ĐẠI HỌC BÁCH KHOA HÀ NỘI
VIỆN CÔNG NGHỆ THÔNG TIN VÀ TRUYỀN THÔNG

IT3160E
Introduction to Artificial Intelligence

Chapter 5 – Uncertain knowledge and reasoning

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Content of the course

- Chapter 1: Introduction
- Chapter 2: Intelligent agents
- Chapter 3: Problem Solving
  - Search algorithms, adversarial search
  - Constraint Satisfaction Problems
- Chapter 4: Knowledge and Inference
  - Knowledge representation
  - Propositional logic and first-order logic
- Chapter 5: Uncertain knowledge and reasoning
- Chapter 6: Advanced topics
  - Machine learning
  - Computer Vision

Outline

- **Chapter 5: Uncertain knowledge and reasoning**
  - Different possible frameworks for uncertain knowledge representation and reasoning
  - Overview of fuzzy logic systems
    - Fuzzy Logic Systems Architecture
    - Fuzzification module
    - Fuzzy Inference Engine
    - De-fuzzification Module
  - Conclusion

Goal of this Lecture

Goal	Description of the goal or output requirement	Output division/ Level (I/T/U)
M1	Understand basic concepts and techniques of AI	1.2

Uncertain knowledge and reasoning

Different possible frameworks for uncertain knowledge representation and reasoning

What is uncertainty?

- Not everything in our world is **certain**
- Humans constantly make decisions under uncertainty
  - *E.g.* what time shall I take the bus for the airport, given that:
    - It is 12km away
    - It usually takes 45 minutes to get there (off-peak)
    - Now, it is peak hour, and the bus might be stuck in the traffic
    - The bus might have a mechanical problem
- The objective of uncertain reasoning is to provide framework(s) enabling the machine to make the best decisions as possible under uncertainty

Different possible frameworks

- Probabilistic Decision Theory
- Fuzzy logic
- Possibility theory
- Dempster–Shafer theory
- Info-gap decision theory
- …

Different possible frameworks

- **Probabilistic Decision Theory**
    - Dates back to 1670, when Blaise Pascal introduced the idea of expected value
    - Generally relies on assumptions that we make about the distributions of the random variables
        - *E.g.* X is Gaussian…

Different possible frameworks

- **Fuzzy logic**
  - Has been studied since the 1920's
  - Based on the concept of **partial truth**
    - Can be seen as a special kind of uncertainty
  - Fuzzy logic is a form of many-valued logic in which the truth values of variables may be any real number in [0,1]
    - 0: completely false
    - 1: completely true
    - … or anywhere in-between
      - *e.g.* Wet(Grass) is True to degree 0.3

Same as Boolean logic

Different possible frameworks

- **Possibility theory**
  - Introduced in the 1970's as an extension of fuzzy logic and fuzzy sets theory
  - Possibility theory is an alternative to probability theory
    - Can be seen as an imprecise probability theory
  - Instead of just probability, it uses two measures:
    - **Possibility in [0,1]**
      - **0: completely impossible**
      - 1: completely possible
    - **Necessity in [0,1]**
      - 0: completely unnecessary
      - **1: completely necessary**

Different possible frameworks

- **Dempster–Shafer theory** (evidence theory)
  - Theory introduced by Dempster in the 1960's
    - Then expanded by Shafer in the 1970s and 1980s
  - Can be seen as a generalization of the Bayesian (probabilistic) theory
  - Uses degrees of belief (or confidence, or trust) instead of probabilities for one question
    - Computed from the probabilities for a related question
    - Degrees of belief are represented by a mathematical object called **belief function**
  - Basically, it combines evidence from different sources and arrives at a degree of belief by taking into account all the available evidence

Focus of this course

- In this course, we will focus on fuzzy logic and probabilistic decision theory
  - Because they are the most widespread (and this is an introduction course)
  - Because Fuzzy Logic is most related to the previous chapters (about logic)
    - Fuzzy Logic will be presented in this lecture
  - Probabilistic decision theory will be presented in the upcoming course about Machine Learning

