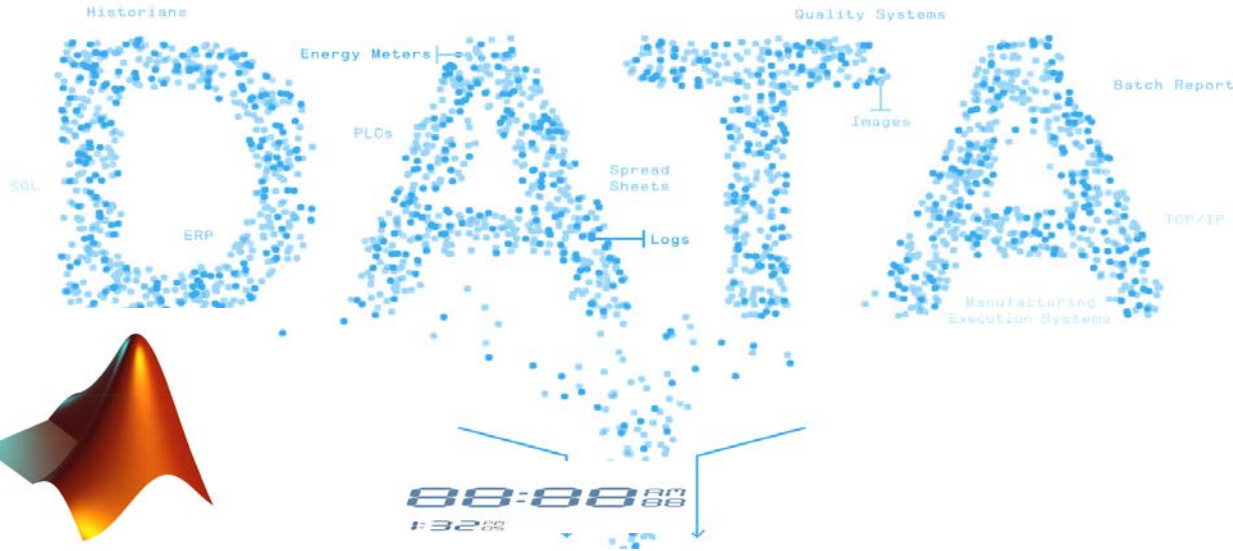
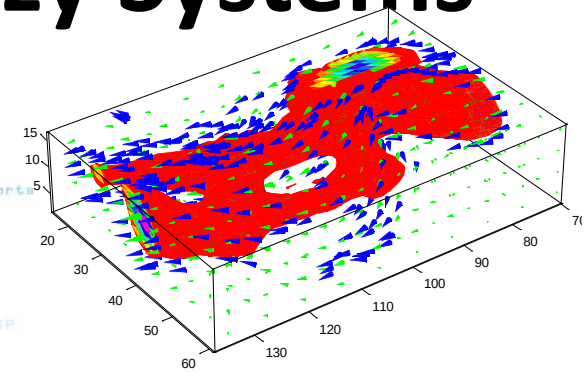
Introduction to Artificial Intelligence

- 04-01 Fuzzy Logic and Fuzzy Systems





Dr Leo Chen
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19/Sep/2022

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2. Evolutionary Computation
3. Artificial Neural Network
4. Fuzzy Logic and Fuzzy Systems
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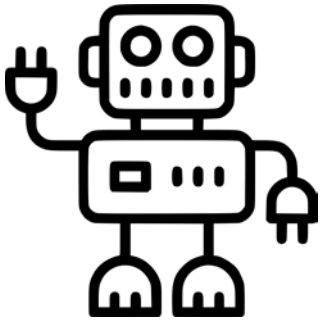

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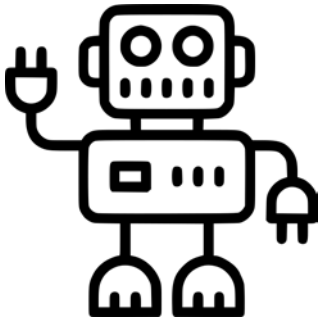


Introduction

Fuzzy *adjective* **not clear or vague**

/ˈfʌzi/

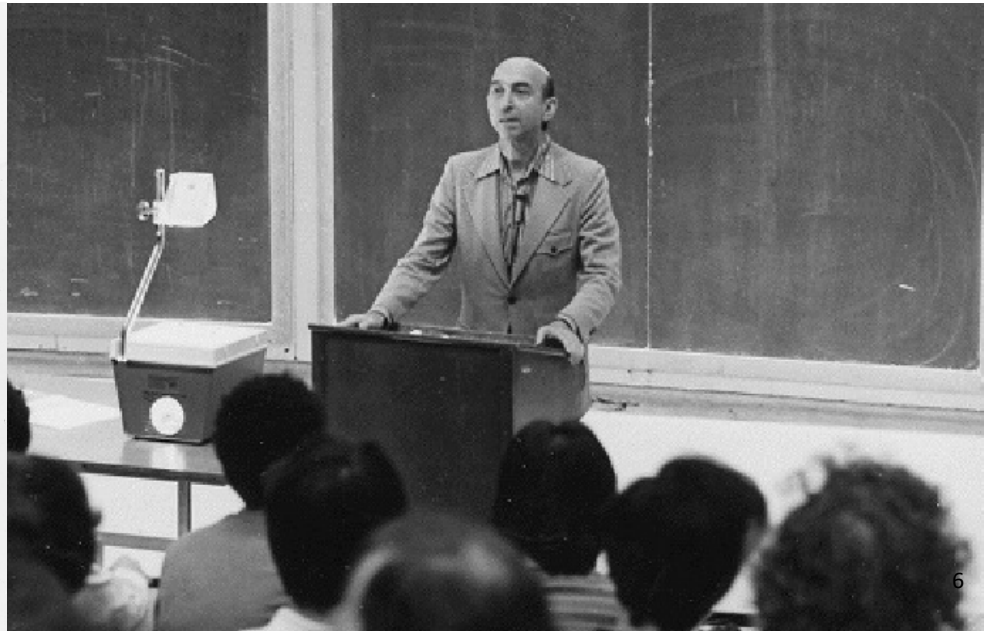
- Fuzzy Logic resembles the **human decision-making** methodology, which deals with **vague** and **imprecise information**. [1]
- This is gross **over-simplification** of the **real-world problems** and based on **degrees of truth** **rather than** usual **true/false** or **1/0** Boolean logic.

