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In the name of God

Introduction to Fuzzy Logic, Fuzzy Systems & Fuzzy Control

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مقدمه ای بر

منطق فازی، سیستم‌های فازی و کنترل فازی

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What does "Fuzzy" mean?

According to the ***Oxford English Dictionary***, the word "fuzzy" is defined as:

"vague, indistinct; imprecisely defined; confused."

Important note:

We emphasize that, *fuzzy systems* are systems to be precisely defined, and *fuzzy control* is a special kind of nonlinear control that also will be precisely defined.

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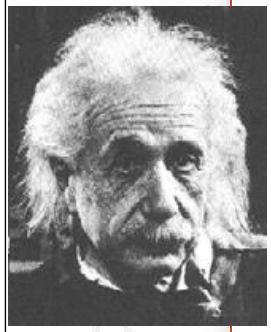
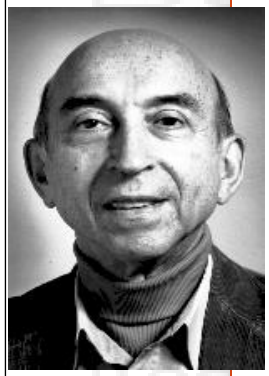
What does "Fuzzy" mean?



So far as the laws of mathematics refer to reality, they are not certain. And so far as they are certain, they do not refer to reality.

- Albert Einstein



As complexity rises, precise statements lose meaning and meaningful statements lose precision.

- Lotfi Zadeh

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What does "Fuzzy" mean?

We can generally say that:

Fuzzy systems are ***precisely defined*** systems, **which use** ***imprecise information*** (*fuzzy information*) to:

- ✓ ***Model***,
- ✓ ***Analyze***, and even
- ✓ ***Control***,

the ***real-world systems***.

What does "Fuzzy" mean?

Summary:

Fuzzy Logic is a ***certain*** and ***precise*** tool,

to deal with the ***imprecise*** ***real-world***.

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Why "Fuzzy Logic" is useful?

Two important justifications:

- The real-world is too complicated for precise descriptions to be obtained,
  - ✓ Therefore approximation (or fuzziness) must be introduced in order to obtain a reasonable, yet tractable, model.

- Human knowledge becomes increasingly important.
  - ✓ We need a theory to formulate human knowledge in a systematic manner.

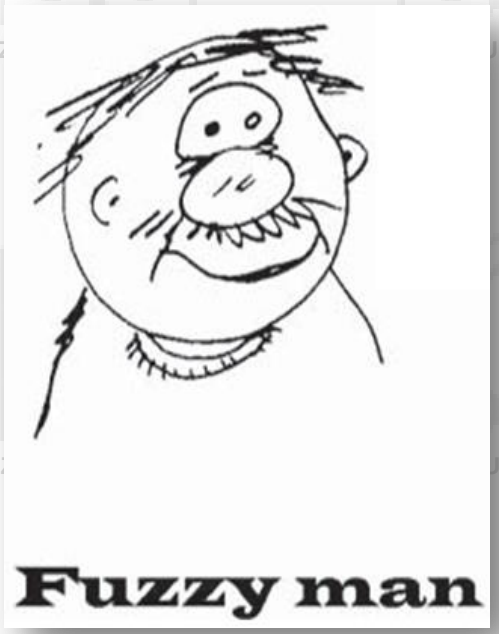
Why "Fuzzy Logic" is useful?

Other reasons:

- ***Based on human intuition and judgment***
- ***No need for a mathematical model***
- ***Relatively simple, fast and adaptive***
- ***Less sensitive to system fluctuations***
- *and, many others…*

Classical Logic vs. Fuzzy Logic

VS.



Some Motivating Examples

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Classical Logic vs. Fuzzy Logic:

Let us observe a (crisp) reference set (our universe)

$$X = \{1, 2, 3, 4, 5, 6, 7, 8, 9, 10\}.$$

Let us form:
The (crisp) subset C of X, $C = \{x \mid 3 < x < 8\}$

$$C = \{4, 5, 6, 7\}$$

(Easy! "Yes, or no" ...)

The set F of **big** numbers in X

$$F = \{10, 9, 8, 7, 6, 5, 4, 3, 2, 1\}$$

(Yes or no? ... More like graded ...)

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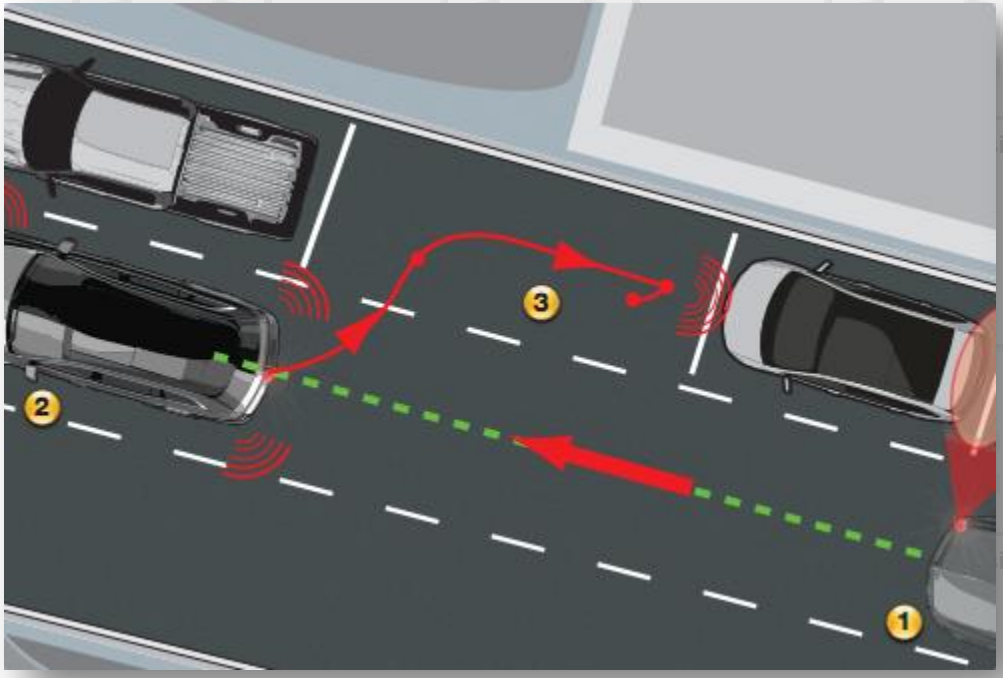
Why we need Fuzzy? (Another Example!)

Question?

How are you going to park a car?

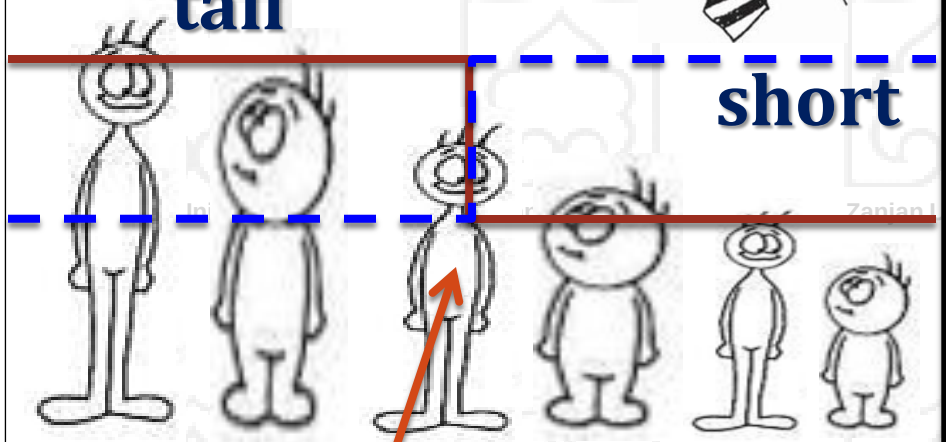


Why we need Fuzzy? (Another Example!)