Overview of fuzzy logic systems

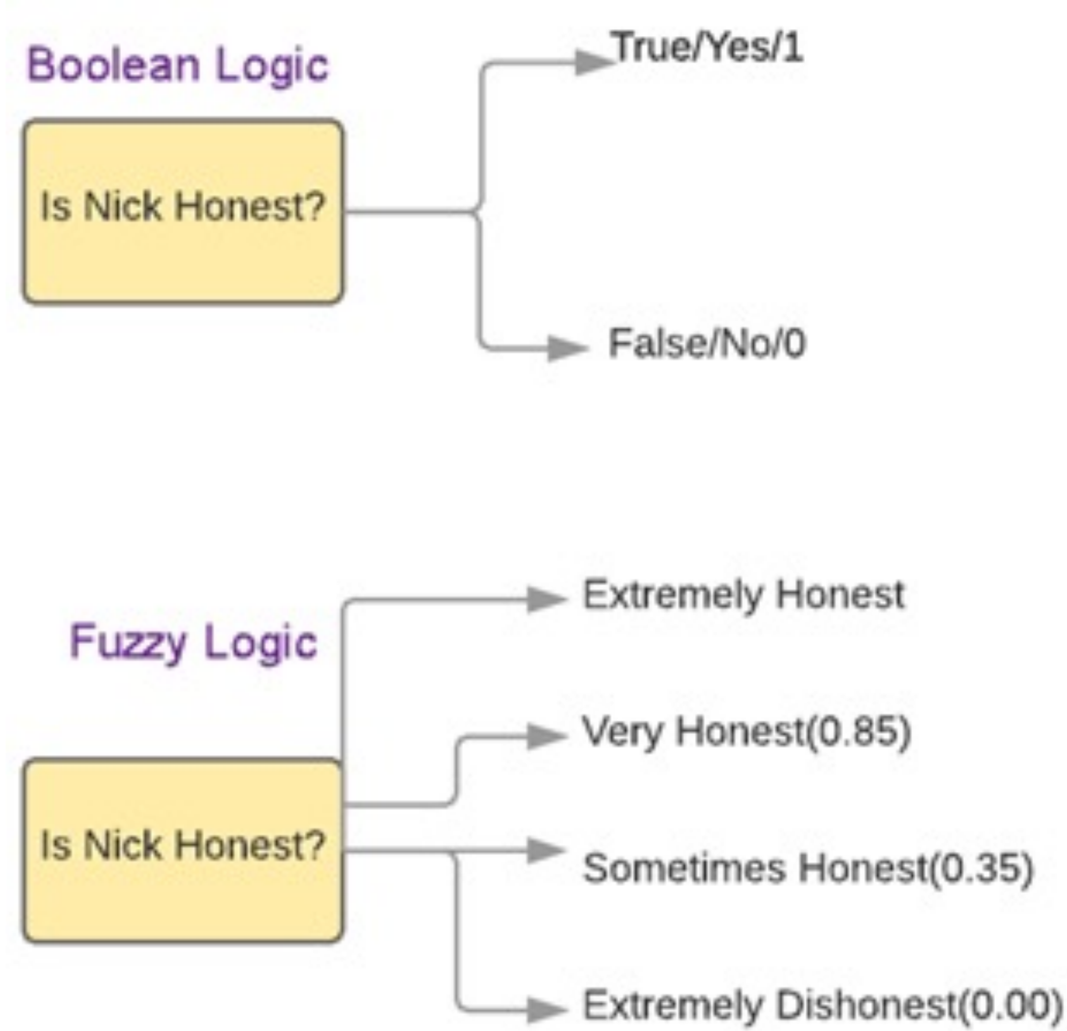
Overview of fuzzy Logic

- Fuzzy Logic (FL) is a method of reasoning that **imitates** the way of decision making in **humans**
  - Involving all intermediate possibilities between YES (True) and NO (False)
  - Examples of possible « human-like » answers

CERTAINLY YES
POSSIBLY YES
CANNOT SAY
POSSIBLY NO
CERTAINLY NO

- Fuzzy Logic Systems (FLS) reason from incomplete, ambiguous, distorted, or inaccurate (fuzzy) KBs

Fuzzy Logic *v.s.* Boolean Logic



Some commercial applications of fuzzy logic

- Nissan - anti-lock brakes
  - controls brakes in hazardous cases depending on car speed, acceleration and wheel speed
- Canon - copy machines
  - For adjusting drum voltage based on picture density, humidity, and temperature.
- Matsushita – dishwashers
  - for adjusting the cleaning cycle, rinse and wash strategies based on the number of dishes and the amount of food served on the dishes
- Fujitec, Mitsubishi Electric, Toshiba… - elevators control
  - to reduce waiting times, based on passenger traffic