Introduction

- An **event**, **process**, or **function** that is changing ***continuously*** can **not** always be defined as either **true** or **false**, which means that we need to **define** such ***activities*** in a *fuzzy* manner.
- In the real world, we encounter a situation when we **can't determine** whether the state is **true or false,** then fuzzy logic provides very **valuable flexibility** for **reasoning**
- Fuzzy Logic was introduced in **1965** by **Lofti A. Zadeh** in his research paper "Fuzzy Sets". He is considered as the **father of Fuzzy Logic**.

Lotfi A. Zadeh (1921–2017) [2-4]

“As complexity rises, precise statements **lose meaning** and meaningful statements **lose precision”**
-- Lotfi A. Zadeh (father of‘fuzzy logic')

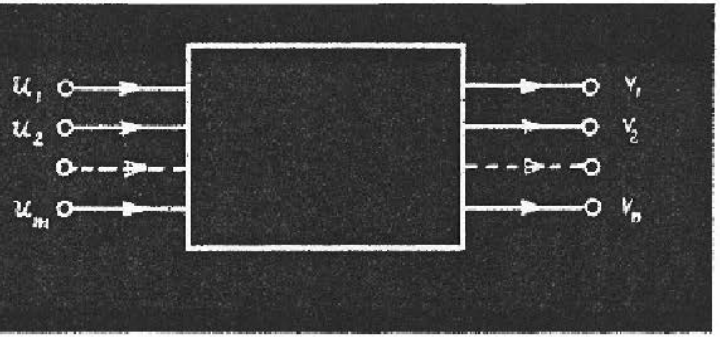


THINKING MACHINES

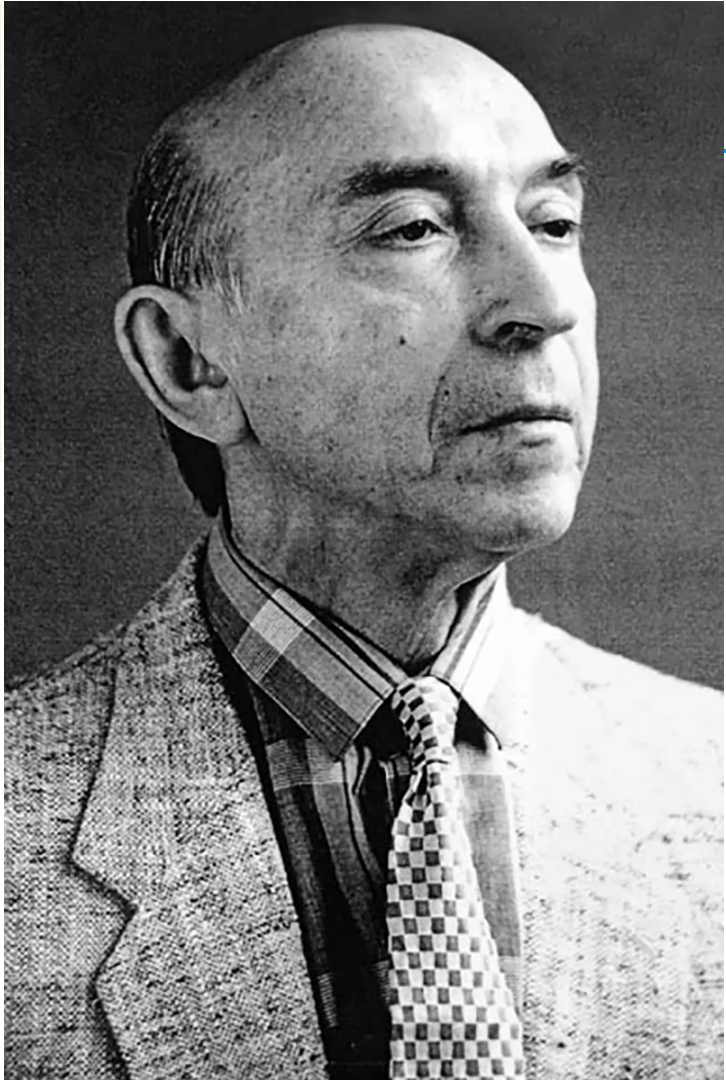
A New Field in Electrical Engineering

DR. LOFTI A. ZADEH
ELECTRICAL ENGINEERING DEPT.

System Theory



L. A. Zadeh
Associate Professor
Electrical Engineering



Fuzzy and Boolean

Do you like roast fish?

Class Discussions

Ask yourself or your friends:

- is it cold today?
- is it a good weather today?
- How much do you love me? (10000 Year?)
- Am I too old to learn a new language? (elvish languages)
- Why does time pass so fast when you're happy? How happy are you?

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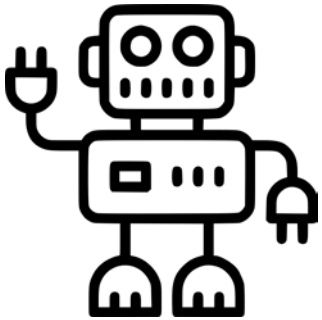

What is Fuzzy Logic

- Fuzzy logic is **not** logic that is fuzzy, but **logic that is used to describe fuzziness**
- Fuzzy logic provides very valuable flexibility for reasoning
- Fuzzy logic is learning human operations when considering the task/system as a **black box (too complex or difficult to)**.
- The ability of humans to deal with **vague** and **imprecise data** makes such tasks easy for us.
- Fuzzy logic must be built so that it is capable of dealing with **vague information**.

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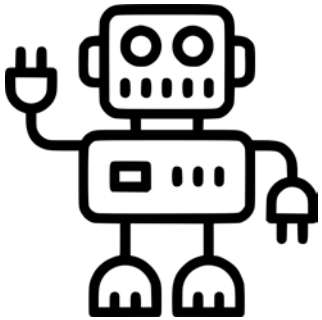

Why Use Fuzzy Logic?