Why we need Fuzzy? (Extra Example!)

Who is tall? Who is short?

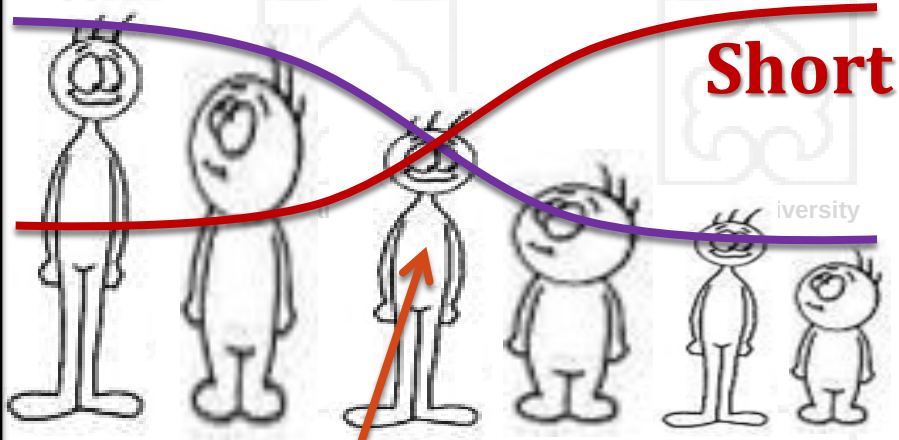
Crisp



Is he really tall?

Is he really short?

Fuzzy



He is 50% tall
and
He is 50% short.

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Why we need Fuzzy? (Another Example!)

Who is fast? Who is slow?

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Crisp

Fuzzy

Classical Logic vs. Fuzzy Logic

Precision vs. Significance

Motivating Example

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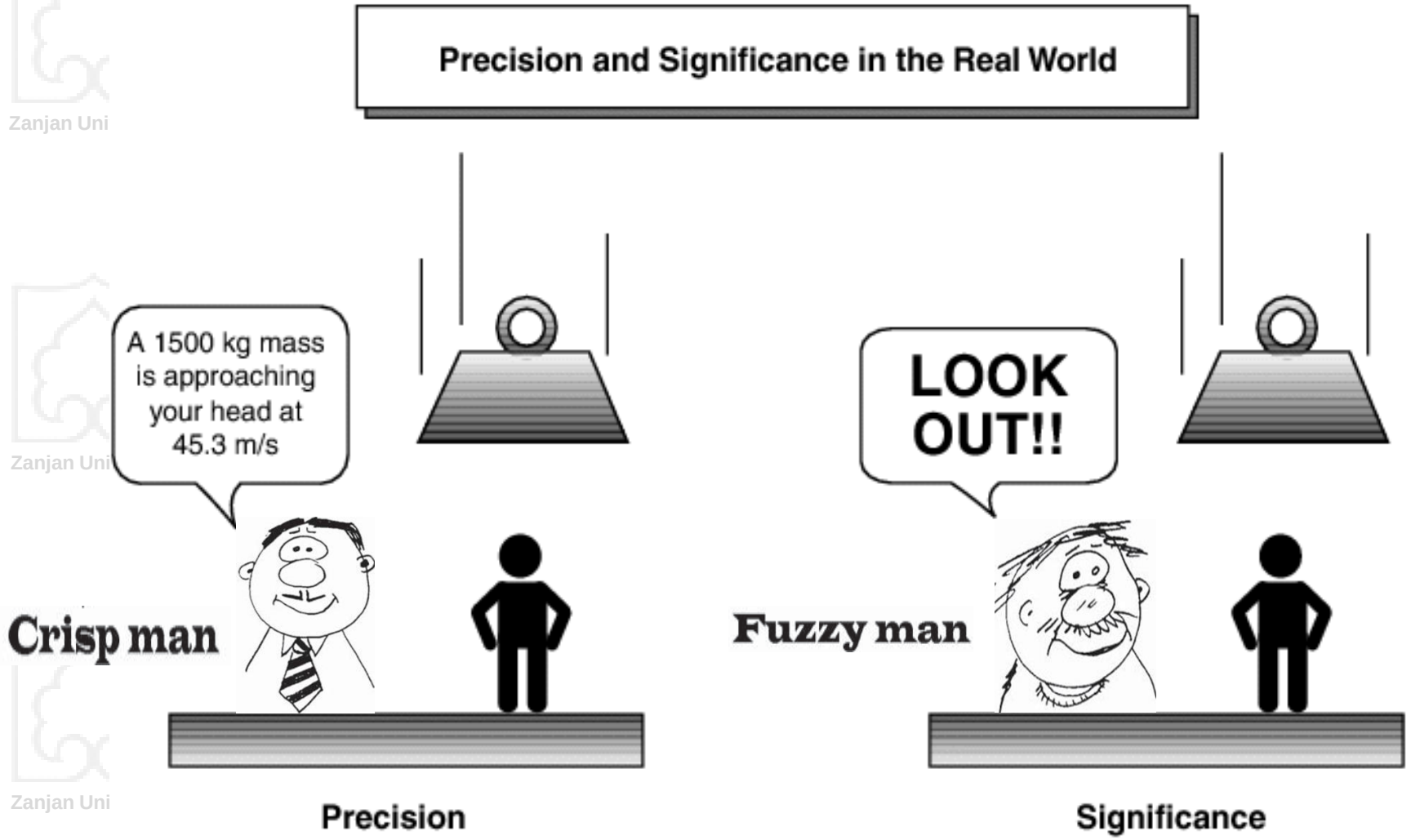
Why we need Fuzzy? (Extra Example!)



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History of Fuzzy Logic

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History of Fuzzy Logic

Lotff A. Zadeh

The Father of Fuzzy

Lotfali Askar Zadeh (born February 4, 1921), better known as **Lotfi A. Zadeh**, is an **Iranian *mathematician*, *electrical engineer, computer scientist, artificial intelligence researcher*** and professor emeritus of computer science at the University of California, Berkeley.

Lotfi A. Zadeh in 2004

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BRIEF HISTORY OF FUZZY TECHNOLOGY

1965 Concept of fuzzy sets theory by Lotfi Zadeh (USA)

1972 ***First working group*** on fuzzy systems in **Japan** by Toshiro Terano

1974 ***Steam engine control*** by ***Ebrahim Mamdani*** (UK)

1980 ***Cement kiln control*** by F. – L. Smidth (Denmark)

(the first permanent industrial application)

1984 ***Subway Sendai Transportation system control (Japan)***

1985 ***First fuzzy chip*** developed by Masaki and Watanabe in Bell Labs (USA)

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BRIEF HISTORY OF FUZZY TECHNOLOGY

1990-2000, ..., 2013, ...

