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Computational Intelligence

Subject9: Fuzzy Controllers

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Agenda

- Fuzzy controller
- Fuzzy controller components
- Fuzzy controller in practice

Fuzzy Controller

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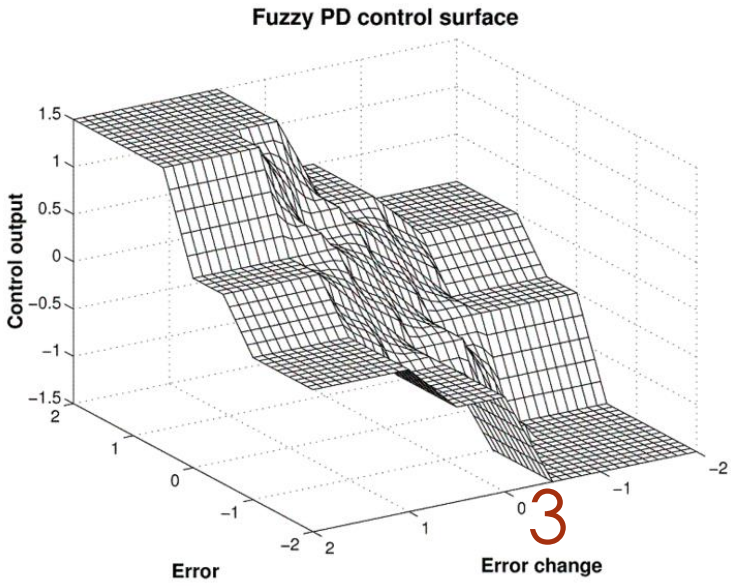
Fuzzy Control System:

- A control system based on Fuzzy logic
- The 1st consumer product using Fuzzy logic in 1987
  - Control of a model steam engine
- A control protocol by means of if-then rules
  - If temperature is high open the valve slightly
- Some of the most common controllers:
  - Mamdani controller
  - Takagi-Sugeno controller



Fuzzy Controller

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Goal: proving a proportional relation between the inputs and outputs of a system

Air Conditioning Compressor for Cars

- **Main Goal**: adjusting the temperature inside the vehicle
- **Output variable**: temperature
- **Control variable**: thermostat
- **Obstacle variable**: high engine temperature, etc.

Fuzzy Controller

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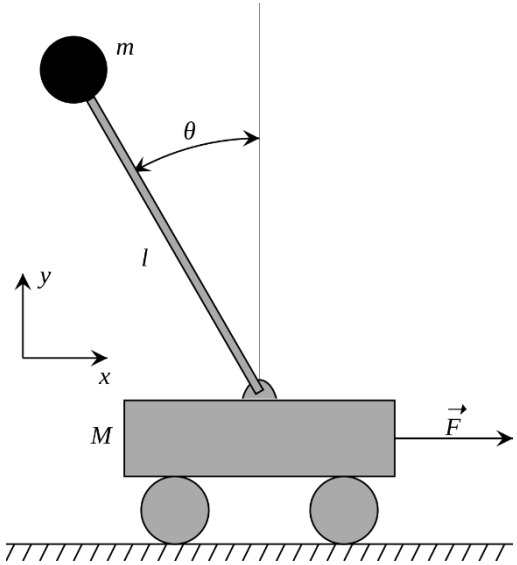
Goal: proving a proportional relation between the inputs and outputs of a system

Inverted Pendulum

- **Main Goal**: the object should not fall over
- **Output variable**: angular displacement θ
- **Control variable**: reaction forces (Newton's law)
- **Obstacle variable**: high speed



Fuzzy Controller

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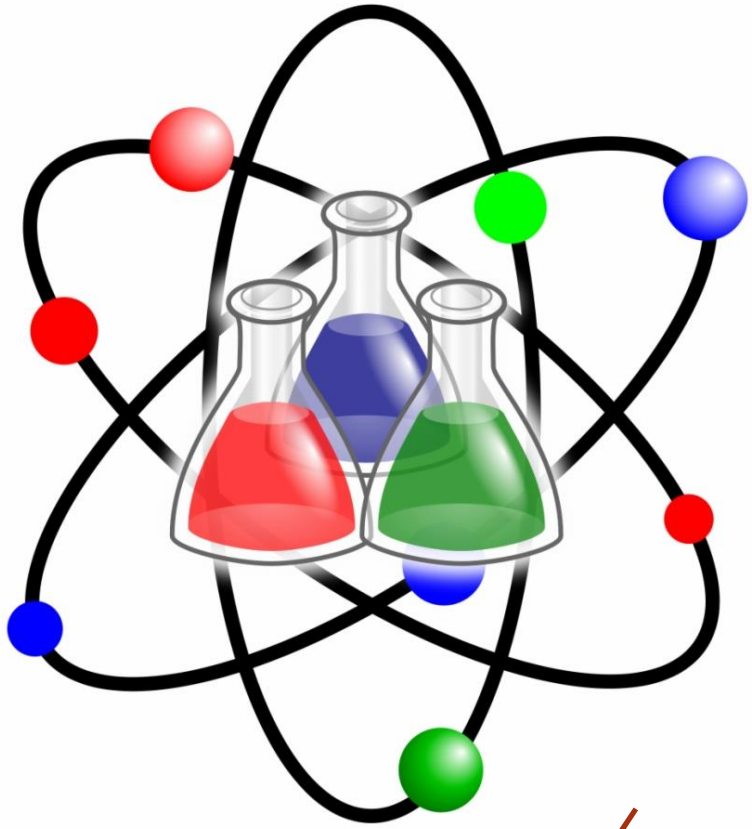
Classic controller