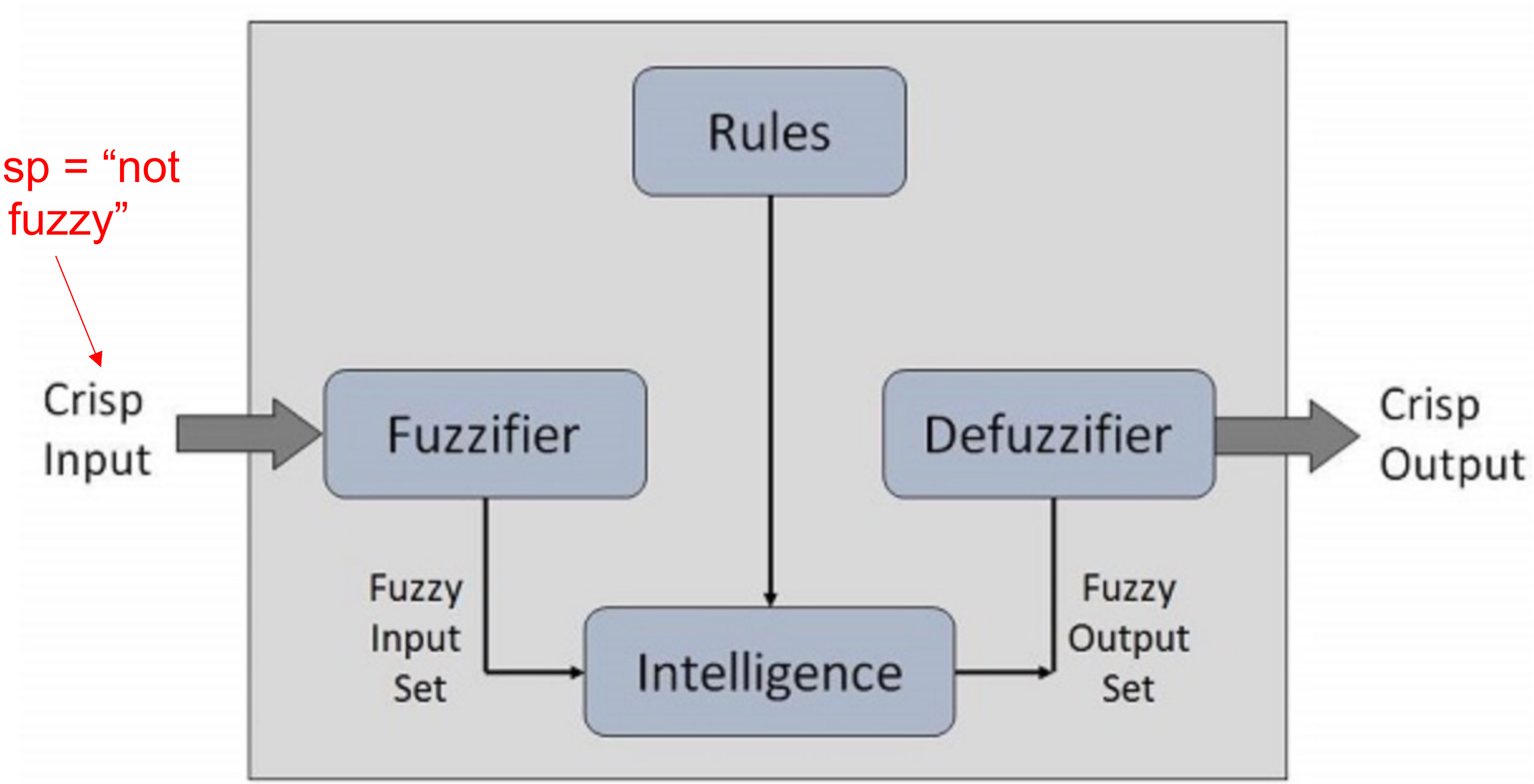
Overview of fuzzy logic systems

Fuzzy Logic Systems architecture

Fuzzy Logic Systems architecture

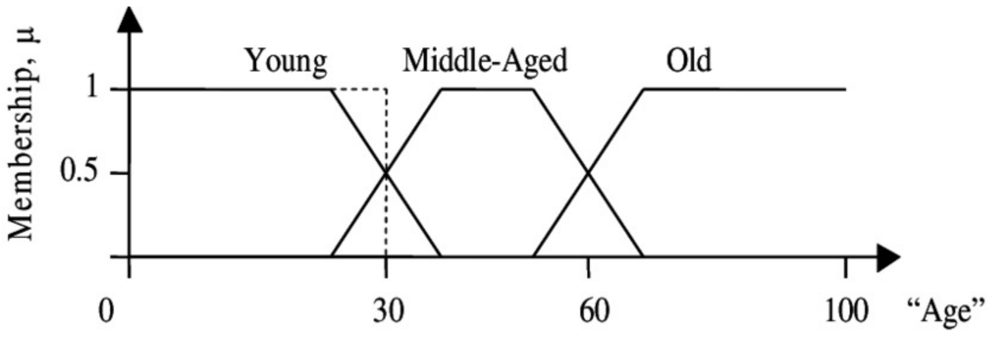
- FLS architecture is based on 4 main components

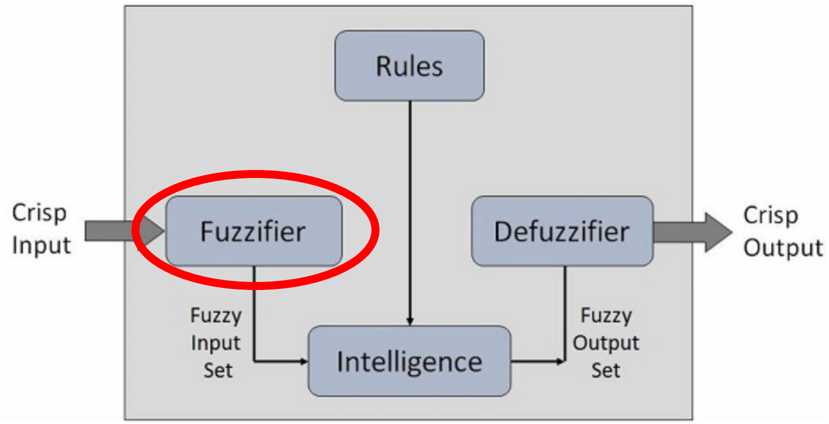
Crisp = “not fuzzy”



Fuzzy Logic Systems architecture

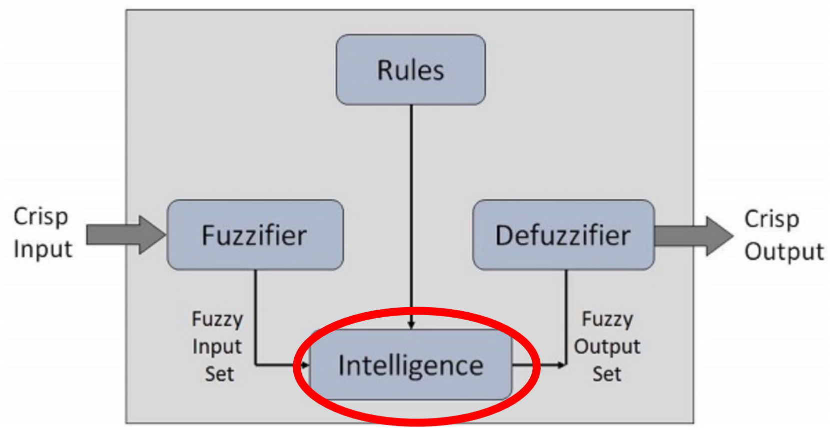
- **Knowledge Base:**
  - Stores IF-THEN (fuzzy) rules provided by experts
- **Fuzzification Module (fuzzifier)**:
  - Transforms the system inputs (crisp numbers) into fuzzy sets
  - **Fuzzy sets**: sets whose elements have degrees of membership μ





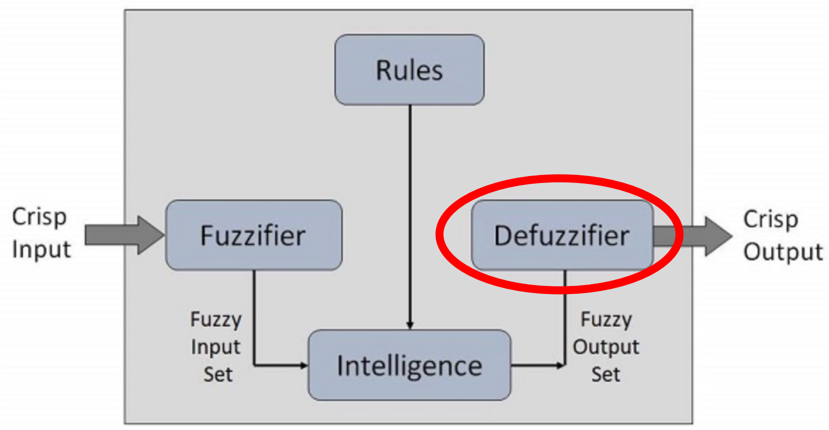
Fuzzy Logic Systems architecture

- **Fuzzy Inference Engine (intelligence)**
  - Makes fuzzy inference on the fuzzy inputs using IF-THEN rules