- We aim to replicate the control actions of a **human operator**, we must be able to model the activities of the **operator** and **not** of the plant itself.
- Many tasks are simple for **humans**, but they create a continuous challenge for **machines:**
  - *Driving a car*
  - *Parking a car*
  - *Walking through a cluttered environment*
  - *Lifting fragile objects*

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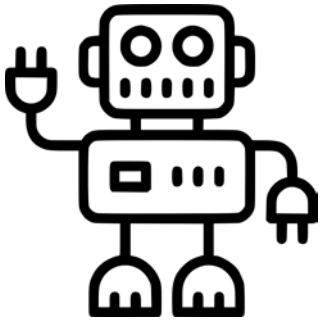


Fundamentals of Fuzzy Logic [5,6]

- Crisp Sets and Fuzzy sets
- Membership Function
- Architecture and Fuzzy Inference Systems
- Advantages and Disadvantages

Crisp Sets

- **Classical logic** is based on the **crisp set**, where a group of distinct objects are considered as a collection.
- **Example01**, the **colours:** white and red are both separate objects, but they can be regarded as a **collection** using the **notation** {red, white}.
- **Crisp sets** are, by convention designated a **capital letter F** hence the above example can be described by,

$$\mathbf{F = \{red, white\}}$$

Crisp Sets

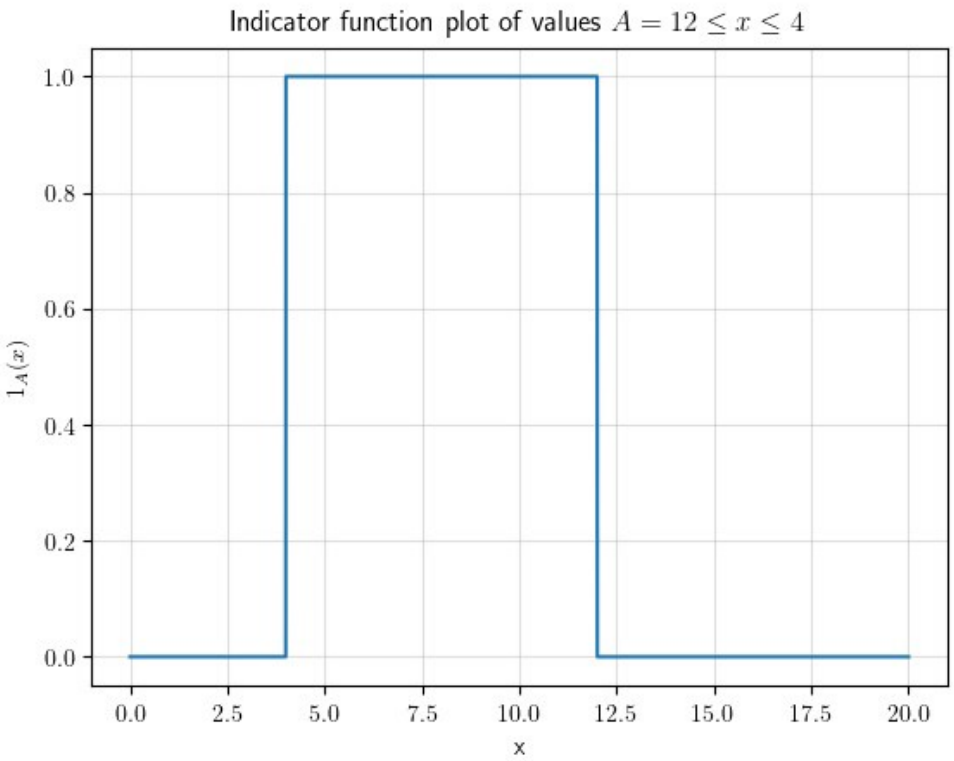
- A crisp subset can be defined from a more **extensive set** where the elements of the set belong to the subset according to some condition
- **Example 02**, **set A** can be defined as the set of numbers that are **greater or equal to 4 and smaller or equal to 12**. This statement can be described using the following notation:

$$A = \{i \mid i \text{ is an integer and } 4 <= i <= 12\}$$

Crisp Sets

A graphical representation:

$$1_A(x) = \begin{cases} 1 & \text{if } 4 \leq x \leq 12 \\ 0, & \text{otherwise} \end{cases}$$