Fuzzy TV set by Sony (Japan)

Intelligent Systems Control Lab in Siemens (Germany)

Educational kit by Motorola (USA)

Too many events, inventions and projects to mention!

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Just a small number of successful projects demonstrating a huge diversity of possible applications.

- Automatic ***control of dam gates*** for hydroelectric power plants (Tokyo Electric Power.)
- *Simplified* ***control of robots (Toshiba, Omron)***
- Efficient and stable control of ***car engines*** (Nissan)
- ***Cruise-control for automobiles (Nissan, Subaru)***
- Substitution of an ***expert for*** the assessment of ***stock exchange*** activities (Yamaichi, Hitachi)

… continued.

- Prediction system for early recognition of ***earthquakes*** (Seismology Bureau of Metrology, Japan)
- ***Medicine technology: cancer diagnosis (Kawasaki Medical School)***
- Recognition of motives in pictures with **video cameras** (Canon, Minolta)

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Panasonic®/National® Fuzzy Logic
National® Deluxe Electric Fuzzy Logic
I see the largest number of applications, included in the tables, are control applications. And most of the inventions are from Japan.
Rice cooker
Fuzzy logic controls the cooking process, self adjusting for rice and water conditions

National® Deluxe Electric Fuzzy Logic
Thermo pot
This unit represents the best technology available in producing clean boiled water on demand for making tea. It is fuzzy logic computer controlled

Fuzzy control applications

Consumer products:

- washing machines
- microwave ovens
- rice cookers
- vacuum cleaners
- TVs and VCRs
- thermal rugs
- word translators

Systems:

- elevators
- train
- cranes
- automotive (engines, transmissions, brakes)
- traffic control

Software:

- medical diagnosis
- Image processing
- data compression

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مقدمه: سیستمهای فازی و کنترل فازی

Lotfi A. Zadeh in 2004

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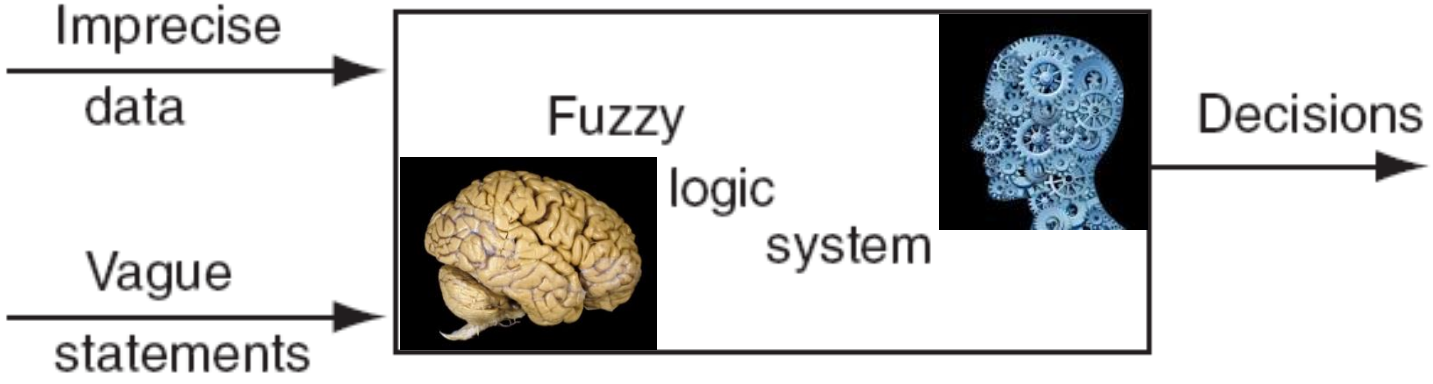
What Are Fuzzy Systems?



Fuzzy system accepts imprecise data and vague statements (such as low, medium, high, …) and provides decisions.

Generally speaking, the FUZZY SYSTEMS mimic the *human' actions* and operations.

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What Are Fuzzy Systems? (IF-THEN rules)

Which strategy do the women use?

How about the washing-machine?

Fuzzy washing-machine tries to mimic the women' strategy.

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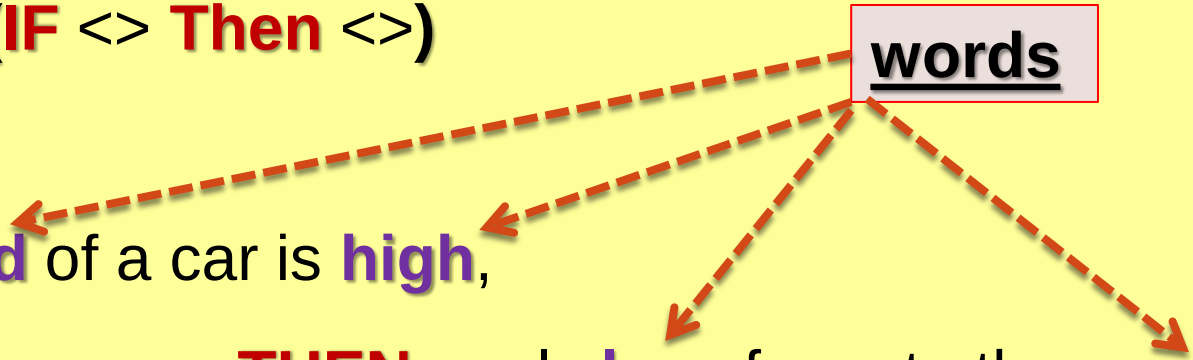
What Are Fuzzy Systems?

Fuzzy systems are **knowledge-based** or **rule-based** systems.

The ***heart of a fuzzy system*** is a:

knowledge based fuzzy IF-THEN rules.

Example: (IF <> Then <>)



We call these words as Linguistic Variables.

- Linguistic Variable

Medical Diagnosis

The best and most useful descriptions of diseases entities often use **linguistic terms** that are irreducibly vague.

Example: **Hepatitis**

"Total proteins are **usually normal**, *albumin is* **decreased**, *alpha-globulin are* **slightly decreased**, *beta-globulins are* **slightly decreased**, *and gamma-globulins are* **increased**."

The linguistic terms printed in **blue** color are inherently vague.

Mimics Doctors' decision making.