- Based on Scientific laws (Physics)
- Requires recognition techniques
- Applying Mathematical models
- Drawbacks:
  - Needs theorical concepts for modeling
  - Complexity
  - Sensitive



Fuzzy Controller

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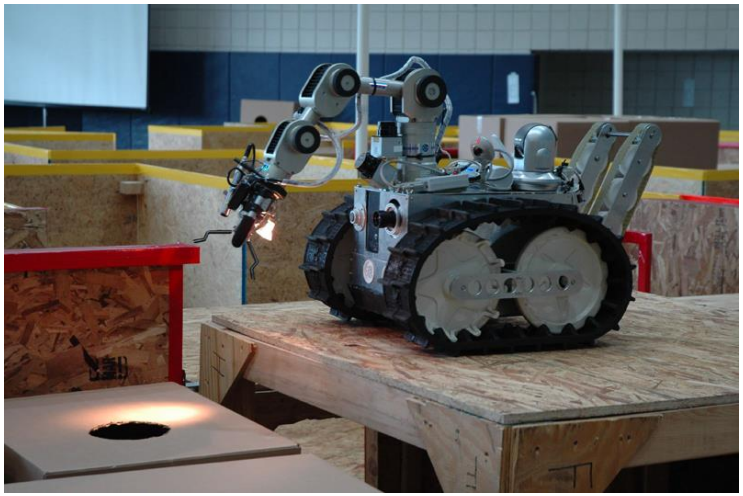
Fuzzy controller

- Based on real-world circumstances
- Design and implementation according to human experience
- Simple and flexible design
- Reliable against noise data
- Samples:
  - Rescue robot
  - Room temperature controller



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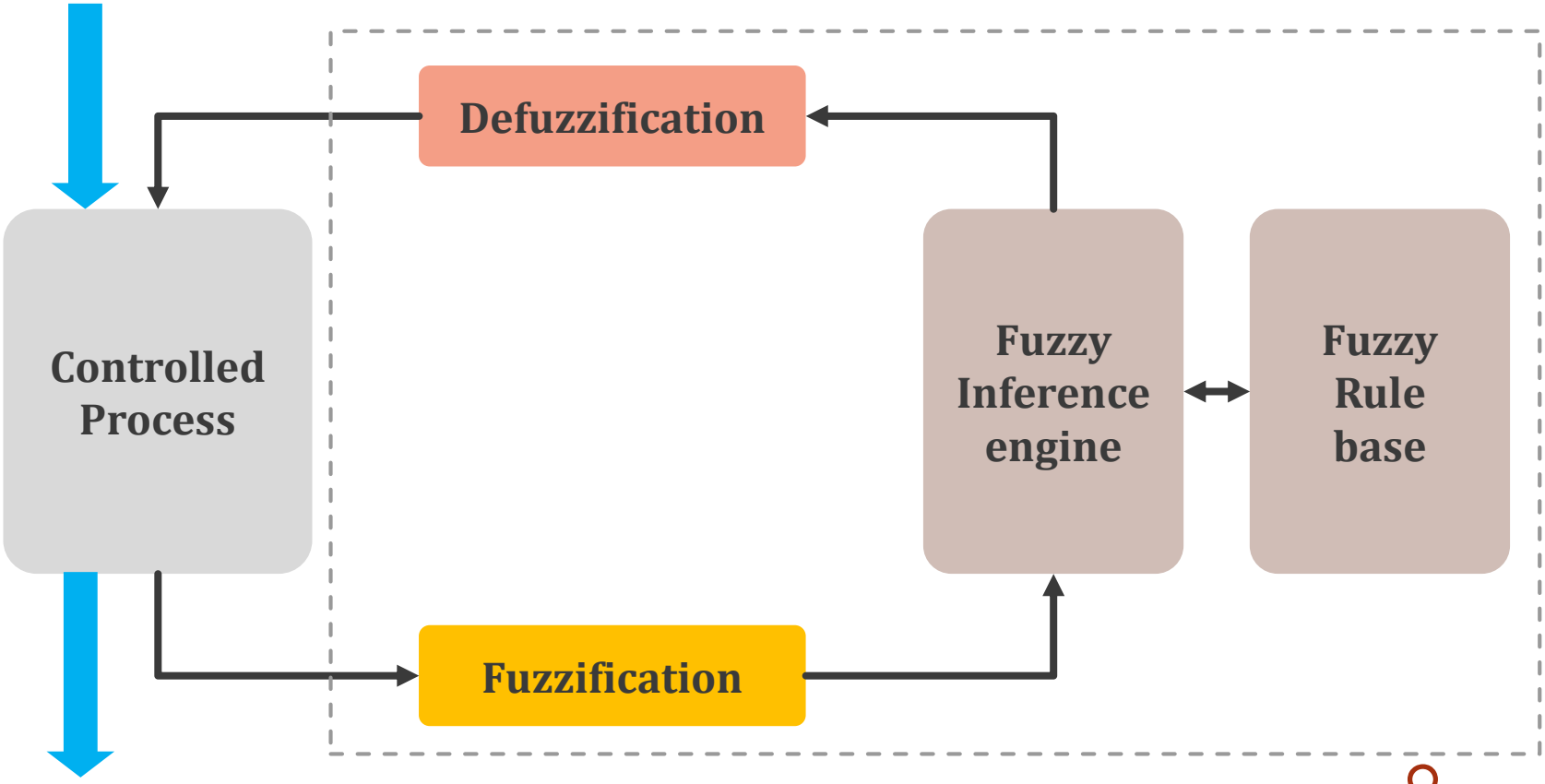
Classic controller - Sample