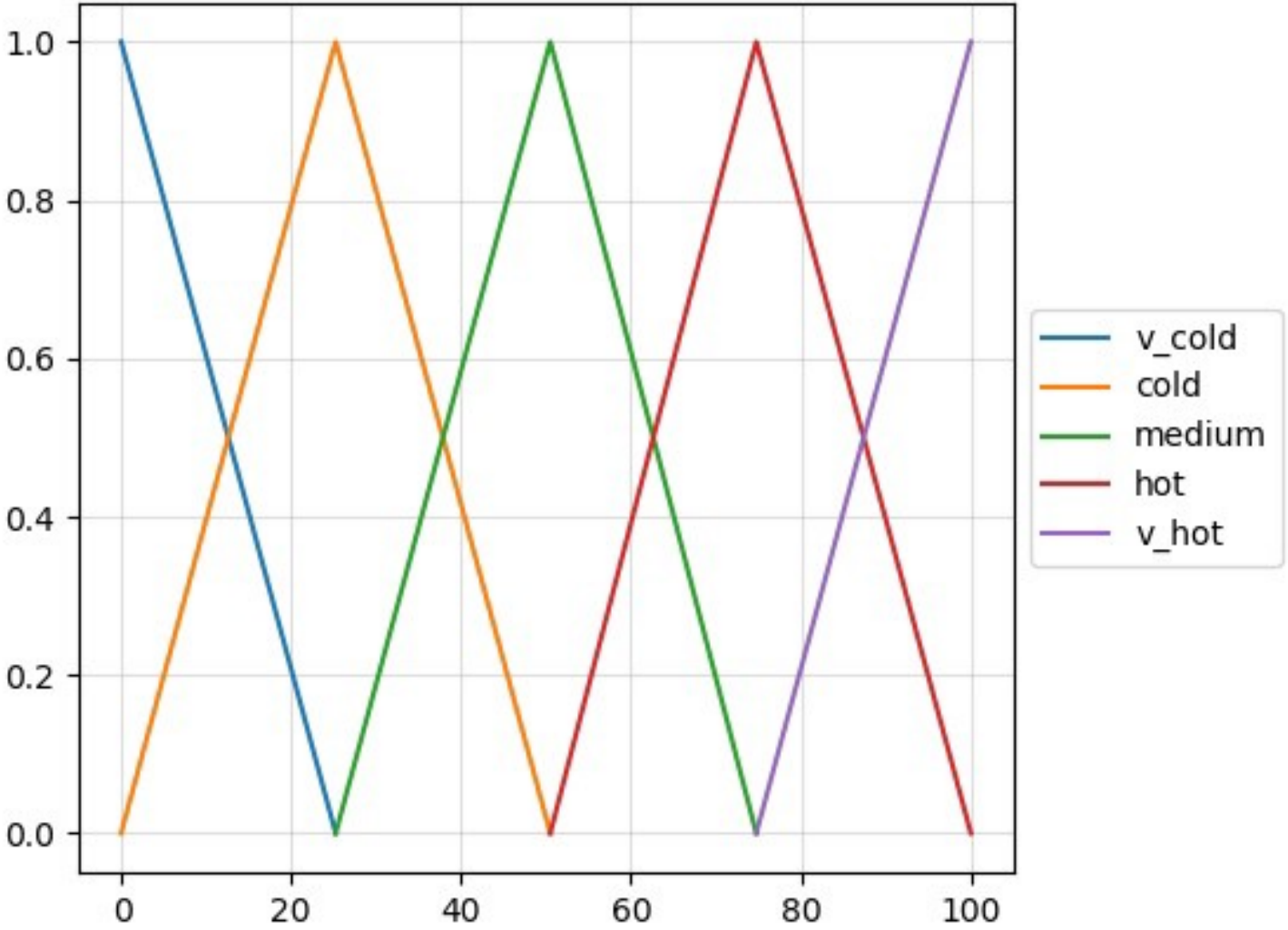
Fuzzy sets

- Fuzzy sets were introduced by **Lotfi Zadeh** in **1965**.
- Unlike crisp sets, a fuzzy set allows **partial belonging** to a set, that is defined by **a degree of membership**, denoted by **μ**, that can take any value from **0** (element does **not** belong at all in the set) to **1** (element belongs **fully** to the set).
- It is evident that if we remove all the values of belonging **except** from 0 and 1, the fuzzy set will **collapse** to a crisp set that was described in the previous section.

Membership Function

- The membership function of the set is the relationship **between the elements** of the set and their **degree-of-belonging**
- An **example** of how membership functions can be applied to **temperature** is shown below:

the fuzzy sets describe ***temperatures of an engine*** *ranging from very cold to very hot.*


1.0
0.8
0.6
0.4
0.2
0.0
0
20
40
60
80
100
v_cold
cold
medium
hot
v_hot

Membership Function

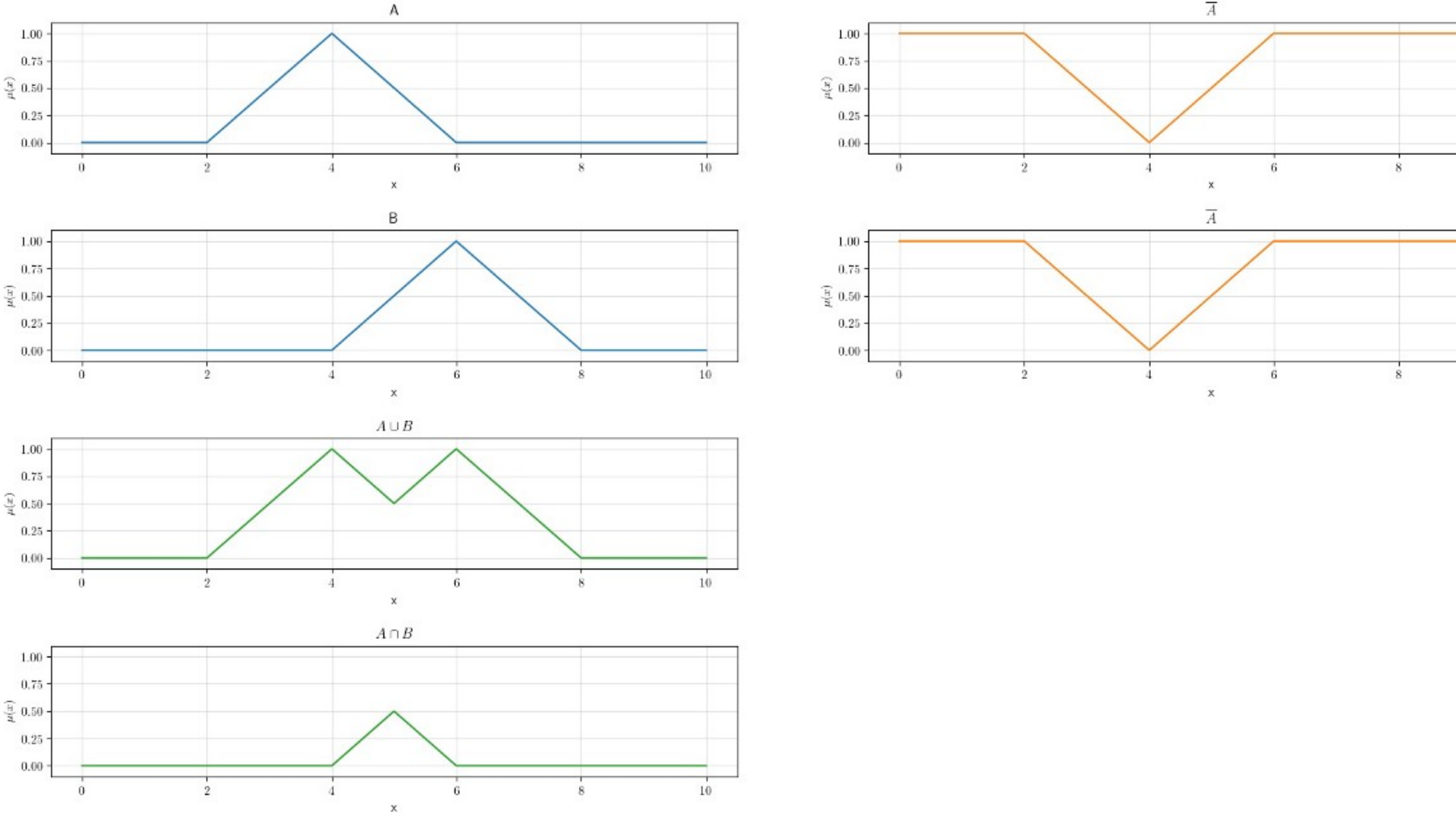
- The membership Function value, **μ**, is the **amount of membership in the set**.
- For example: that at a temperature of **80 degrees**, the engine can be described as being **hot** to a factor of 0.8, and **very hot** to a factor of 0.2.
- The most common **methods of computing** the **union** of **two fuzzy sets** are: the **maximum operator, minimum operator**, the **product operator** on the two sets.