Examples of fuzzy measures (Linguistic Variables) include:

close, ***heavy***, *light*, *big*, *small*, *smart*, *fast*, *slow*, *hot*, *cold*, *Tall*, ***Short***, *young*, *old*, ...,

- **Examples:**

  John is ***tall***

  Dan is ***young***

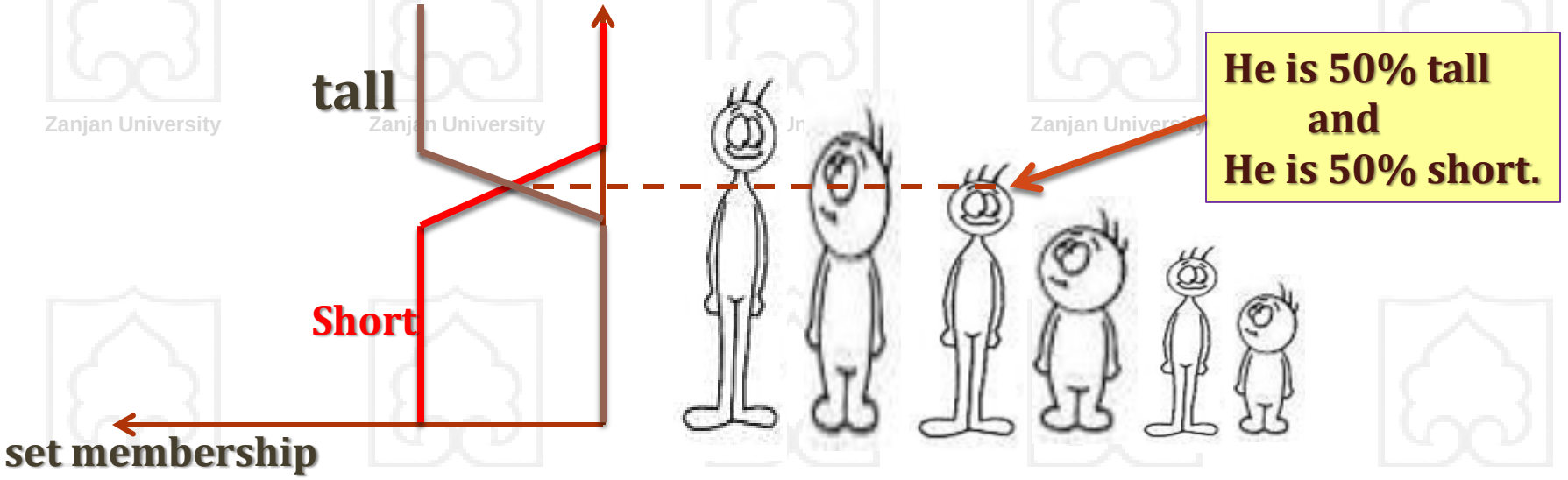
  Alex is ***happy***

  The class is ***hot***

  Tiger is ***fast***

Computing with Words

Prof. Zadeh proposed the ***set membership*** idea to make suitable decisions when uncertainty occurs.



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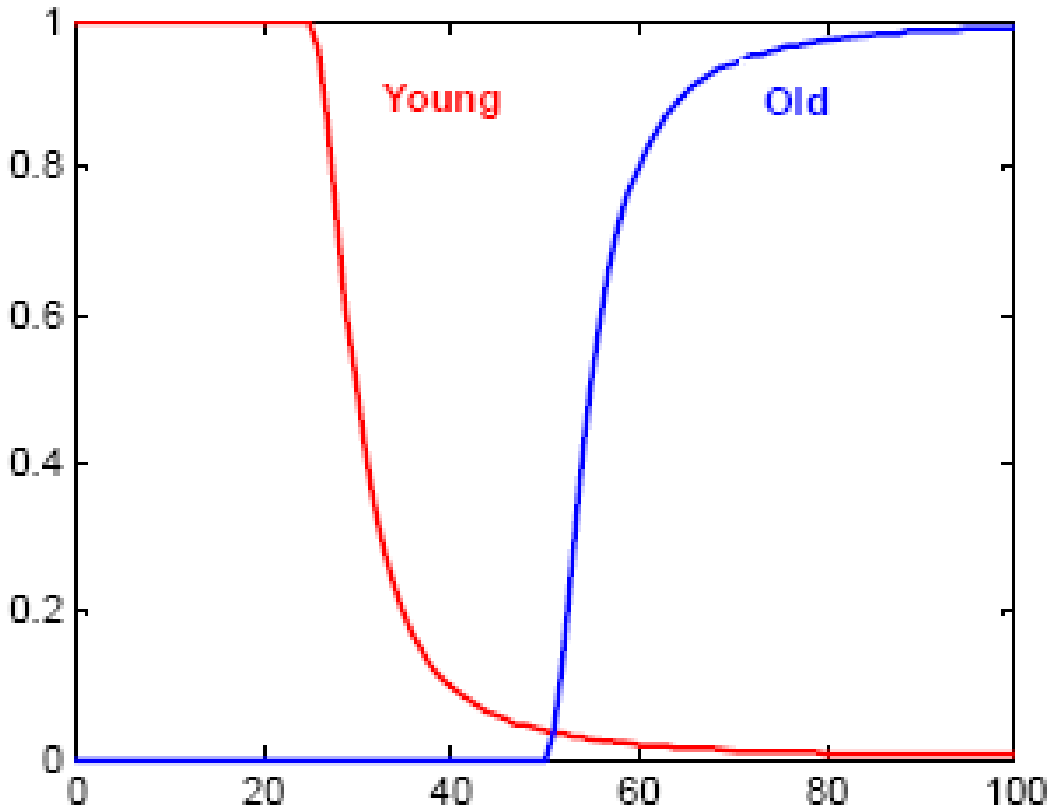
How to define Membership Functions?

Example 1: *Let the age of a person is considered.*

*The **age** can be: "Young" or "Old"*



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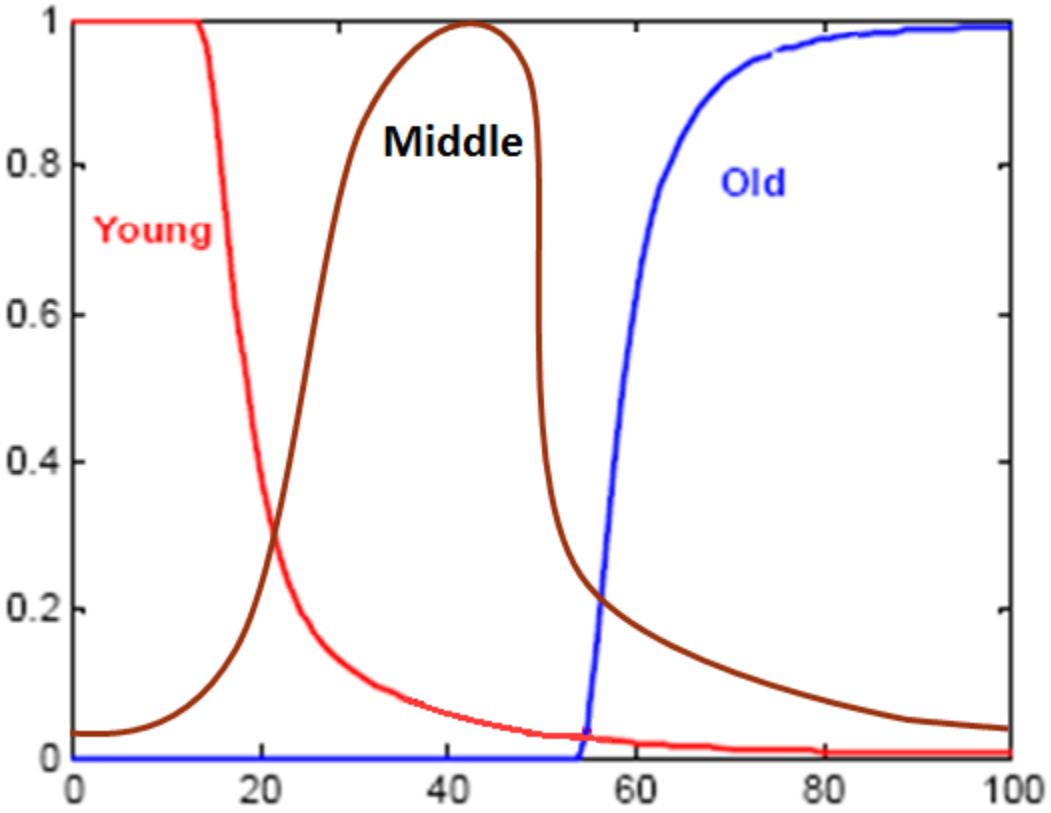
How to define Membership Functions?