- Room Temperature Controller
  - Temperature < threshold ➔ turn on heater
  - Temperature > threshold ➔ turn on cooler
  - Temperature and Intensity should be Fuzzy values
    - So, we need Fuzzy variables, rules, relations, etc.
  - System application changes regarding circumstances

Fuzzy Controller Components



Fuzzy Controller in Practice

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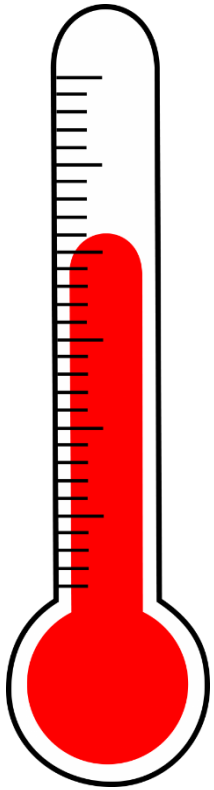
Room Temperature Controller (Fuzzy)

- Step 1: What are the variables?
  - Choosing Fuzzy values
  - For input ***T*** (temperature):
    - Cold – Cool – Normal – Warm – Hot
  - For output ***F*** (fan speed):
    - Very slow – Slow – Mid – Fast – Very fast

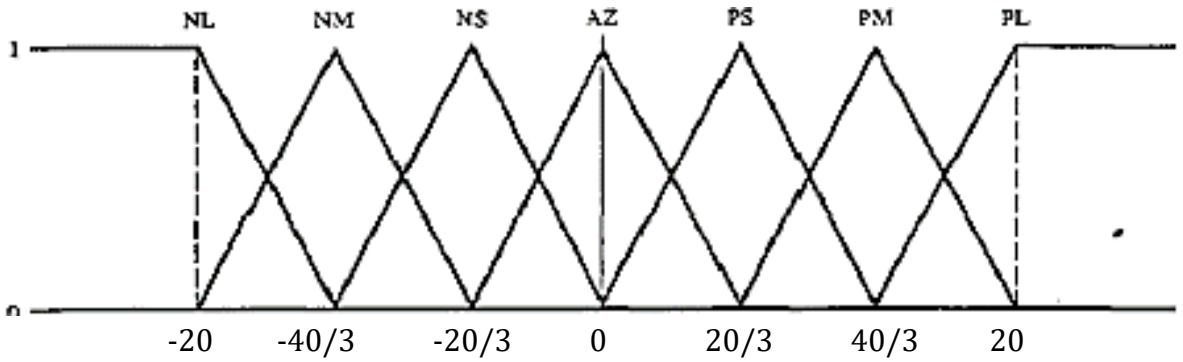


Fuzzy Controller in Practice

Room Temperature Controller (Fuzzy)

- Step 1: What are the variables?
  - Choosing Fuzzy values
  - Sometimes we can use Qualitative values
    - **Sample**: for values $\in [-20, 20]$

NL	Negative Large
NM	Negative Medium
NS	Negative Small
AZ	Approximately Zero
PS	Positive Small
PM	Positive Medium
PL	Positive Large