Membership Function

- The **complement** of a **fuzzy set** is calculated by **subtracting** the set membership function **from 1**.
- One crucial observation is that an element can have a degree of belonging both in **a set** and in **the complement** of the **set.**
- As an example, element **x** can be both in **A** and also in '**not-A**' with degree of specific **degree-of-belonging.**
- A graph that defines how each point in the input space is **mapped** to membership value between 0 and 1.

Three types of fuzzifiers for Membership Function :

- Singleton fuzzifier
- Gaussian fuzzifier
- Trapezoidal or triangular fuzzifier

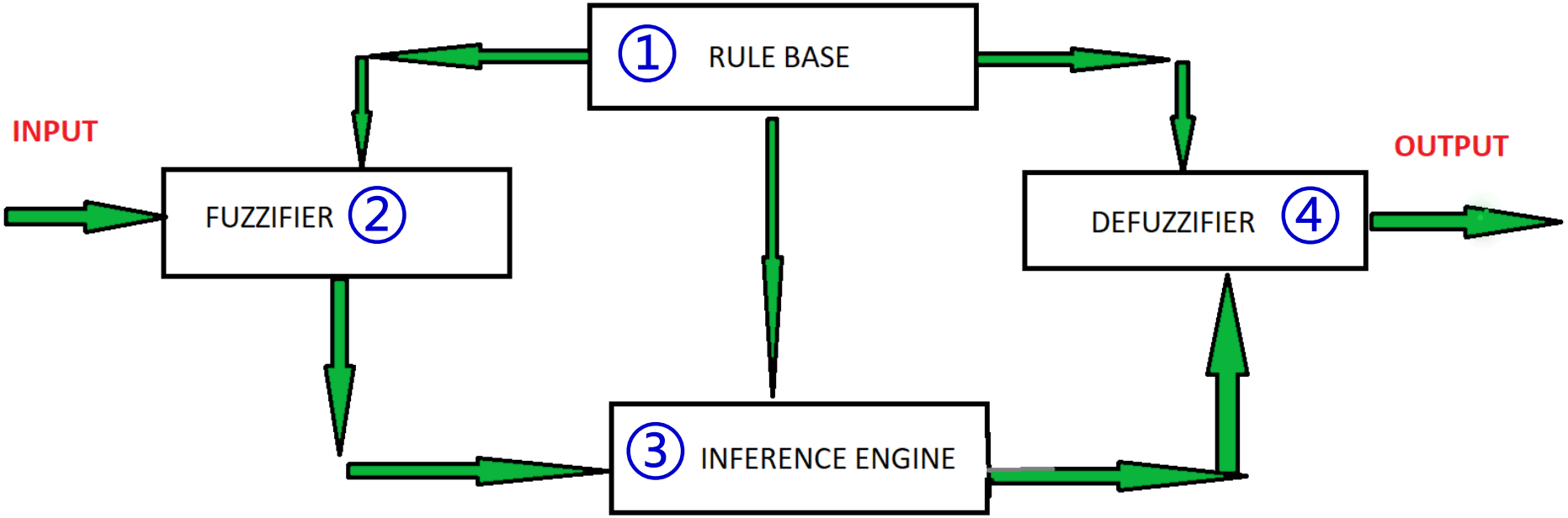

A
$\overline{A}$
B
$\overline{A}$
$A \cup B$
$A \cap B$
$\mu(x)$
x
1.00
0.75
0.50
0.25
0.00
0
2
4
6
8
10

Architecture (configuration)

The Architecture of ‘Fuzzy’ system contains **four** parts :

1. **Rule Base**
2. **Fuzzification (Fuzzifier)**
3. **Inference Engine**
4. **Defuzzification (Defuzzifier)**

Architecture



FUZZY LOGIC ARCHITECTURE

①Rule Base

- It contains the set of rules and the **IF-THEN** conditions provided by the experts to govern the decision-making system, on the basis of **linguistic information**.
- Recent developments in fuzzy theory offer several effective methods for the design and tuning of fuzzy controllers.
- Most of these developments reduce the number of fuzzy rules.

②Fuzzification (Fuzzifier)

- It is used to **convert inputs** i.e. **crisp numbers** into **fuzzy sets via membership function.**
- Crisp inputs are basically the exact inputs measured by sensors and passed into the control system for processing, such as temperature, pressure, rpm’s, etc.

③Inference Engine

- It **determines** the **matching degree** of the current **fuzzy input** with respect **to each rule** and decides which rules are to **be fired** according to the input field.
- Next, the fired rules are **combined** to form the control actions using the **methods of computing** the **union** of **two fuzzy sets (maximum operator, minimum operator**, the **product operator, etc.)**

④Defuzzification (Defuzzifier)

- It is used to **convert** the **fuzzy sets** obtained by the inference engine **into a crisp value**.
- There are several **defuzzification methods** [7] and the best-suited one is used with a **specific expert system** to reduce the error.