Fuzzy Logic Systems architecture

- **Defuzzification Module (defuzzifier)**
  - Transforms the fuzzy set obtained by the inference engine into a crisp value



Overview of fuzzy logic systems

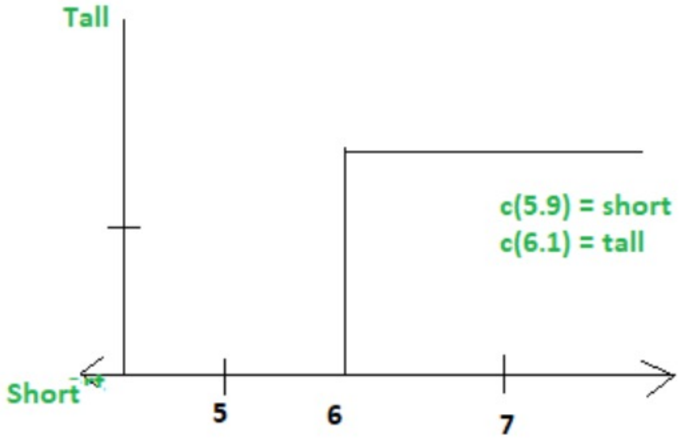
Fuzzification module

Crist sets *v.s.* fuzzy sets

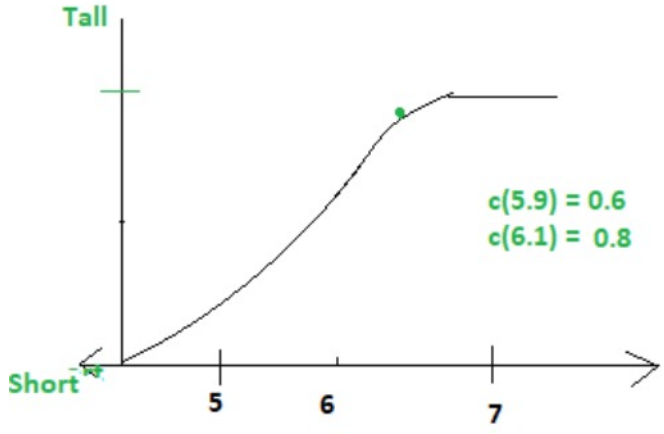
Crisp set (classical set)	Fuzzy set
Crisp set defines the value is either 0 or 1.	Fuzzy set defines the value between 0 and 1 including both 0 and 1.
It is also called a classical set.	It specifies the degree to which something is true.
It shows full membership	It shows partial membership.
Eg1. She is 18 years old. Eg2. Rahul is 1.6m tall	Eg1. She is about 18 years old. Eg2. Rahul is about 1.6m tall.
Crisp set application used for digital design.	Fuzzy set used in the fuzzy controller.
It is bi-valued function logic.	It is infinite valued function logic
Full membership means totally true/false, yes/no, 0/1.	Partial membership means true to false, yes to no, 0 to 1.

Crist sets *v.s.* fuzzy sets

- Example taken from https://www.geeksforgeeks.org/difference-between-crisp-set-and-fuzzy-set/



Crisp set (classical set)



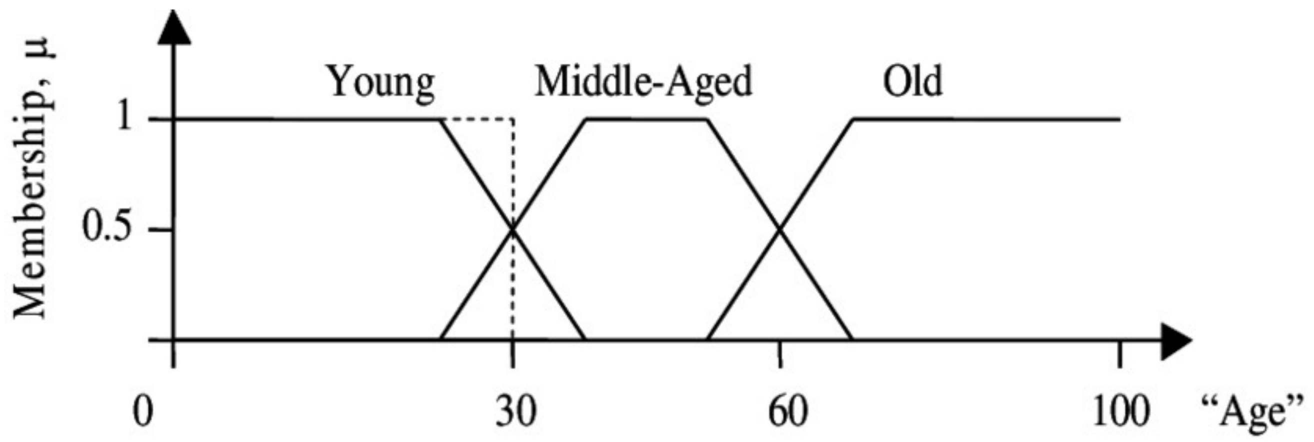
Fuzzy set

Fuzzy Linguistic Variables and Terms

- **Linguistic variables** are often used in Fuzzy Logic Systems
- They are often initially numeric, but can be described by categorical variables whose modalities are words or sentences from a natural language
  - These modalities are called **linguistic terms**
- Simple example:
  - Linguistic variable: age
  - Linguistic terms: Young, Middle-Aged, Old

