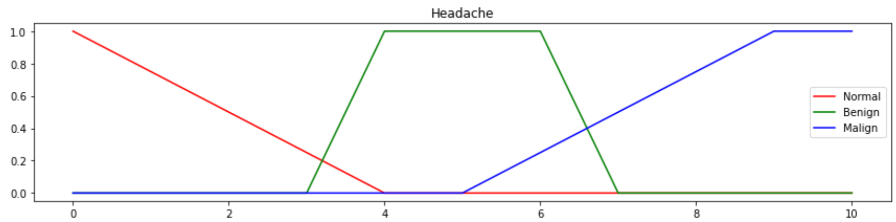


Illustration of the input sets and set ranges used for headache.

Output Sets:

The three output membership sets are evenly distributed across the range of zero to one hundred to maintain readability and interpretable outputs. Each set is defined by a recommended treatment range for the patient's problem. The membership sets are non-urgent, semi-urgent, and urgent, each of which using a trapezoidal membership function to reduce the ambiguity of abstract numeric outputs.

A non-urgent output indicates that the patient's problem does not risk them any harm and can be resolved with simple treatments such as resting, hydration, or sufficient nutrition. Semi-urgent outputs are for more complex problems where the patient may need some assistance, such as prescription medications, or medical advice. An urgent output indicates that the patient has a severe problem and will need specialist attention to aid their recovery.

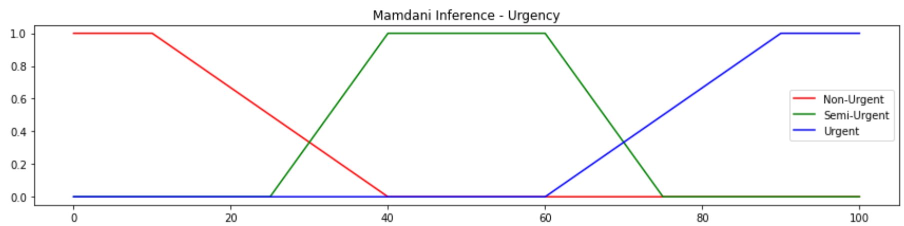


Illustration of the output sets and set ranges used for urgency.

Rule Set:

The rule set used was simplified from twenty-seven exhaustive rules, which detailed all permutations of the input sets, into seven simplified rules:

1) IF Temperature is Hypothermic OR Headache is Malign THEN Urgency is Urgent

Whenever a patient is hypothermic, they will always need immediate specialist attention without exception. Conversely, if a patient has a malign headache, they will need specialist advice or treatments.

2) IF Temperature is Average AND Headache is Normal THEN Urgency is Non-Urgent

The patient does not exhibit any immediate symptoms of a problem, consequently they do not currently need any treatment.

3) IF Temperature is Fever AND Headache is Normal THEN Urgency is Semi-Urgent

The patient may be developing an illness and will likely need assistance to prevent additional symptoms. It is also not always recommended to see a doctor unless you exhibit more symptoms than just a fever ([7]).

4) IF Age is NOT Adult AND Temperature is Average AND Headache is Benign THEN Urgency is Semi-Urgent

Children and the elderly are likely to suffer headaches with greater severity than adults, or risk an underlying condition, and will likely desire prescription drugs, or advice.

5) IF Age is Adult AND Temperature is Average AND Headache is Benign THEN Urgency is Non-Urgent

Adults are likely to suffer headaches with lesser severity and reduced potential risks than children or the elderly.

6) IF Age is NOT Adult AND Temperature is Fever AND Headache is Benign THEN Urgency is Urgent

Children and the elderly are more at risk of harm from illnesses and would need higher priority attention for their problems – children would need a specialist in the form of a paediatrician, whereas the elderly would need checks to ensure that no additional conditions have developed. Recommended fever treatments also differ for adults ([5]) and children ([6]) as per the NHS.

7) IF Age is Adult AND Temperature is Fever AND Headache is Benign THEN Urgency is Semi-Urgent

Adults are less at risk of harm than children and the elderly, however they may still need a medical attention, or advice to aid their recovery.

Example inputs and outputs for each rule can be found in the appendices or tested in the attached python files.