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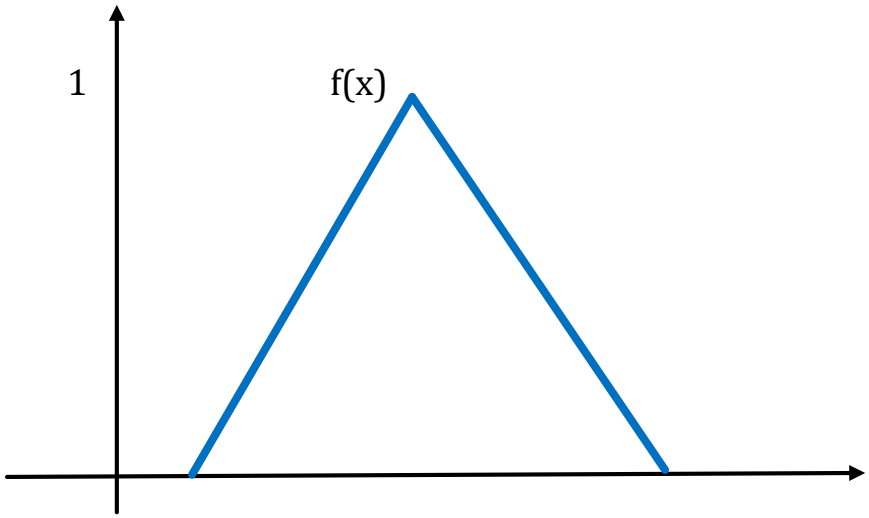
Room Temperature Controller (Fuzzy)

- Step 2: Fuzzification
  - Now, convert input values to Fuzzy
  - Triangles can be good MFs!

$$f: [-a, a] \rightarrow R$$



Fuzzy Controller in Practice

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Room Temperature Controller (Fuzzy)

- Step 2: Fuzzification

N: $\mu(T) = 0$

Y: $0 < \mu(T) < 1$

Y^*: $\mu(T) = 1$

Room Temperature

Temperature (Celsius)	Cold	Cool	Normal	Warm	Hot
0	Y*	N	N	N	N
5	Y	Y	N	N	N
10	N	Y	N	N	N
12.5	N	Y*	N	N	N
15	N	Y	N	N	N
17.5	N	N	Y*	N	N
20	N	N	N	Y	N
22.5	N	N	N	Y*	N
25	N	N	N	Y	Y
27.5	N	N	N	N	Y
30	N	N	N	N	Y*

Fuzzy Controller in Practice

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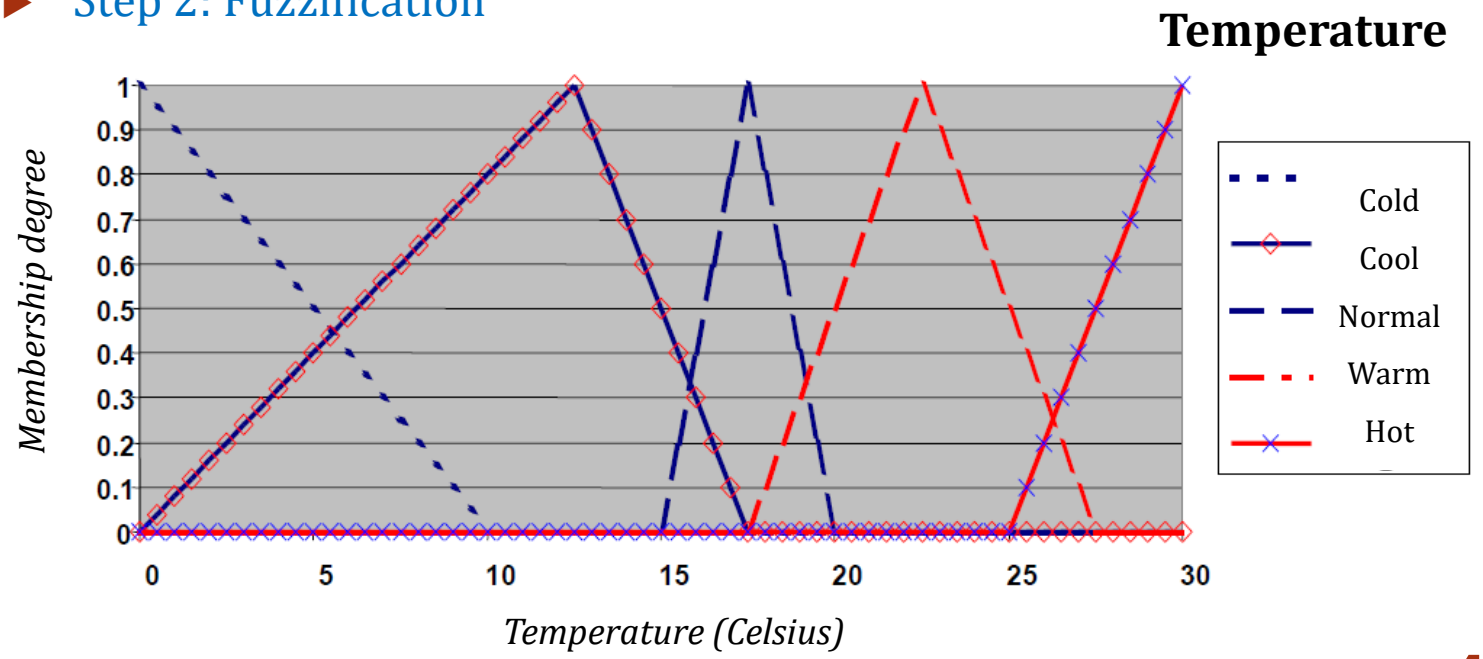
Room Temperature Controller (Fuzzy)