  - *Max-Membership Method*
  - *Centroid Method*
  - *Weighted Average Method*
  - *Mean-Max Membership*
  - *Centre of Sums*
  - *Centre of Largest Area*

Fuzzy Inference Systems

- A fuzzy system is a repository of fuzzy expert knowledge tha can **reason data in vague**
- The expert knowledge is a **collection** of **fuzzy membership functions** and a **set of fuzzy rules**, known as the **rule-base**, having the form:

  IF (conditions are fulfilled)

  THEN (consequences are inferred)
- *Mamdani inferencing model* (***Max-Min Inference*** *Method)*
- *Takagi-Sugeno inferencing model* (***IF*** *x IS X* ***and*** *y IS Y* ***THEN*** *z=f(x,y))*

Advantages

- This system can work with any type of **inputs** whether it is **imprecise**, **distorted** or **noisy** input **information**.
- The construction of Fuzzy Logic Systems is **easy** and **understandable**.
- Fuzzy logic comes with **mathematical concepts** of **set theory** and the **reasoning** of that is quite simple.
- It provides a very **efficient solution** to complex problems in all fields of life as it resembles human reasoning and decision-making.
- The algorithms can be described with **little data**, so little memory is required.

Disadvantages

- Many researchers proposed **different ways** to solve a given problem through fuzzy logic which leads to **ambiguity**. There is **no systematic approach** to solve a given problem through fuzzy logic.
- Proof of its characteristics is difficult or impossible in most cases because every time we do **not** get a **mathematical** description of our approach.
- As fuzzy logic works on **precise as well as imprecise data** so most of the time accuracy is compromised.

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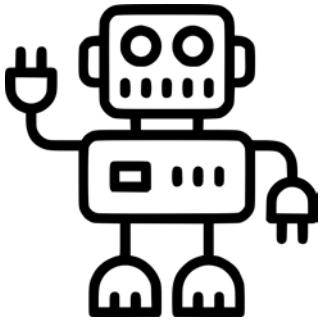
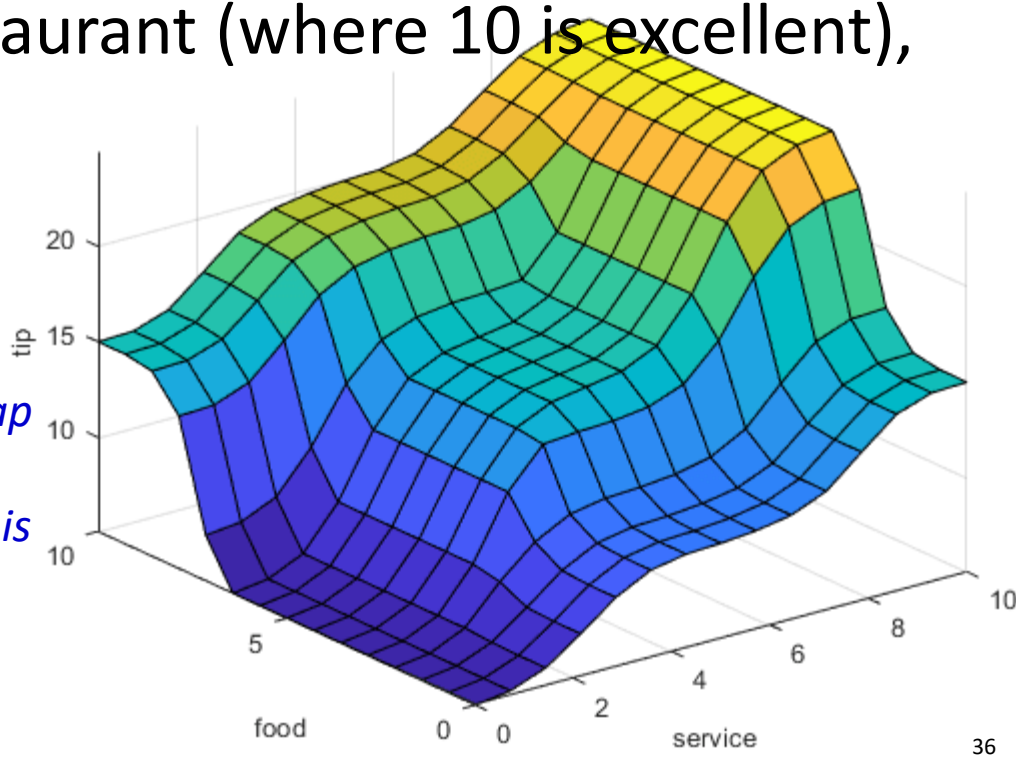


Fuzzy Systems – Basic Tipping Problem[9]

- Given a number from 0 through 10 that represents the **quality of service** at a restaurant (where 10 is excellent), what should the tip be?



- *If service is poor or food is rancid, tip is cheap*
- *If service is good, tip is average*
- *If service is excellent or food is delicious, tip is generous*

Applications

- **Aerospace**: control of spacecraft and satellites
- **Automotive**: speed control, traffic control
- **Decision-making** support systems
- **Chemical industry** for controlling the pH, drying, chemical distillation process.
- Natural **language** processing
- **Expert** systems.
- working with **Neural Networks** as it mimics how a person would make decisions much faster.
- **Data Aggregation** and changing it into more meaningful data by forming partial truths as Fuzzy sets.

A Simple Mental Health Pain Scale

thegracefulpatient.wordpress.com

MILD

1 Everything is a-okay! There is absolutely nothing wrong. You're probably cuddling a fluffy kitten right now. Enjoy!

2 You're a bit frustrated or disappointed, but you're easily distracted and cheered up with little effort.

3 Things are bothering you, but you're coping. You might be overtired or hungry. The emotional equivalent of a headache.

MODERATE

4 Today is a bad day (or a few bad days). You still have the skills to get through it, but be gentle with yourself. Use self-care strategies.

5 Your mental health is starting to impact on your everyday life. Easy things are becoming difficult. You should talk to your doctor.

6 You can't do things the way you usually do them due to your mental health. Impulsive and compulsive thoughts may be hard to cope with.

SEVERE

7 You're avoiding things that make you more distressed, but that will make it worse. You should definitely seek help.This is serious.