System Models:

System 1: Numeric Inputs

For our first system, the user may provide a singular input value for each input set – the user may provide inputs for multiple patients at once. Each input then has its membership values for each set calculated.

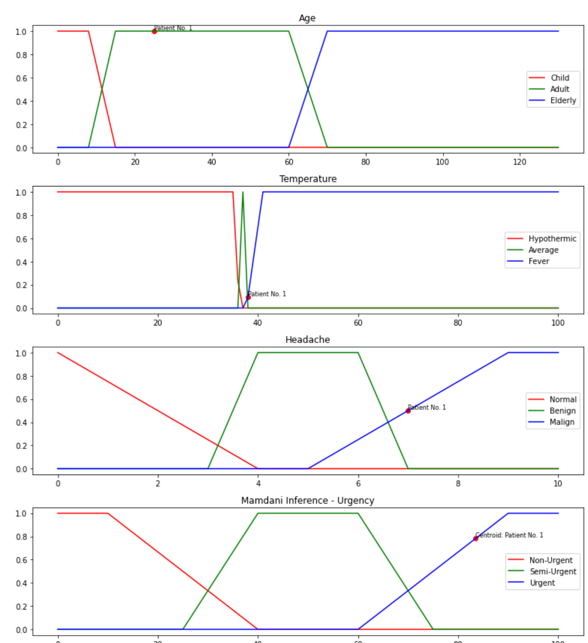
The rule set established above will generate a firing strength according to each invoked set's membership. These firing strengths will be applied to the respective output set wherein a new temporary set will be created. This temporary set will then have a defuzzification method applied to produce a crisp output.

System 2: Interval Inputs

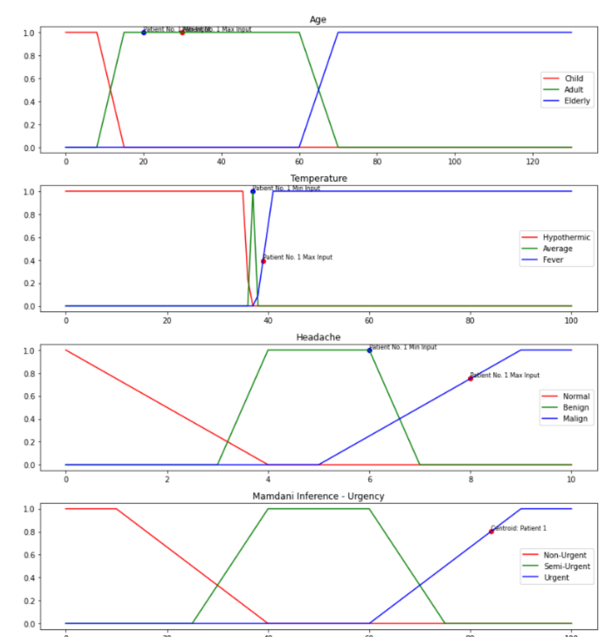
The foundations of system 2 are identical to system 1, with the key difference of allowing an input range. The consequence of this is that the system deals with defuzzification for two values. Firstly, the system will iterate through the input ranges to find the lowest and highest possible output it can produce. From these two outputs, a new membership set is created, where the centroid of this set will be the final crisp output.

An example of the similarities between these functions is the following input:
System 1 – example 1: Age = 25, Temperature = 38, Headache = 7
System 2 – example 1: Age = 20 – 30, Temperature = 37 – 39, Headache = 6 – 8

With a minor interval within the same input set, the output is identical (84), however if the ranges became unevenly distributed or skewed, the output range would also deviate, creating a bias towards the centre.