- Step 2: Fuzzification



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Room Temperature Controller (Fuzzy)

- Step 2: Fuzzification

N: $\mu(T) = 0$

Y: $0 < \mu(T) < 1$

Y^*: $\mu(T) = 1$

Fan Speed

Speed (RPM)	Very Slow	Slow	Mid	Fast	Very Fast
0	Y*	N	N	N	N
10	Y	N	N	N	N
20	Y	Y	N	N	N
30	N	Y*	N	N	N
40	N	Y	N	N	N
50	N	N	Y*	N	N
60	N	N	N	Y	N
70	N	N	N	Y*	N
80	N	N	N	Y	Y
90	N	N	N	N	Y
100	N	N	N	N	Y*

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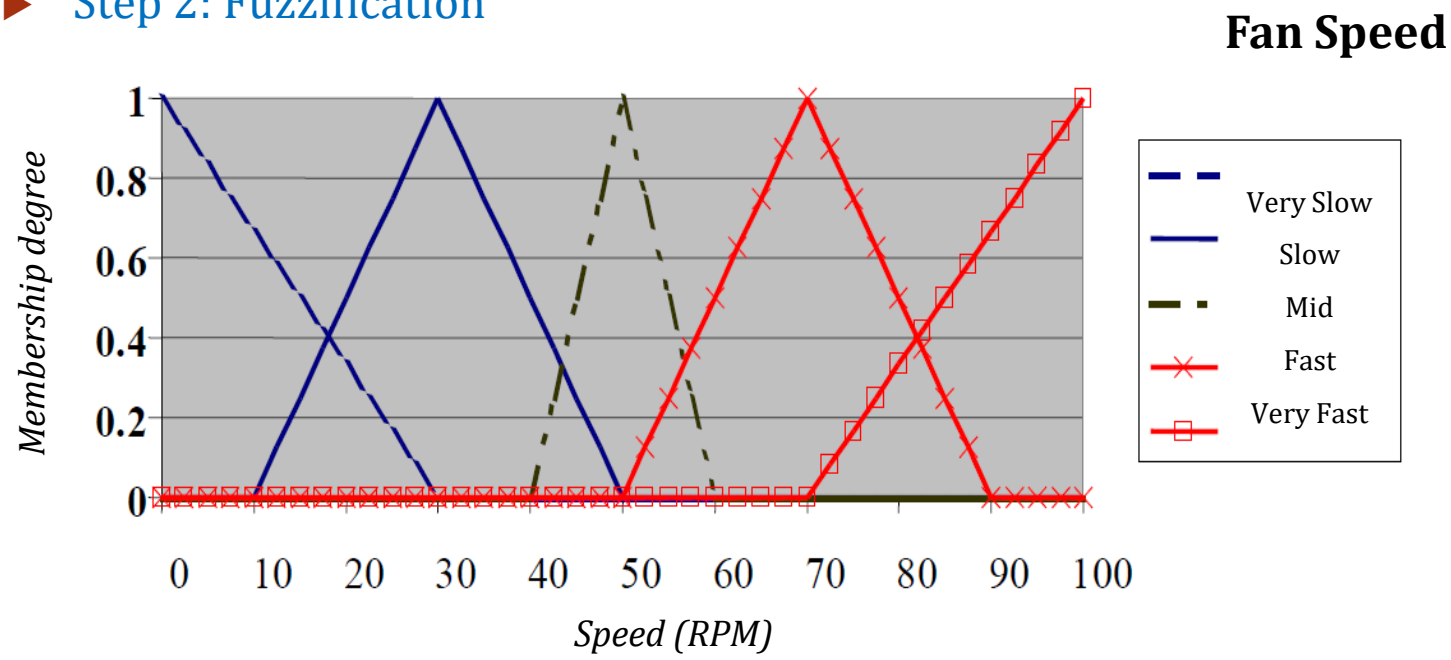
Room Temperature Controller (Fuzzy)

- Step 2: Fuzzification



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Room Temperature Controller (Fuzzy)

- Step 3: Fuzzy inference
  - Some rules based on our demands

Temperature	Fan Speed
Cold	Very Slow
Cool	Slow
Normal	Mid
Warm	Fast
Hot	Very Fast