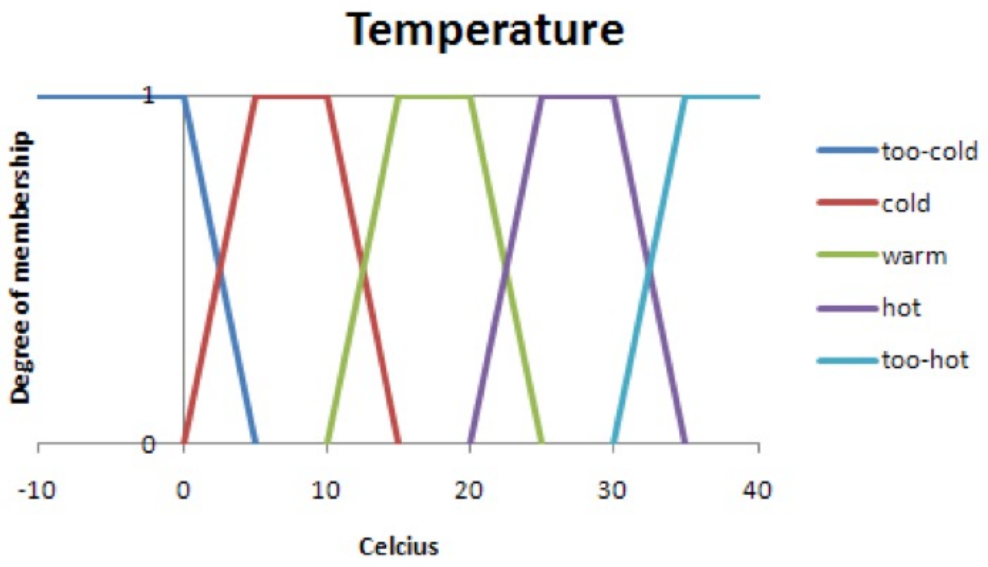
Fuzzification module

- **Fuzzification** is the process of assigning the numerical input of a linguistic variable to fuzzy sets corresponding to the linguistic terms
  - with some degree of membership
- Example, with the value of the linguistic variable « age » = 30:
  - $\mu_{YOUNG}(30)=0,5$; $\mu_{MIDDLE\text{-}AGED}(30)=0,5$; $\mu_{OLD}(30)=0$



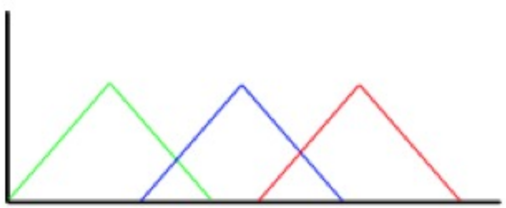
Fuzzy sets – membership functions

- A membership function μ_A for a fuzzy set A on the universe of discourse X is defined as μ_A:X → [0,1]
- Example with:
  - X=Temperature (linguistic variable)
  - $\{\mu_{TC}, \mu_C, \mu_W, \mu_H, \mu_{TH}\}$ correspond to the degrees of membership to the linguistic terms {too-cold, cold, warm, hot, too-hot}
  - -8°C is definitely too cold, but…
  - .. 2°C is both “cold” and “too-cold”, with different degrees of memberships

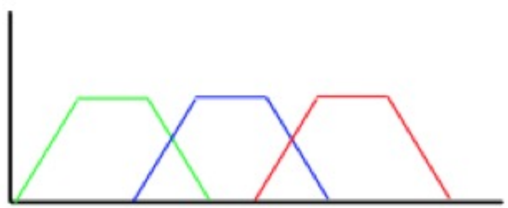


Fuzzy sets – membership functions

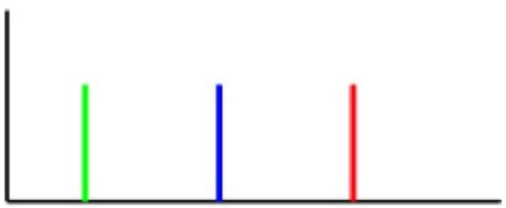
- Different types of membership function can be used, depending on the application
  - The most common types of membership functions are triangular, trapezoidal, and Gaussian shapes
    - Very used in fuzzy controller design
    - For some practical examples of these membership functions, look at https://www.youtube.com/watch?v=HILZIQKfM9s