8 You can't hide your struggles anymore. You may have issues sleeping, eating, having fun, socialising, and work/study. Your mental health is affecting almost all parts of your life.

9 You're at a critical point. You aren't functioning anymore. You need urgent help. You may be a risk to yourself or others if left untreated.

10 The worst mental and emotional distress possible. You can no longer care for yourself. You can't imagine things getting any worse. Contact a crisis line immediately.

FAQ

- **FAQ01 Journals in the area**
- **FAQ02 MATLAB Fuzzy Logic webinars**
- **FAQ03 Fuzzy PID Control**

FAQ01 Journals in the area

- IEEE Transactions on Fuzzy Systems
- Elsevier Fuzzy Sets and Systems
- Fuzzy Information and Engineering

FAQ02 MATLAB Fuzzy Logic webinars

- **Fuzzy Logic, Part 1: What Is Fuzzy Logic?(19mins)**

https://www.mathworks.com/videos/fuzzy-logic-part-1-what-is-fuzzy-logic-1629280959444.html

- **Fuzzy Logic, Part 2: Fuzzy Inference System Walkthrough(16mins)**

https://www.mathworks.com/videos/fuzzy-logic-part-2-fuzzy-inference-system-walkthrough-1629283055057.html

FAQ03 Fuzzy PID Control

- Part 1: What Is PID Control?

https://www.youtube.com/watch?v=wkfEZmsQqiA&ab_channel=MATLAB

- Part 2: Expanding Beyond a Simple Integral

https://www.youtube.com/watch?v=NVLXCwc8HzM&ab_channel=MATLAB

- Part 3: Expanding Beyond a Simple Derivative

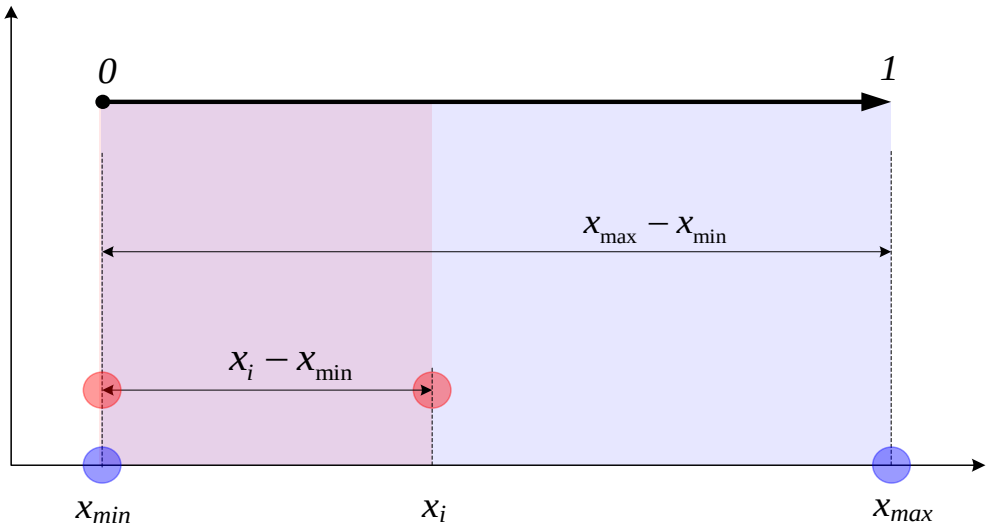
https://www.youtube.com/watch?v=7dUVdrs1e18&ab_channel=MATLAB

FAQ 04 Normalisation

- Step 1 : check data length and data location
- Step 2 : scale
- Step 3 : shift

Step 1 : check data length and data location

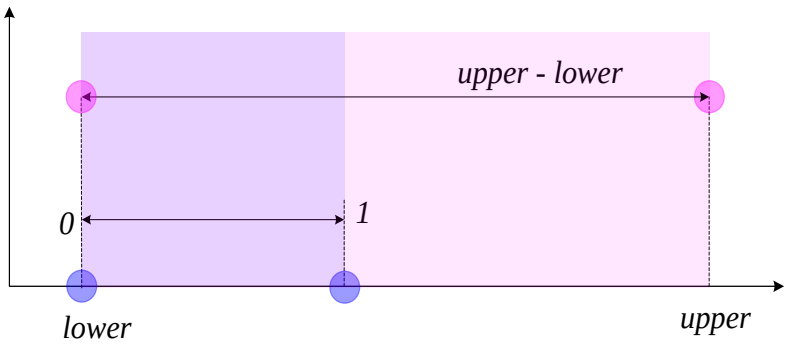
$$norm_x_i|_{[0,1]} = \frac{x_i - x_{min}}{x_{max} - x_{min}}$$



Step 2 : scale

$$norm_x_i|_{scale} = (upper - lower) \times norm_x_i|_{[0,1]}$$

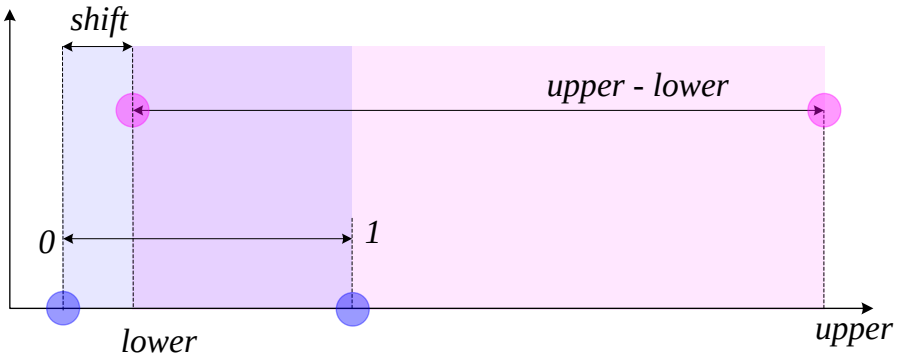
$$scale = \frac{(upper - lower)}{1 - 0} = (upper - lower)$$