Fuzzy Controller in Practice

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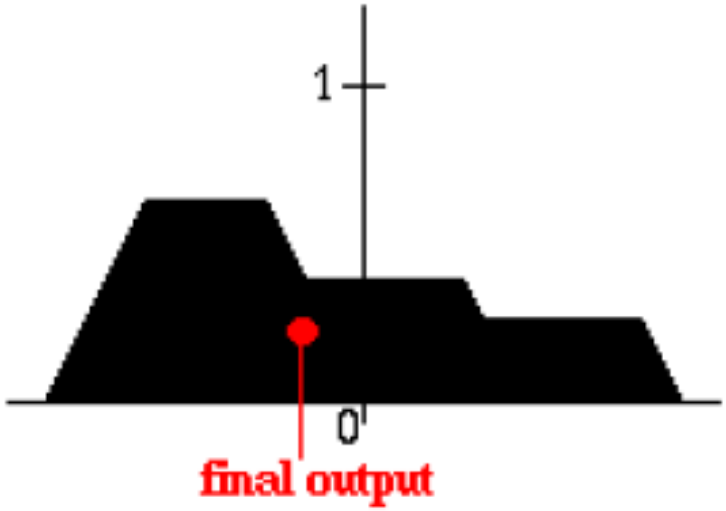
Room Temperature Controller (Fuzzy)

- Step 4: Defuzzification
  - A common method: **Center of Area (CA)**

discrete
$$D_{CA}(t) = \frac{\sum_{k=1}^{n} C(z_k) z_k}{\sum_{k=1}^{n} C(z_k)}$$

continuous
$$D_{CA}(t) = \frac{\int_{-C}^{C} C(z) z dz}{\int_{-C}^{C} C(z) dz}$$

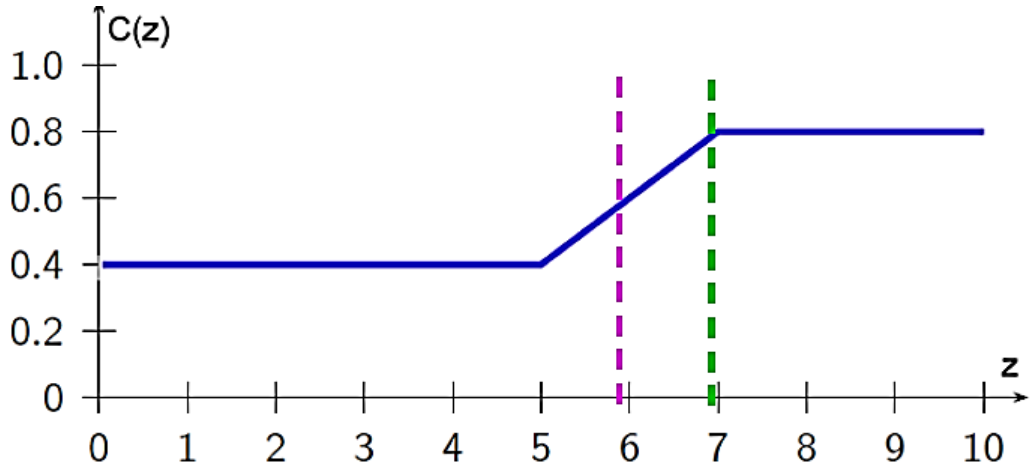


  - Other methods: Maximum, Max. Average, etc.

Fuzzy Controller in Practice

Room Temperature Controller (Fuzzy)

- Step 4: Defuzzification
  - **Center of Area (CA)** – Sample:



$$D_{CA}(t) = \frac{\sum_{k=1}^{n} C(z_k) z_k}{\sum_{k=1}^{n} C(z_k)}$$

$$= \frac{0.4\,(0+1+2+3+4+5)}{(0.4*6)+(0.6*1)+(0.8*4)} + \frac{0.6*6}{(0.4*6)+(0.6*1)+(0.8*4)} + \frac{0.8\,(7+8+9+10)}{(0.4*6)+(0.6*1)+(0.8*4)}$$