System 1 – Example 1 Inputs and Output Plots

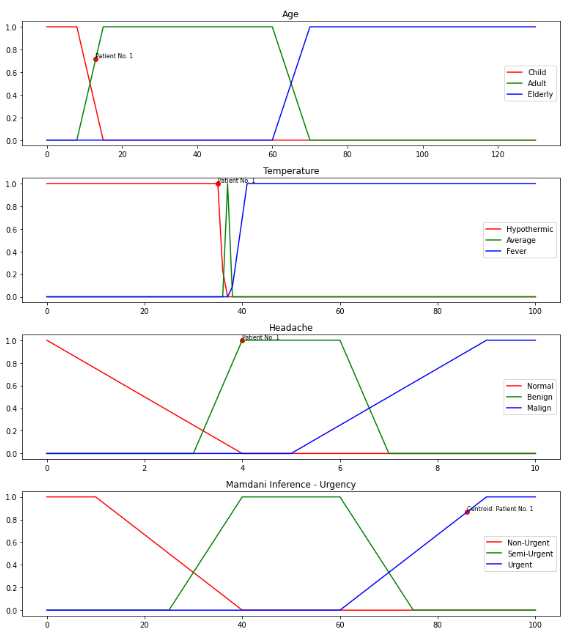


System 2 – Example 1 Inputs and Output Plots

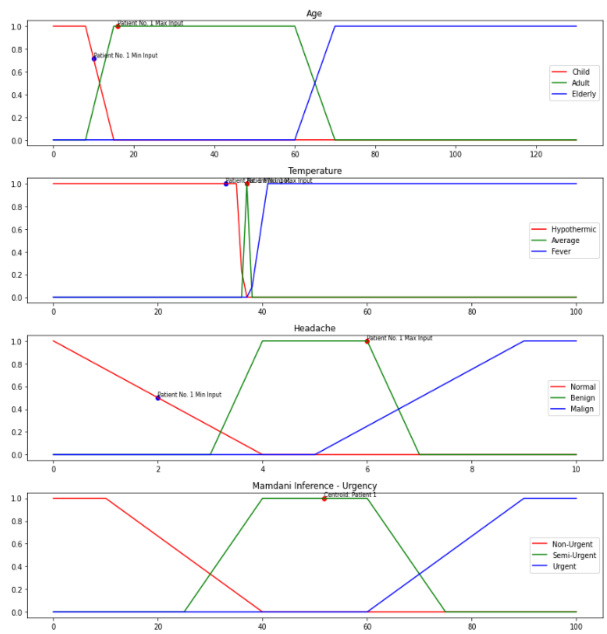
In contrast, an interval range within the overlapping ranges of input sets will create a more extreme variation:

System 1 – example 2: Age = 13, Temperature = 35, Headache = 4
System 2 – example 2: Age = 10 – 16, Temperature = 33 – 37, Headache = 2 – 6

System 1 with its precise inputs will provide an urgent output value of 86, as the system is certain that the patient is hypothermic and a child. In contrast, the interval system is uncertain if the patient is a child or adult, hypothermic or average, or has a normal headache range, benign, or even a malign headache range. With such a broad set of applicable rules created by the uncertain ranges of the interval inputs, the system gave an uncertain output of 51.7.



System 1 – Example 2 Input and Output Plots



System 2 – Example 2 Input and Output Plots

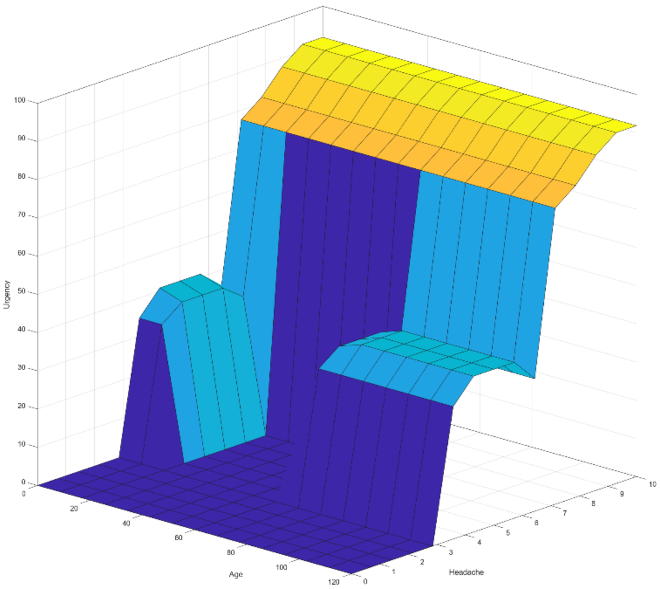
Although the input for system 1 was the midpoint for system 2's interval, it does not mean that the two outputs will be similar as the interval system will have to account for input uncertainty, as the greater the input uncertainty, the greater the output uncertainty.