Example 1: *Let the age of a person is considered.*

*The **age** can be: "Young" or "middle" or "Old"*



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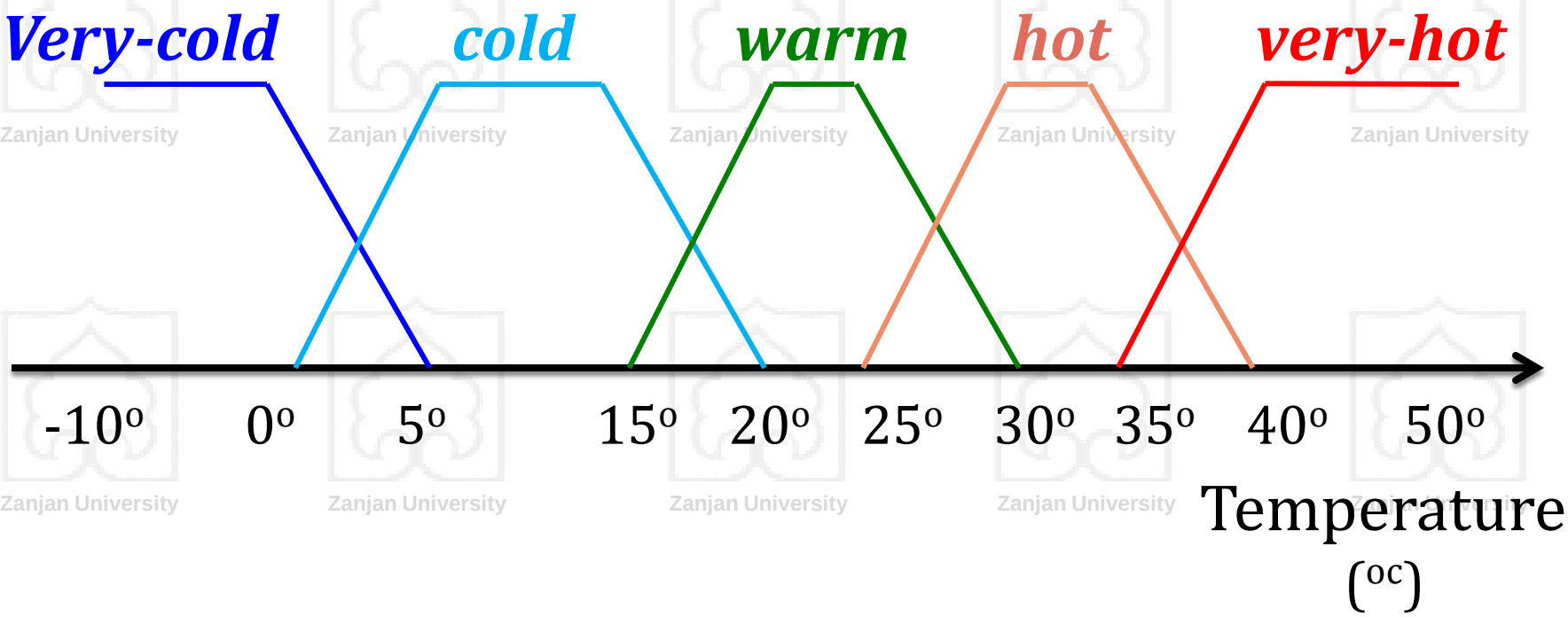
How to define Membership Functions?

Example 2: *Assume the* ***weather temperature****.*

*It can be: "**very-cold**", "**cold**", "**warm**", "**hot**", "**very-hot**"*



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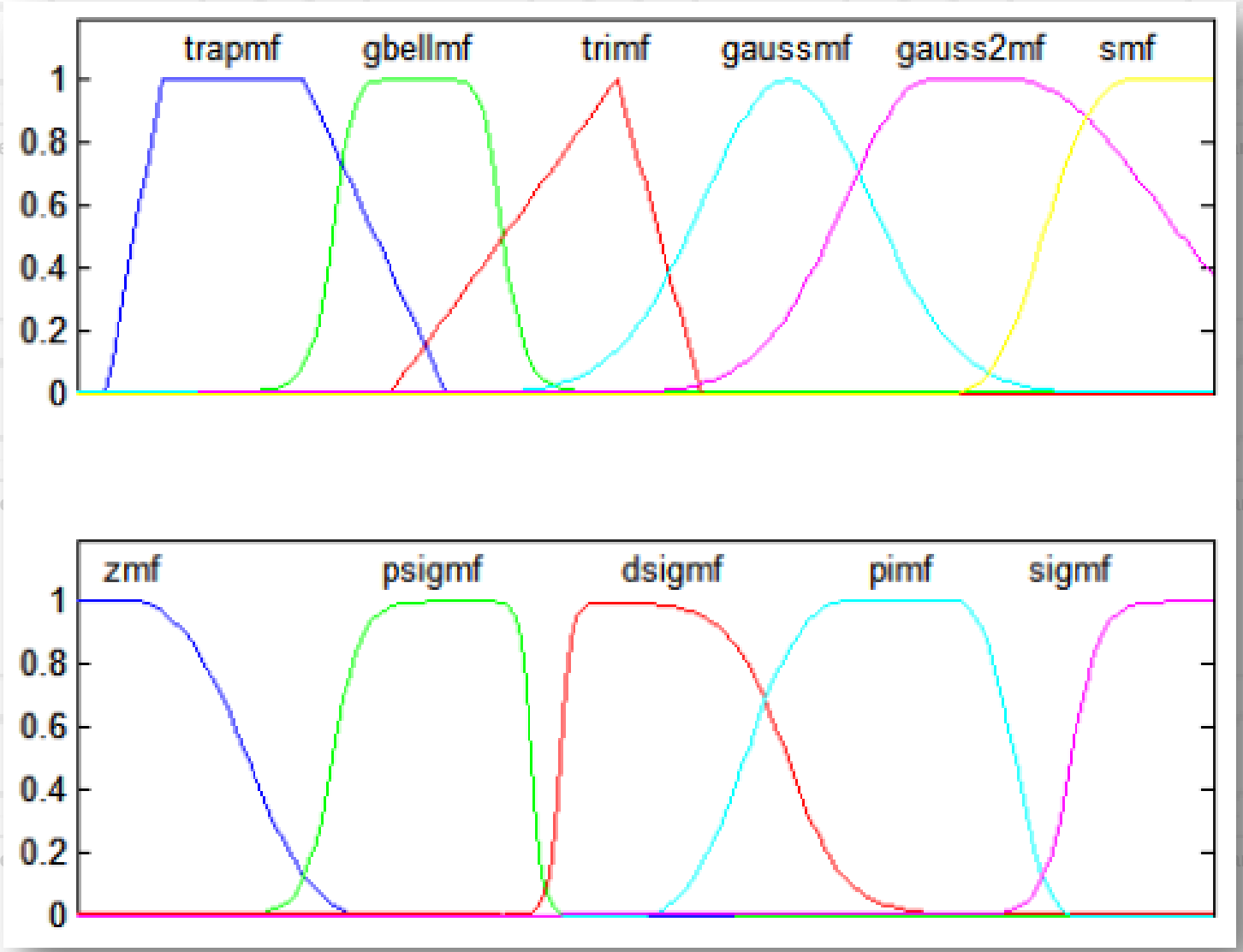
All Fuzzy Membership functions @ MATLAB