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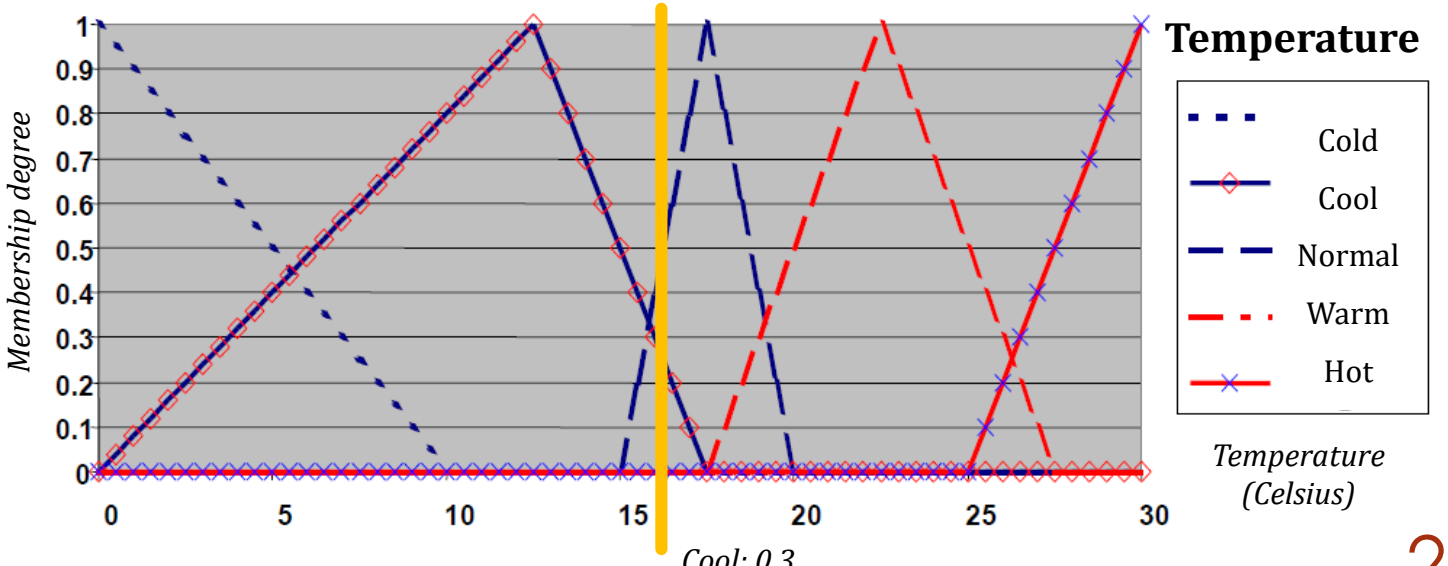
Room Temperature Controller (Fuzzy)

Q: Assume the temperature is 16, what will be the fan's speed?



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Room Temperature Controller (Fuzzy)

Q: Assume the temperature is 16, what will be the fan's speed?

- So, it is 0.3 Cool and 0.4 Normal

	Temperature	Fan Speed
	Cold	Very Slow
$\mu = 0.3$	Cool	Slow
$\mu = 0.4$	Normal	Mid
	Warm	Fast
	Hot	Very Fast

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Room Temperature Controller (Fuzzy)

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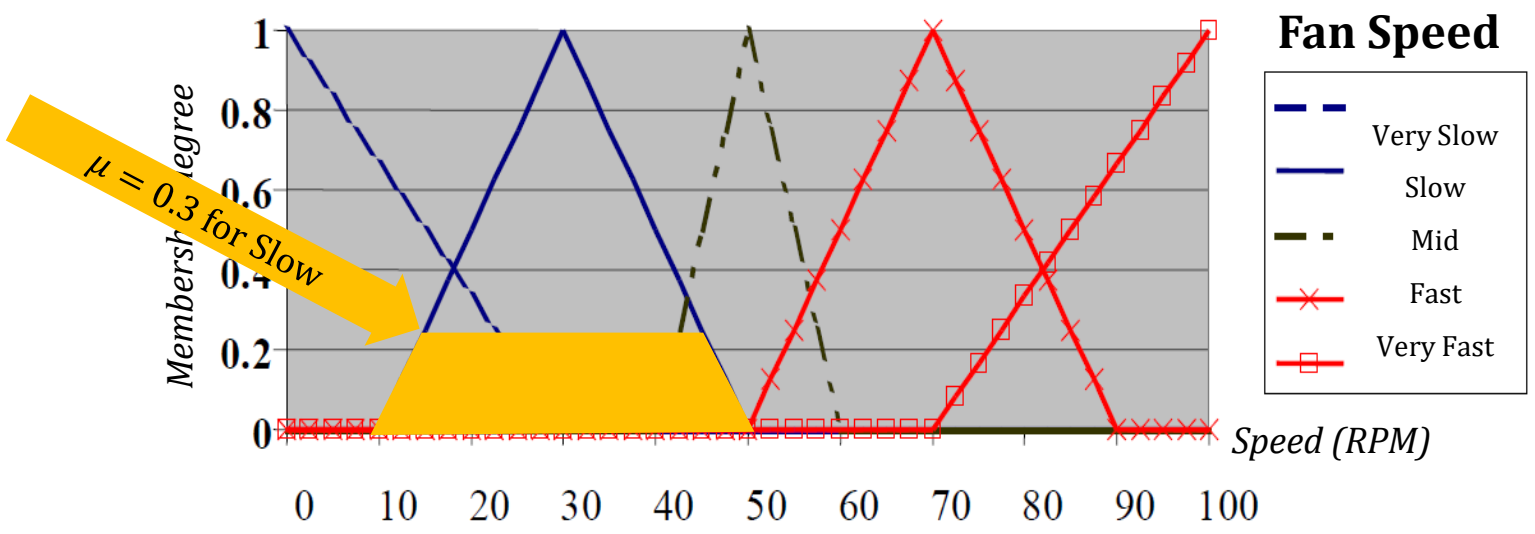

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Room Temperature Controller (Fuzzy)