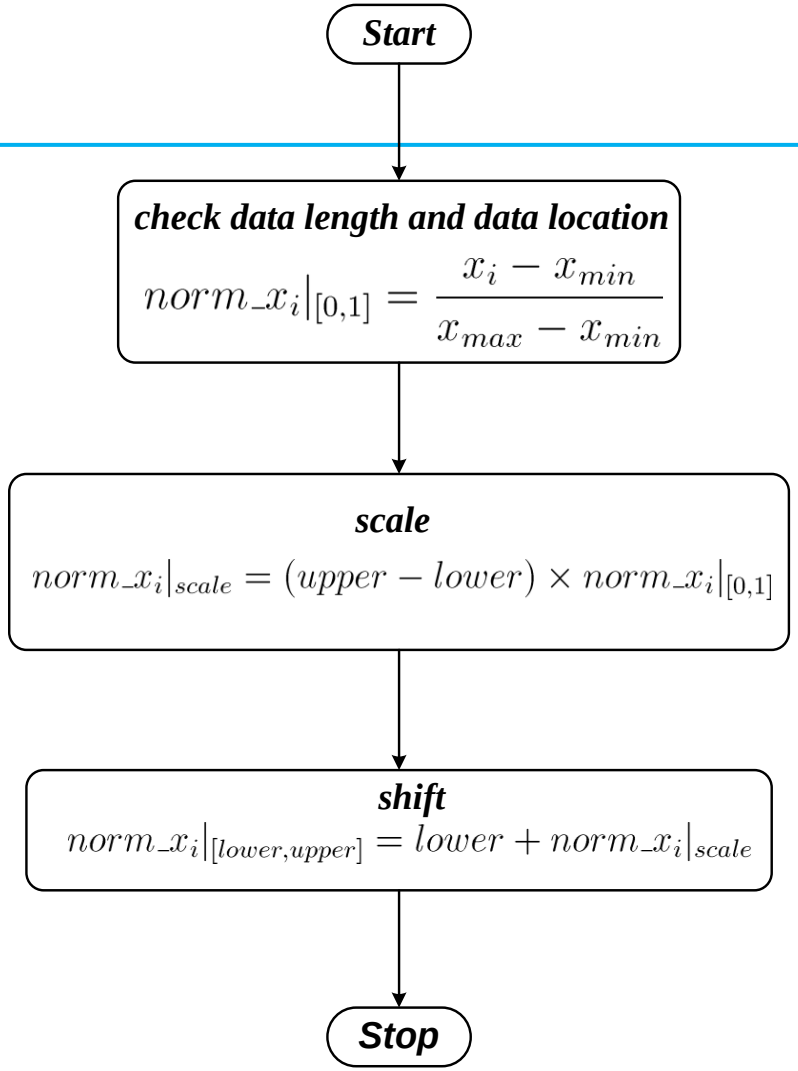


Step 3 : shift

$$norm_x_i|_{[lower,upper]} = lower + norm_x_i|_{scale}$$

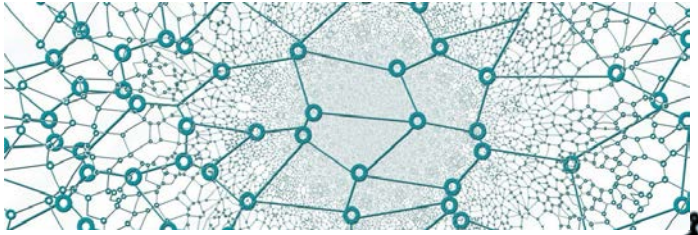
$$shift = (lower - 0) = lower$$

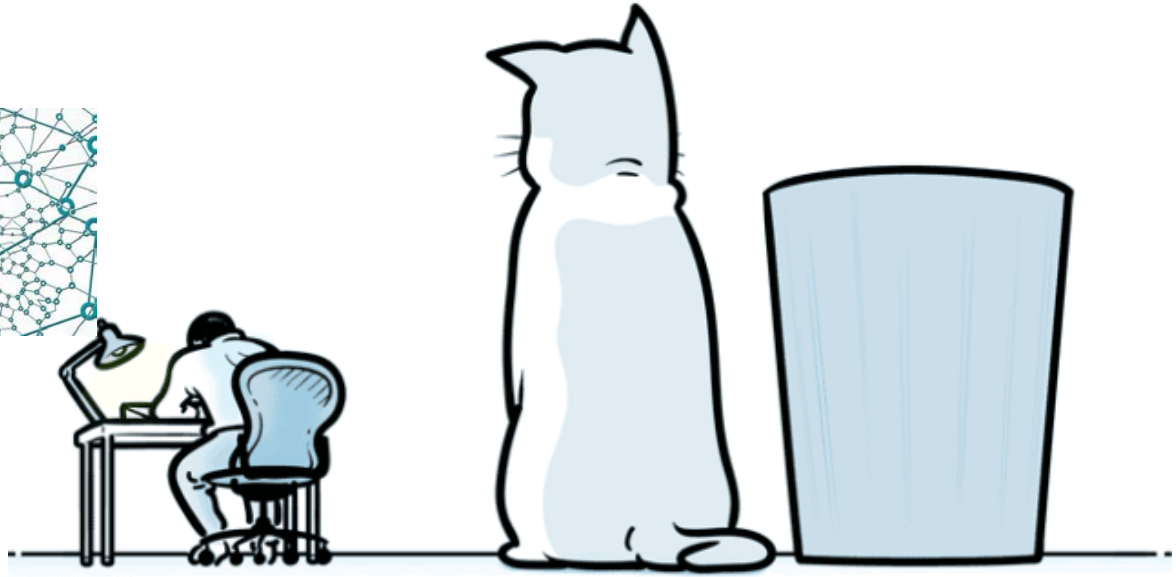



Start
check data length and data location
$norm_x_i|_{[0,1]} = \frac{x_i - x_{min}}{x_{max} - x_{min}}$
scale
$norm_x_i|_{scale} = (upper - lower) \times norm_x_i|_{[0,1]}$
shift
$norm_x_i|_{[lower,upper]} = lower + norm_x_i|_{scale}$
Stop

Thanks and Questions

https://github.com/LeoYiChen/Introduction2AI-202010





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19/Sep/2022

Thanks and Questions