3 System Comparison

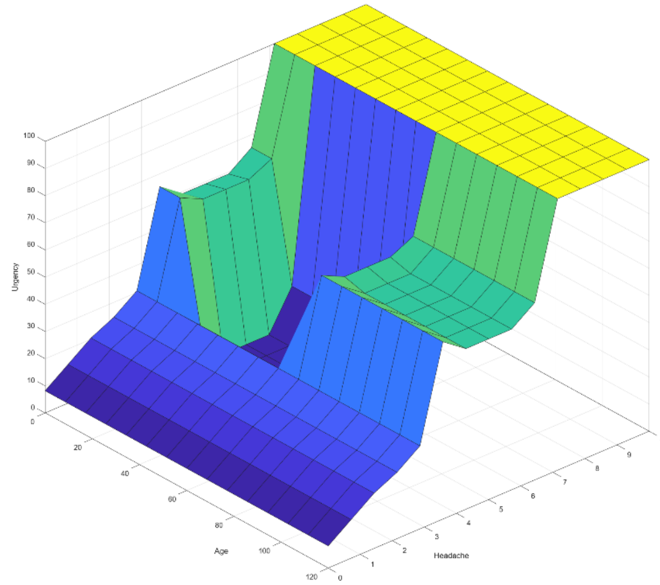
Defuzzification Methods:

When testing each system, various defuzzification methods were applied, however each method presented different strengths and weaknesses. The tested approaches were centroid, bisector, mean of maxima, min of maxima, max of maxima, zero-order TSK, and first-order TSK. Linguistic defuzzification was also considered, however since all inputs would be numeric rather than linguistic, this defuzzification method was not applicable.

From these approaches, max and min of maxima produced the most extreme outputs, as min of maxima lacked responsiveness, whilst max of maxima produced extreme responsiveness, whereas the ideal system would produce a smoother distribution. In contrast, mean of maxima was very similar to centroid and bisector, however its outputs would often plateau.

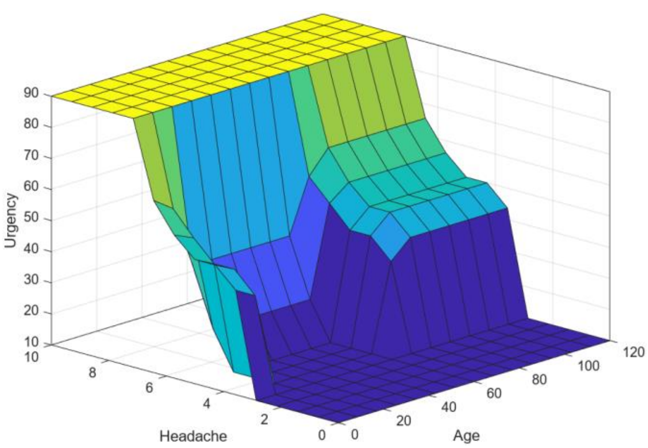


Min of Maxima control surface – lacks reactivity for low headache distributions.

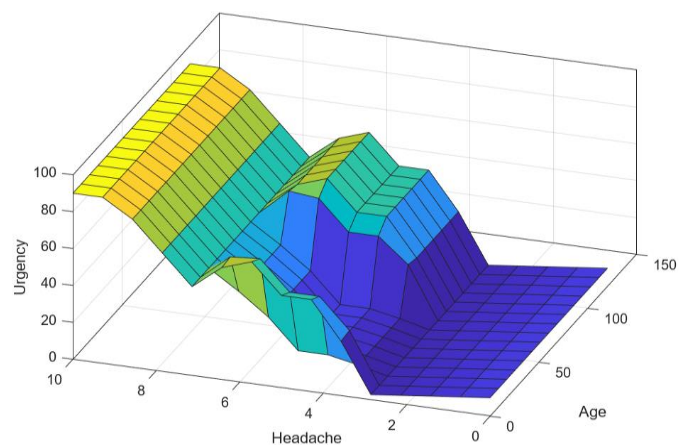


Max of Maxima control surface – generates too much output spread for headache distributions.