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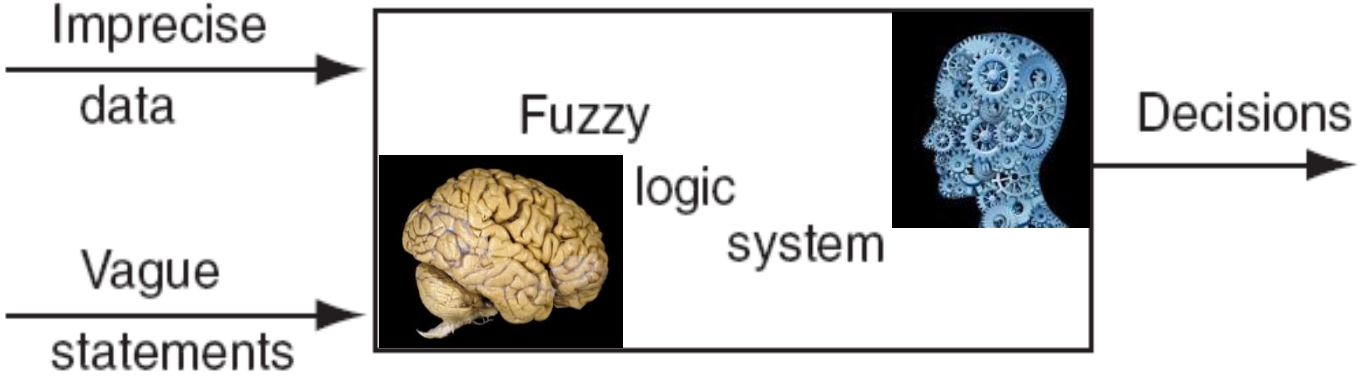
سیستم‌های فازی:

- سیستم فازی محض **(Pure Fuzzy Systems)**
- سیستم فازی (سیستم فازی دارای فازی‌ساز و نافازی‌ساز)

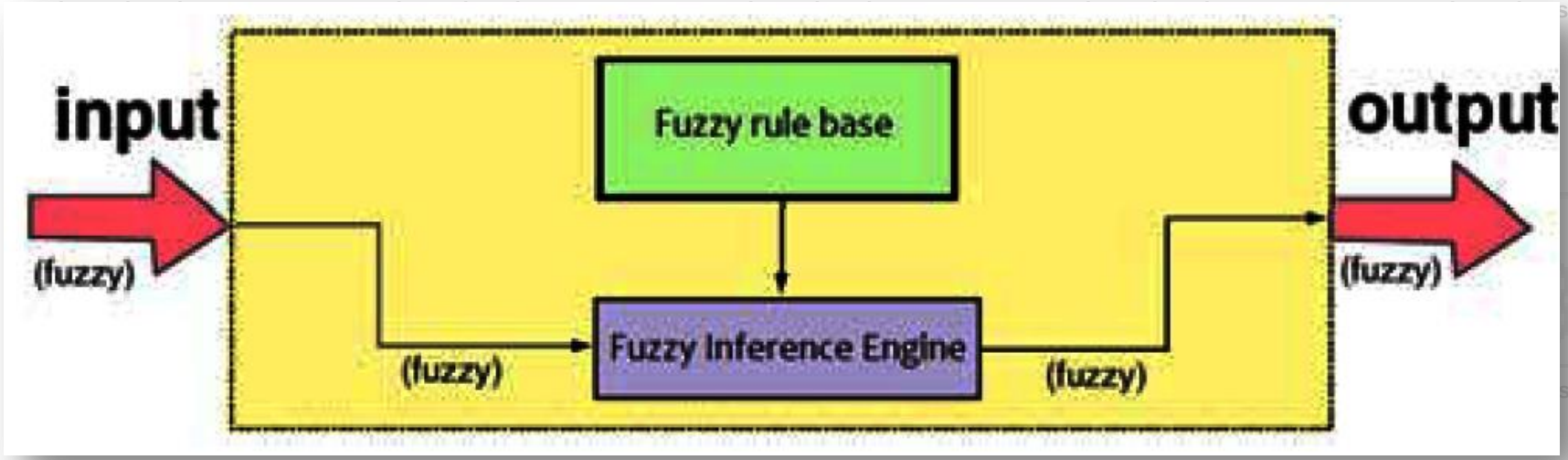
(Fuzzy Systems with Fuzzifier & Defuzzifier)

- سیستم فازی TSK

(Takagi-Sugeno-Kang (TSK) Fuzzy Systems)



ساختار سیستمهای فازی محض:



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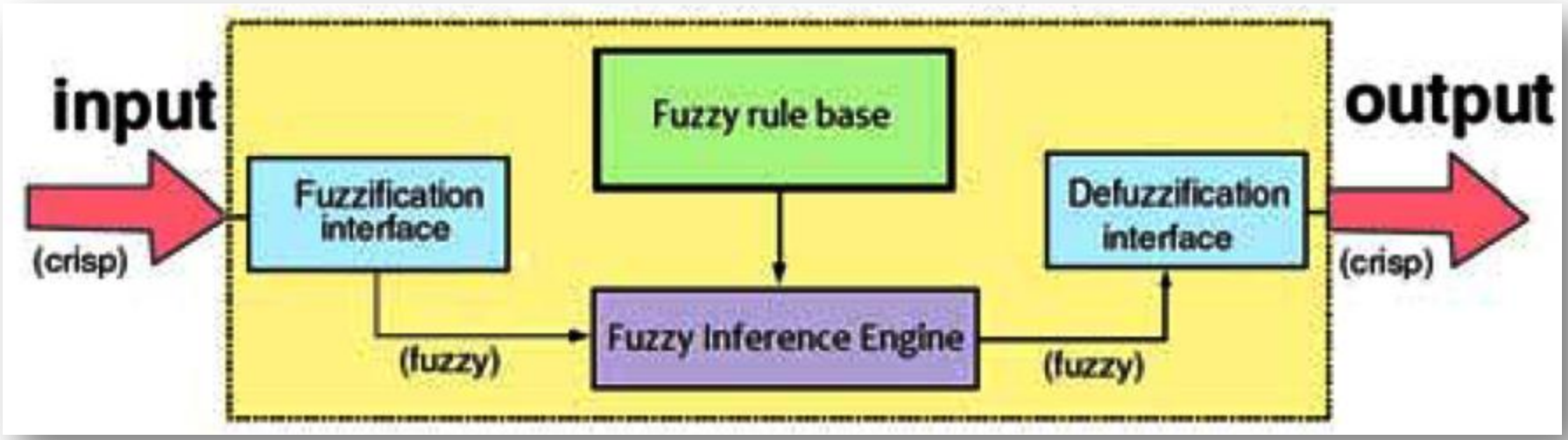
ساختار سیستمهای فازی دارای فازی ساز و غیر فازی ساز:



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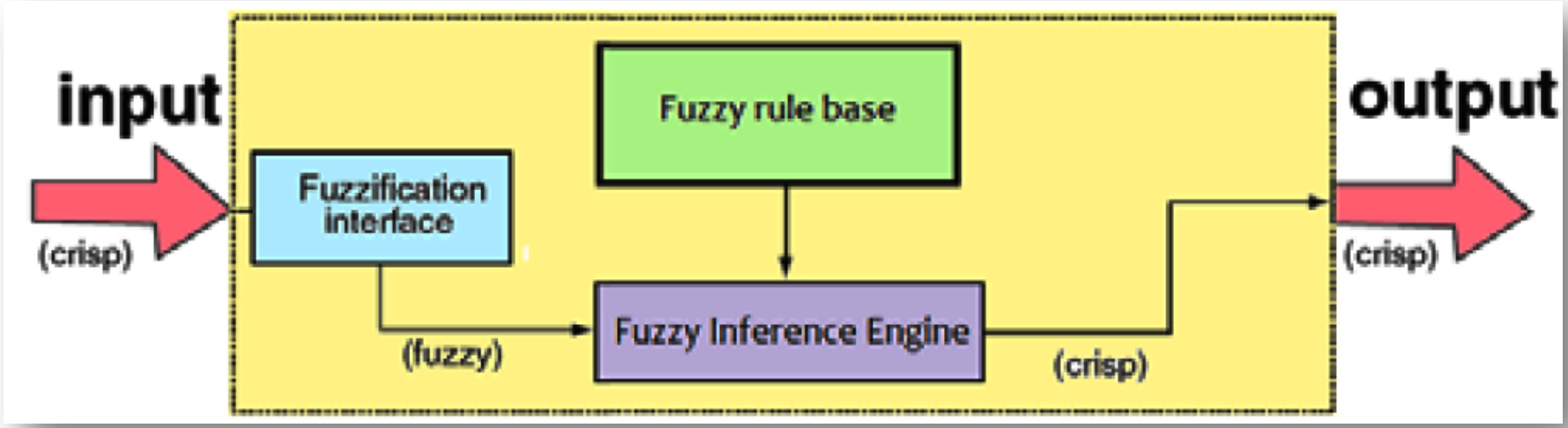
ساختار سیستمهای فازی TSK:



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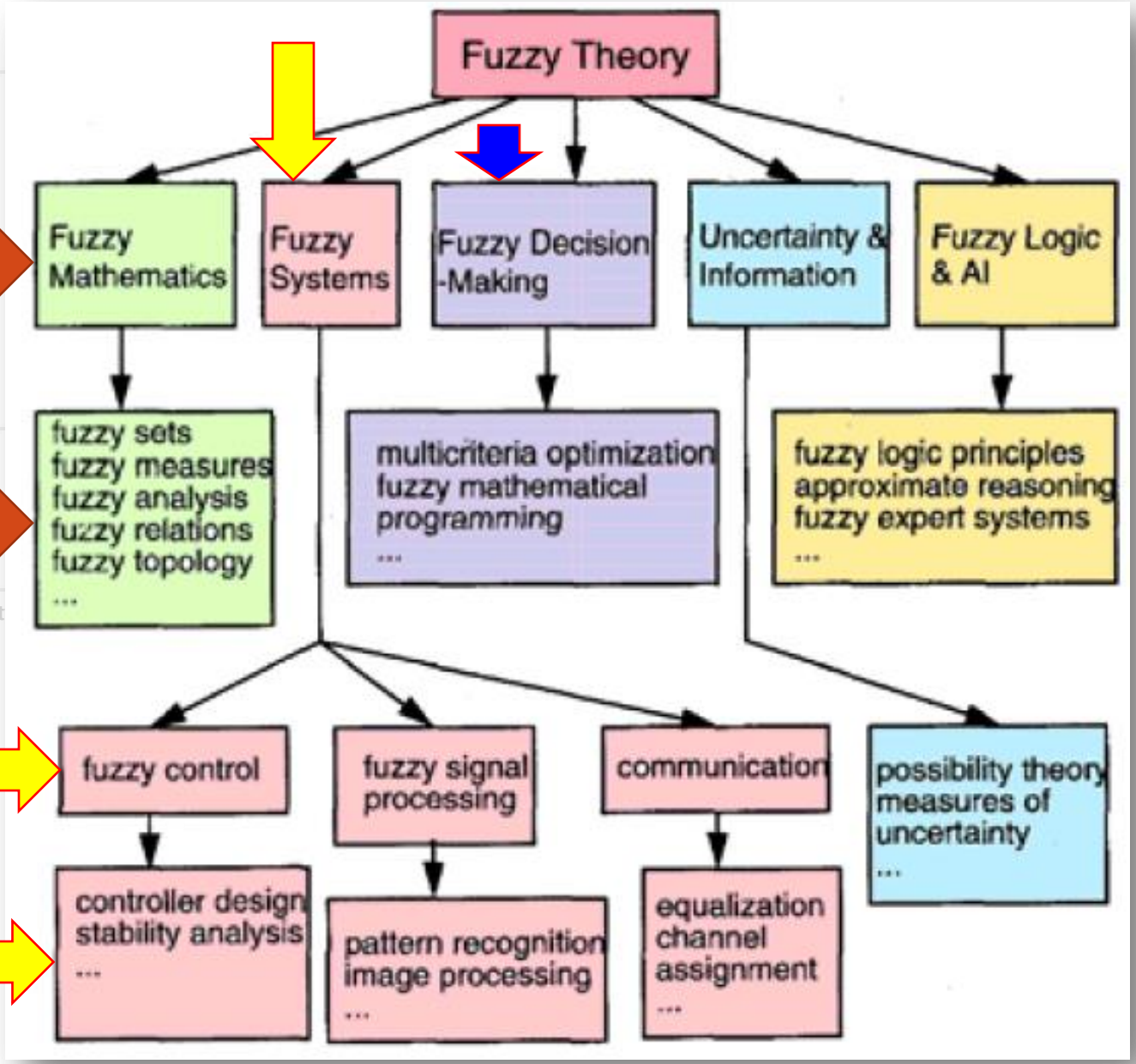
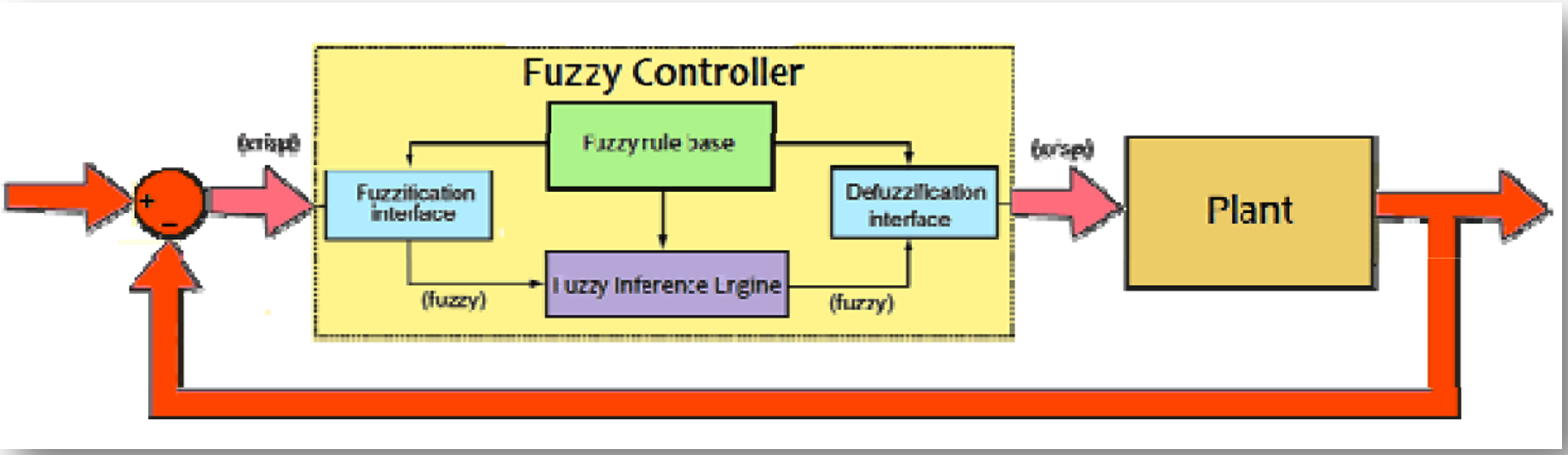
مقدمه: سیستمهای فازی و کنترل فازی