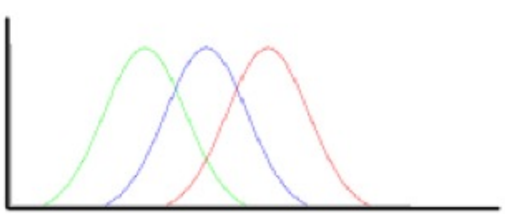
triangular



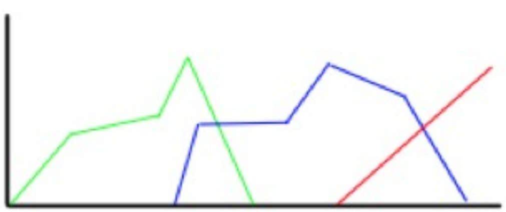
trapezoidal



singleton



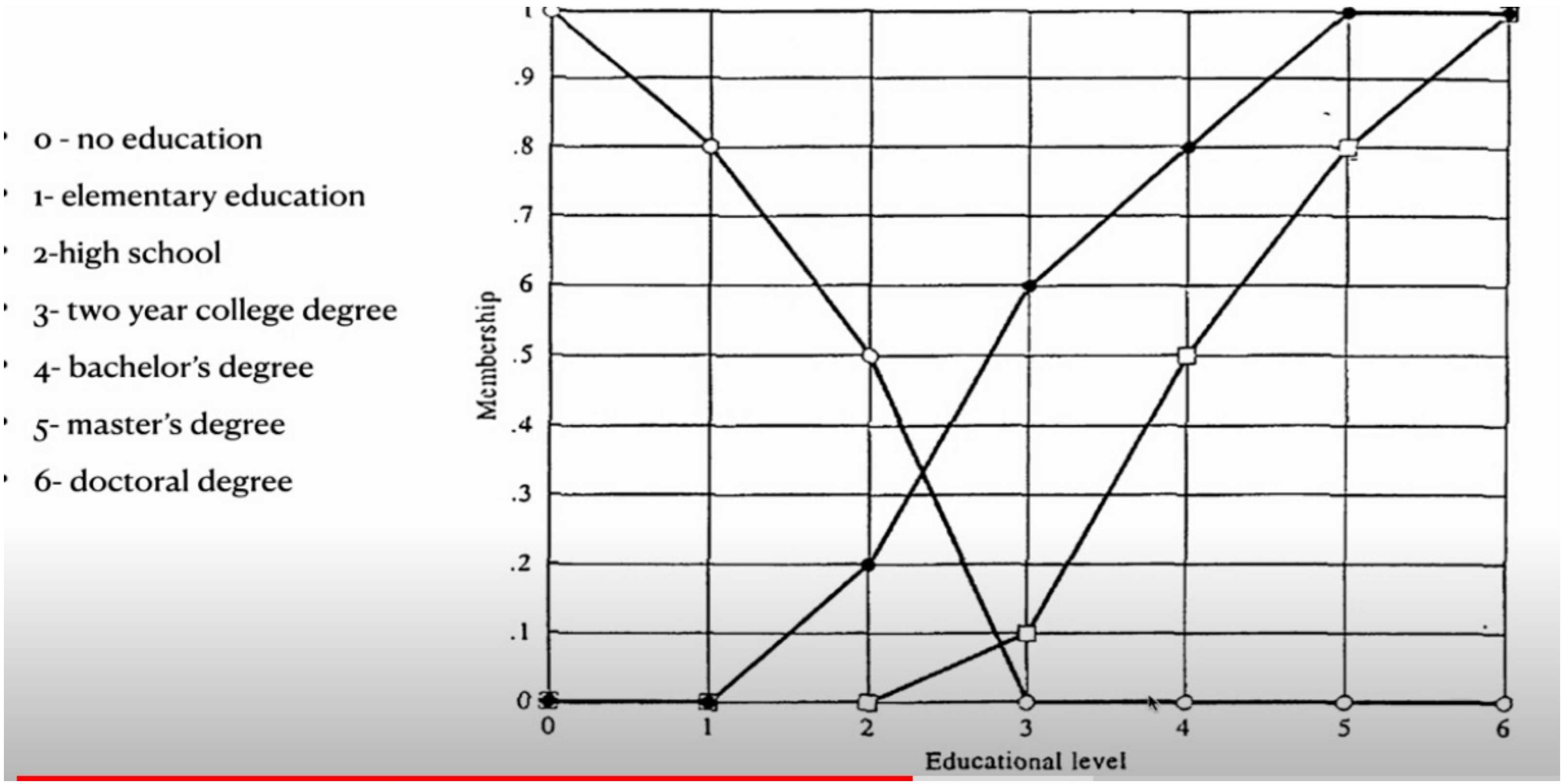
Gaussian



Piecewise linear

Fuzzy sets – membership functions

- Example of piecewise linear membership function



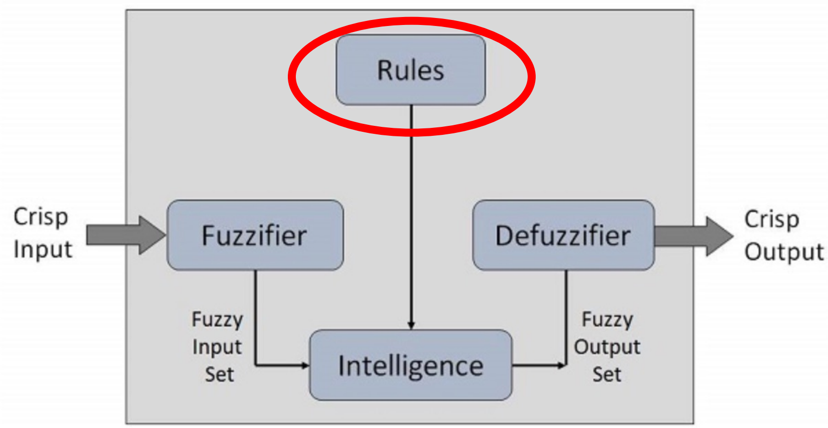
Overview of fuzzy logic systems

Fuzzy inference engine

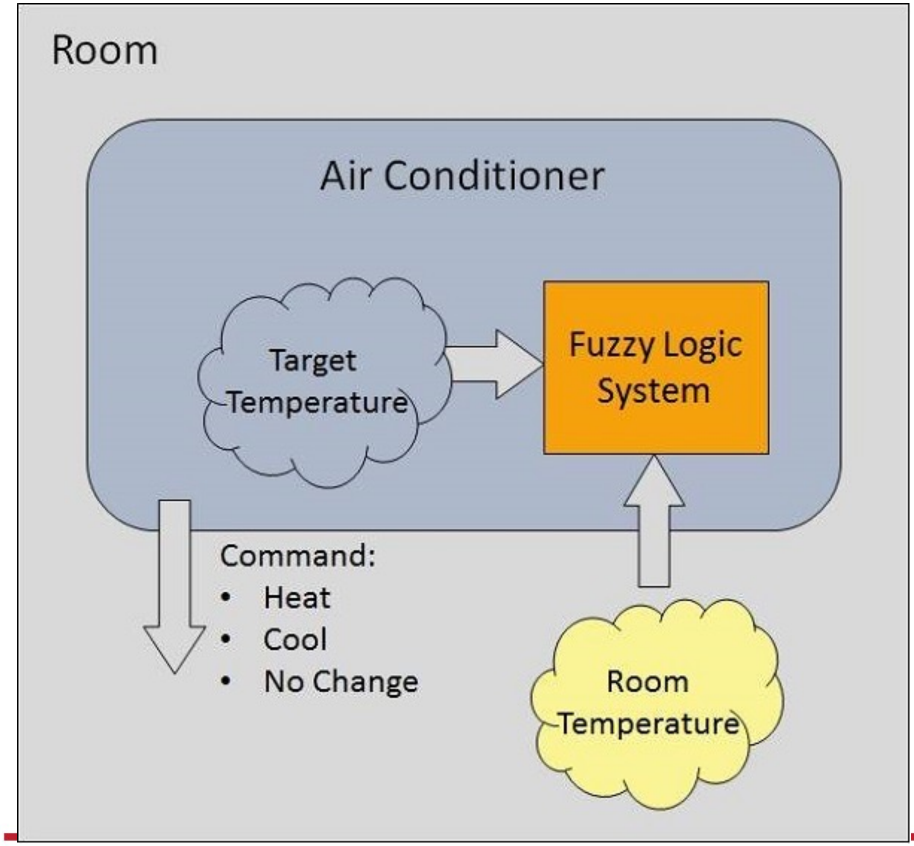
Fuzzy inference engine – fuzzy rules

❑ Fuzzy rules

- Based on IF-THEN rules, using the membership functions



Example of a heating system



Fuzzy inference engine – fuzzy rules

❑ Fuzzy rules

- Based on IF-THEN rules, using the membership functions
- Example of some fuzzy rules that can be used for a heating system