TSK systems were also attempted however, zero-order TSK's did not provide a sufficient reaction to normal headaches, however it produced a reasonable output distribution. In contrast, first-order TSK produced peaks and troughs for each input set, which resulted in inconsistent and contradictive outputs.

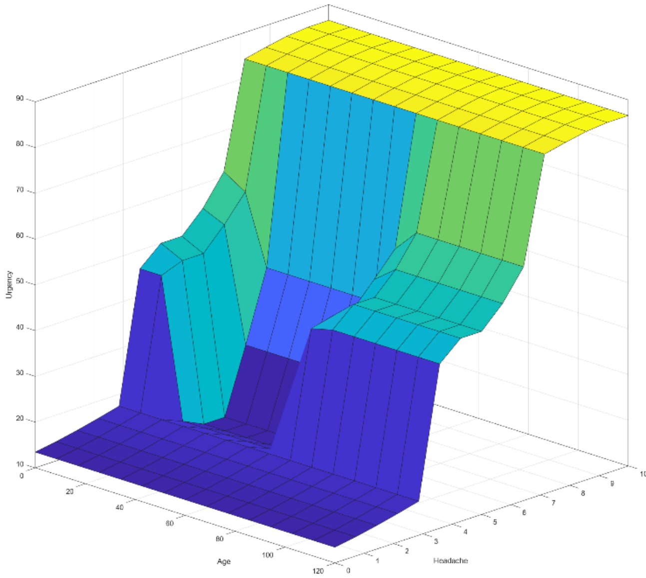


Zero-Order control surface

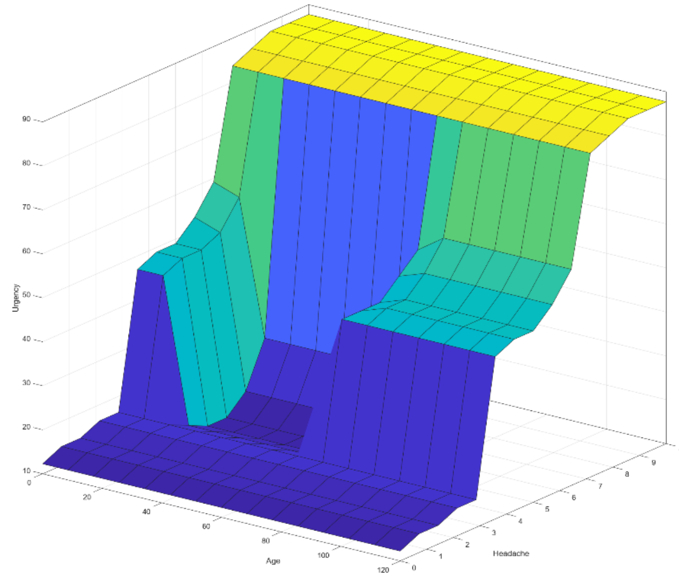


First-Order control surface

Finally, the best method for generating outputs used Mamdani inference. Centroid and bisector defuzzification provided the smoothest surface between input set ranges, however the primary difference is that centroid produces a smoother output between input set ranges, while bisector produces minor plateaus. Consequently, centroid defuzzification through Mamdani inference produced the ideal model for the task.



Centroid defuzzification control surface



Bisector defuzzification control surface

<u>System Methodology Comparison:</u>

While system 1 would produce a certain response, this is not always realistic, as certainty is rarely available, especially where objectivity is lacking. This uncertainty can be mitigated by providing an interval range for an input; however, this could greatly increase the uncertainty of the output, depending on the uncertainty of the interval.

Where inputs such as age and temperature are objective and should be certain, minor uncertainty would rarely affect the output. Meanwhile, the ambiguity of a headache's severity would vary depending on the person, therefore the input of headache severity would benefit from the application of an interval to account for uncertainty. However, larger interval ranges would not be beneficial, as this would produce an uncertain output which could be dangerous in the medical field.