ساختار سیستمهای کنترل فازی حلقه بسته:



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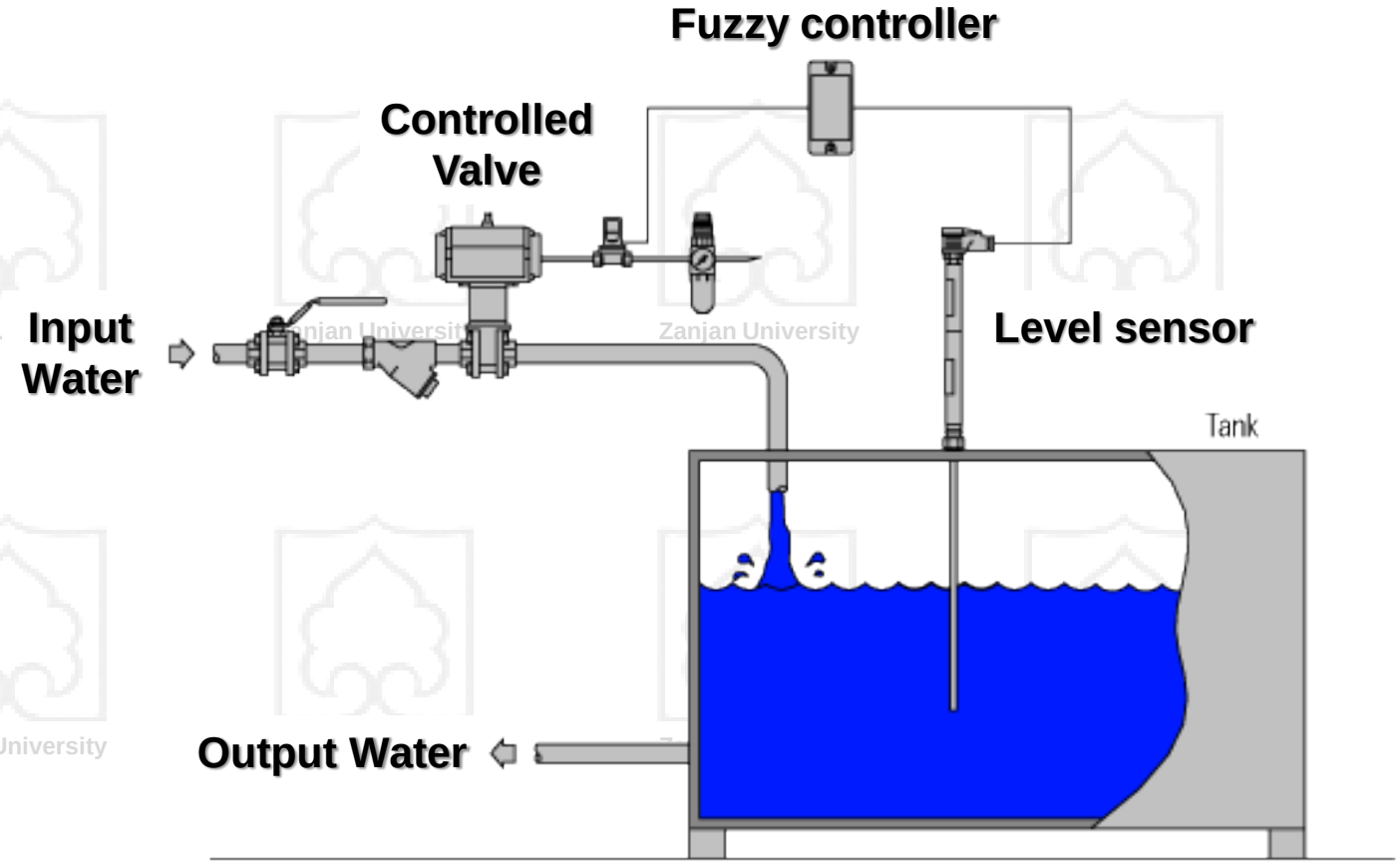
مثال. کنترل فازی سطح مایع در مخزن:

در این بخش می خواهیم با استفاده از *دانش و تجربیات یک شخص خبره* یک *کنترل کننده فازی* برای کنترل سطح مایع در مخزن طراحی کنیم.



کنترل فازی سطح مایع در مخزن:

$$\dot{h}(t) = -k_o\sqrt{h(t)} + bu(t)$$

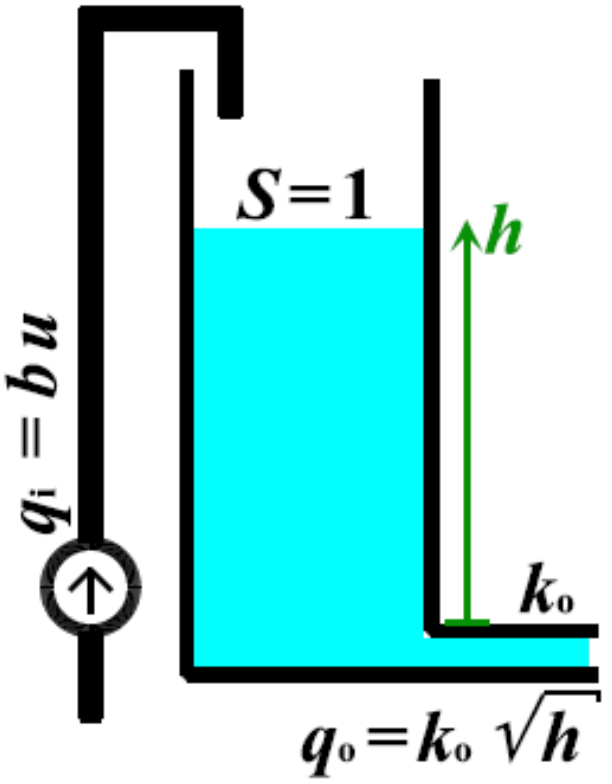


Figure 1: Water tank system

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Questions? Discussion? Suggestions ?

"Give a man a fish and

he will eat for a day.

Teach a man to fish and

he will eat for the rest of his life."

<<Proverb>>

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