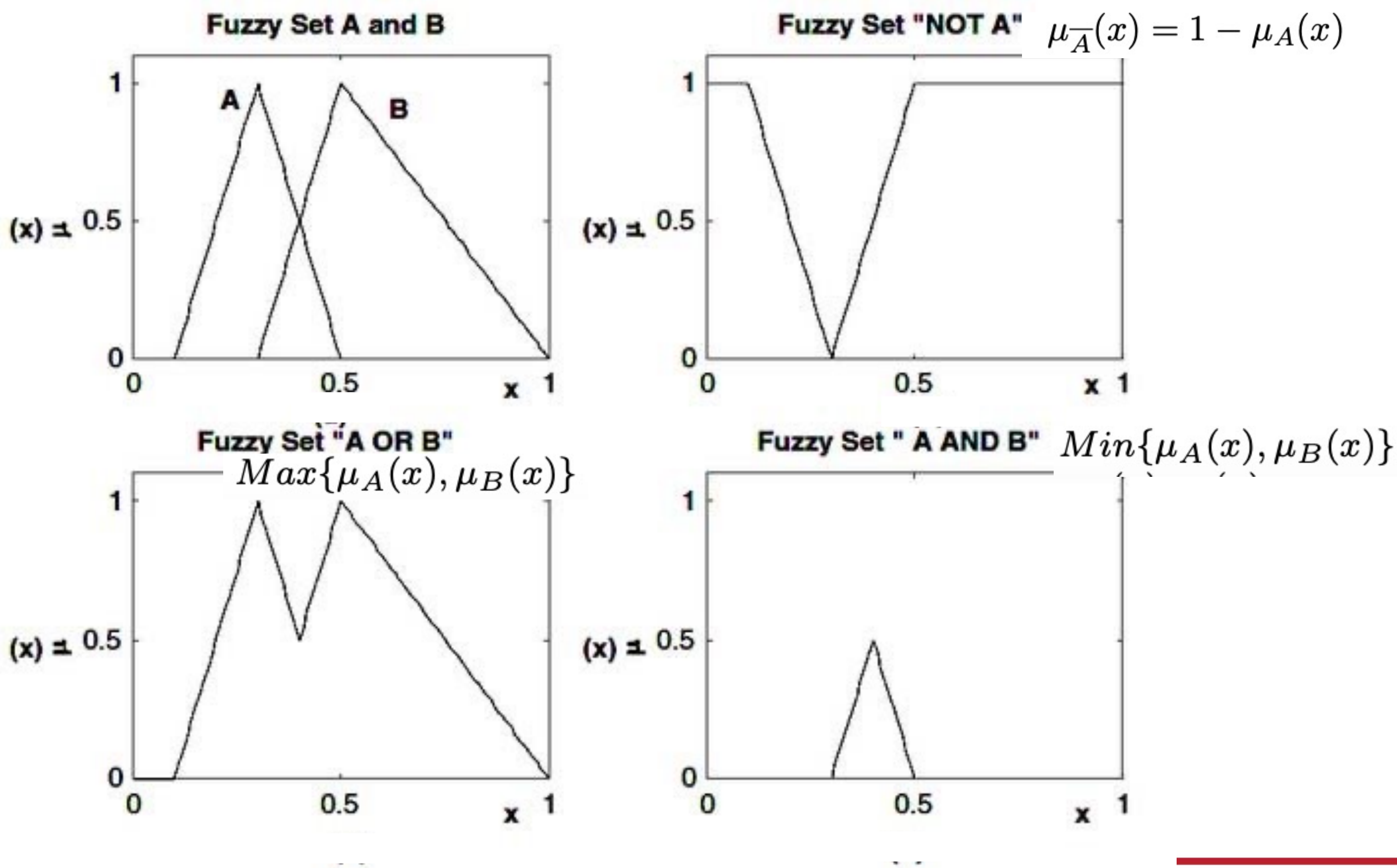
	Fuzzy Rules
1.	IF (temperature is *cold* OR *too-cold*) AND (target is *warm*) THEN command is *heat*
2.	IF (temperature is *hot* OR *too-hot*) AND (target is *warm*) THEN command is *cool*
3.	IF (temperature is *warm*) AND (target is *warm*) THEN command is *no-change*

- Fuzzy matrix of the heating system (more complete)

temperature/target	**too-cold**	**cold**	**warm**	**hot**	**too-hot**
too-cold	no-change	heat	heat	heat	heat
cold	cool	no-change	heat	heat	heat
warm	cool	cool	no-change	heat	heat
hot	cool	cool	cool	no-change	heat
too-hot	cool	cool	cool	cool	no-change

Fuzzy inference engine - operations

- **Fuzzy rules** are based on the AND, OR operators
  - Different operations can be used, but the most popular ones are



Fuzzy inference engine – fuzzy rules

- **Fuzzy rules**
  - The output of the FLS (Heat – Cool – No Change) can also depend on other parameters (beyond the room temperature)
    - *E.g.* the electricity comsumption
  - In general, in order to make a good decision, the inference engine (intelligence) needs to use multiple rules
    - All these rules might **not** give the same output
    - -> Need for **accumulation**