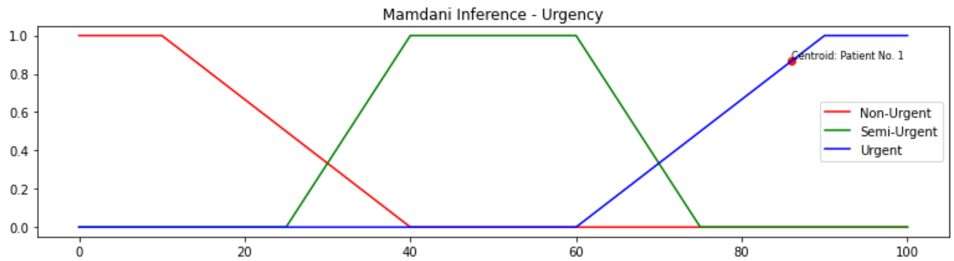
Consequently, numeric inputs are always beneficial to prevent output uncertainty, however it is not always realistic to be certain - so long as the input interval is small, the result will not vary greatly. Interval ranges are ideal for an abstract input such as headache severity, as an individual will not always assign the same value to what they experience, regardless of how similar it is to the description, or their previous ratings.

4 Self-reflection

Throughout the assignment, both Benjamin and I discussed our design decisions for each fuzzy set while also proof-checking each other’s work to ensure that all was consistent and of sufficient quality. After we had both collaborated to establish the foundations of our system, we both created the rule set for our system to use. Finally, I focused on creating the python system foundations for our models, as we had decided to reuse my design documentation from lab sheet 2. Meanwhile, Benjamin would research different methodologies and approaches for how we could improve our systems, as well as to create alternative systems for comparisons.

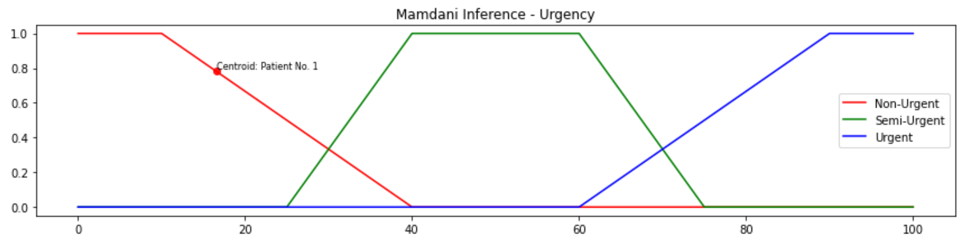
5 Appendix

- Rule 1 - Example 1: Age = 21, Temperature = 34, Headache = 0
- Rule 1 - Example 2: Age = 21, Temperature = 37, Headache = 9



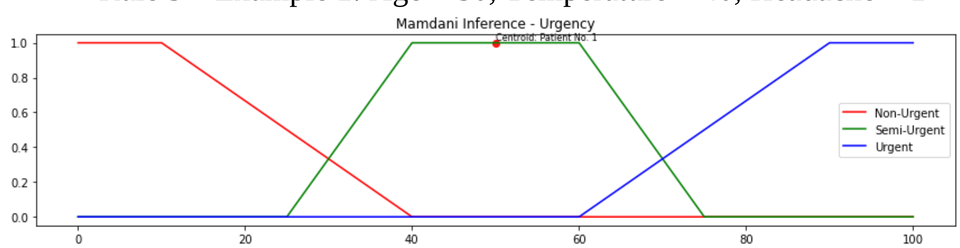
Rule 1 - Example 1 & 2: Output – Urgency value (centroid) = 86, Urgent membership = 0.866

- Rule 2 – Example 1: Age = 5, Temperature = 37, Headache = 2



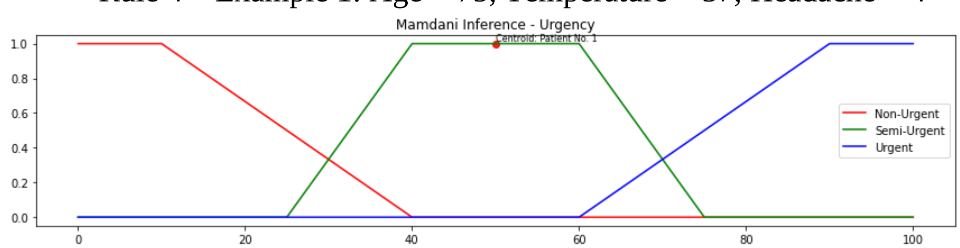
Rule 2 – Example 1: Output – Urgency value (centroid) = 16.54, Non-Urgent membership = 0.78

- Rule 3 – Example 1: Age = 50, Temperature = 40, Headache = 1



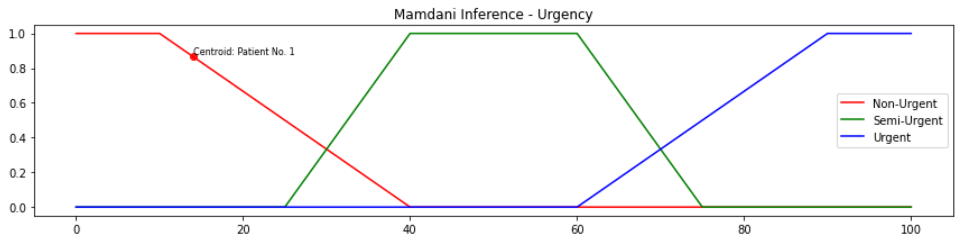
Rule 3 – Example 1: Output – Urgency value (centroid) = 50, Semi-urgent membership = 1

- Rule 4 – Example 1: Age = 75, Temperature = 37, Headache = 4



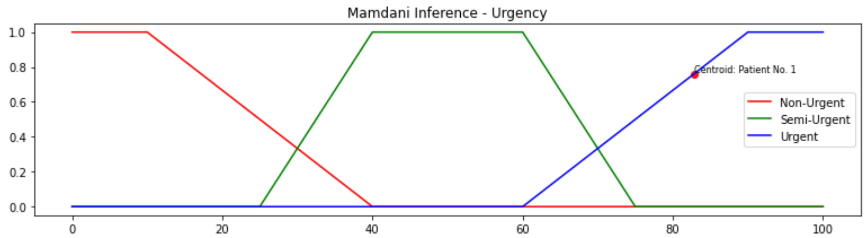
Rule 4 – Example 1: Output – Urgency value (centroid) = 50, Semi-urgent membership = 1

- Rule 5 – Example 1: Age = 32, Temperature = 37, Headache = 4



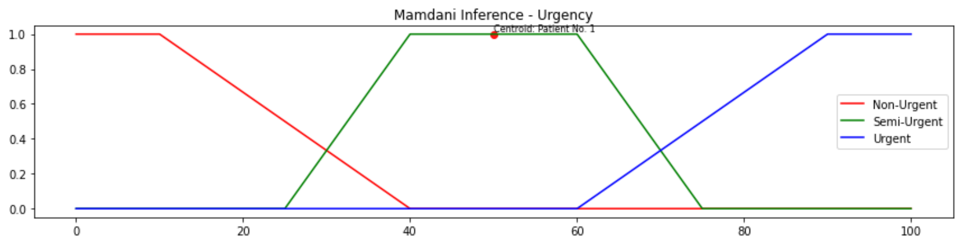
Rule 5 – Example 1: Output – Urgency Value (centroid) = 13.99, Non-urgent membership = 0.866

- Rule 6 – Example 1: Age = 5, Temperature = 39, Headache = 4



Rule 6 – Example 1: Urgency value (centroid) = 82.79, Urgent membership = 0.759

- Rule 7 – Example 1: Age = 25, Temperature = 39, Headache = 4



Rule 7 – Example 1: Urgency value (centroid) = 50, Semi-urgent membership = 1

6 References

[1] https://www.pregnancybirthbaby.org.au/how-your-babys-immune-system-develops

[2] https://www.nhs.uk/conditions/vaccinations/nhs-vaccinations-and-when-to-have-them/

[3] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5291468/#:~:text=Beginning%20with%20the%20sixth%20decade,to%20support%20appropriate%20wound%20healing

[4] https://www.nhsinform.scot/illnesses-and-conditions/brain-nerves-and-spinal-cord/headaches/#:~:text=a%20cold%20or%20flu,carbon%20monoxide%20poisoning

[5] https://www.nhs.uk/conditions/fever-in-adults/

[6] https://www.nhs.uk/conditions/fever-in-children/

[7] https://www.betterhealth.vic.gov.au/health/conditionsandtreatments/fever

[8] https://www.mayoclinic.org/diseases-conditions/hypothermia/symptoms-causes/syc-20352682