Fuzzy inference engine - accumulation

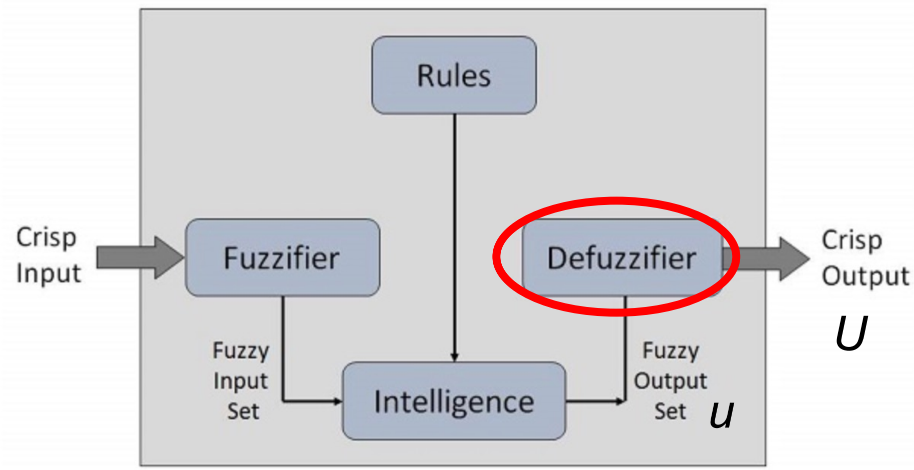
- **Fuzzy inference**:
  - After evaluating the result of each rule, these results should be combined (accumulated) to obtain a final (fuzzy) result
    - In our example, Y is then the universe of the action
      - With membership function $\{\mu_{COOL}, \mu_{HEAT}, \mu_{NO\text{-}CHANGE}\}$
  - Different **accumulation methods** can be used, but one of the most popular is the max algorithm
    - For more details, see:
      - https://books.google.com.vn/books?id=Mkm6BQAAQBAJ&pg=PA92&lpg=PA92&dq=%22accumulation+method%22+fuzzy+logic&source=bl&ots=mfhiS3lqAw&sig=ACfU3U1lwWKwHRpfJqRXtFhl-Qmwo0xwQQ&hl=en&sa=X&ved=2ahUKEwjl6OKs9_P0AhWxGKYKHRXIAmUQ6AF6BAgHEAM#v=onepage&q=%22accumulation%20method%22%20fuzzy%20logic&f=false

Overview of fuzzy logic systems

De-fuzzification module

Defuzzification module

- The output of the fuzzy inference engine is a fuzzy number
- But, we want to make a « crisp » decision
  - COOL, NO-CHANGE XOR HEAT…
  - …Or even the output temperature / speed of the fan, etc.



Defuzzification module

- Example of de-fuzzification
  - The shaded areas all belong to the fuzzy output
  - We can compute the crisp output by using different algorithms
    - One of the most popular is the Center Of Gravity
    - Gives the output *y shown in the graphic ->
    - For more explanation, see https://www.youtube.com/watch?v=N3sLFAUBt_s&list=PLUVnh0w_cCjIzH0i8B6yQcXs567mST9cQ&index=19

COG

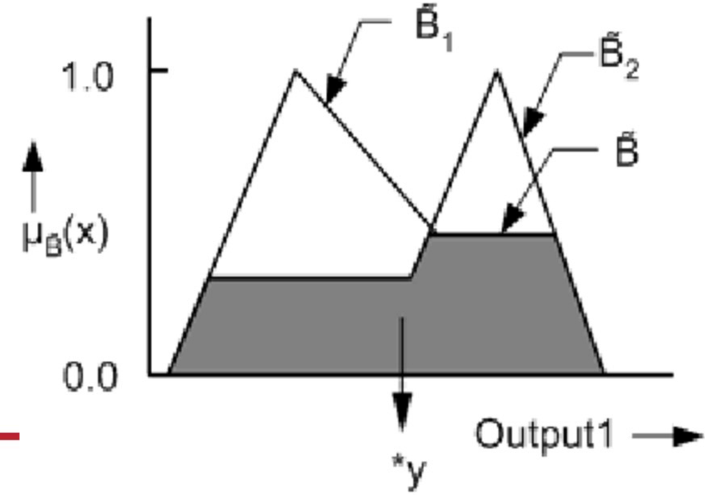
$$U = \frac{\int_{Min}^{Max} u\,\mu(u)\,du}{\int_{Min}^{Max} \mu(u)\,du}$$

COGS

$$U = \frac{\sum_{i=1}^{p} [u_i\,\mu_i]}{\sum_{i=1}^{p} [\mu_i]}$$

where:

U :	result of defuzzification
u :	output variable
p :	number of singletons
μ :	membership function after accumulation
i :	index
Min :	lower limit for defuzzification
Max :	upper limit for defuzzification



Uncertain knowledge and reasoning

Conclusion

Advantages of Fuzzy Logic Systems

- Mathematical concepts within fuzzy reasoning are very simple
  - Simple to understand
  - Simple to implement
- Very flexible: FLS can be adjusted by adding or deleting rules
- FLS can take imprecise, distorted, or noisy input information
- Fuzzy logic can provide solutions to complex problems in all fields of life
  - Because it is meant to mimic human reasoning and decision making

Disadvantages of Fuzzy Logic Systems

- There is no systematic approach to fuzzy system designing
- Some parameters might be difficult to settle
  - *E.g.* which fuzzy set shape? Which accumulation method ? Which de-fuzzification algorithm to use?
- FLS are suitable only for problems that do not need high accuracy

Tutorials using Python

- Complete and comprehensive tutorials using Python:
  - https://towardsdatascience.com/a-very-brief-introduction-to-fuzzy-logic-and-fuzzy-systems-d68d14b3a3b8
  - https://towardsdatascience.com/fuzzy-inference-system-implementation-in-python-8af88d1f0a6e

Chapter 5

Questions

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Thank you for your attention!