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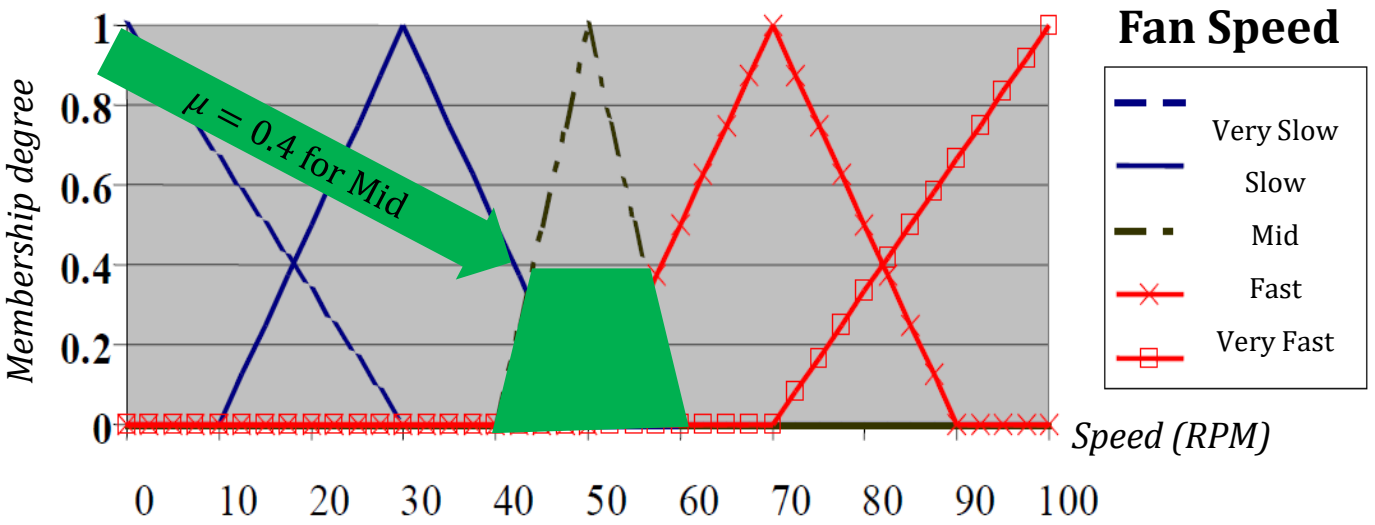

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Room Temperature Controller (Fuzzy)

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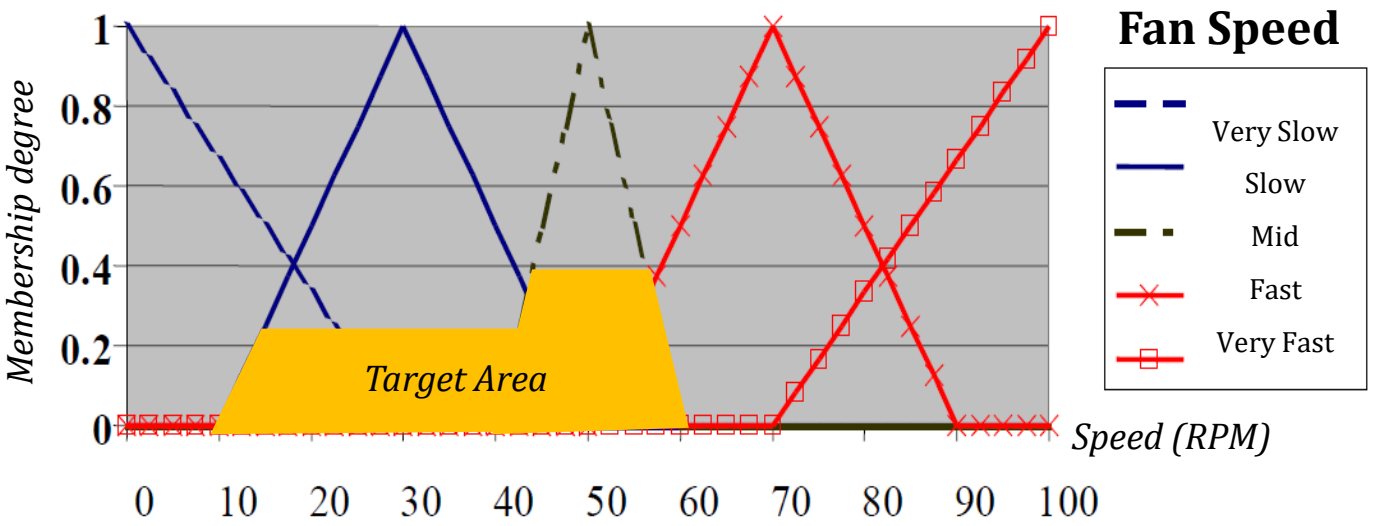

Fuzzy Controller in Practice

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Room Temperature Controller (Fuzzy)

Q: Assume the temperature is 16, what will be the fan's speed?

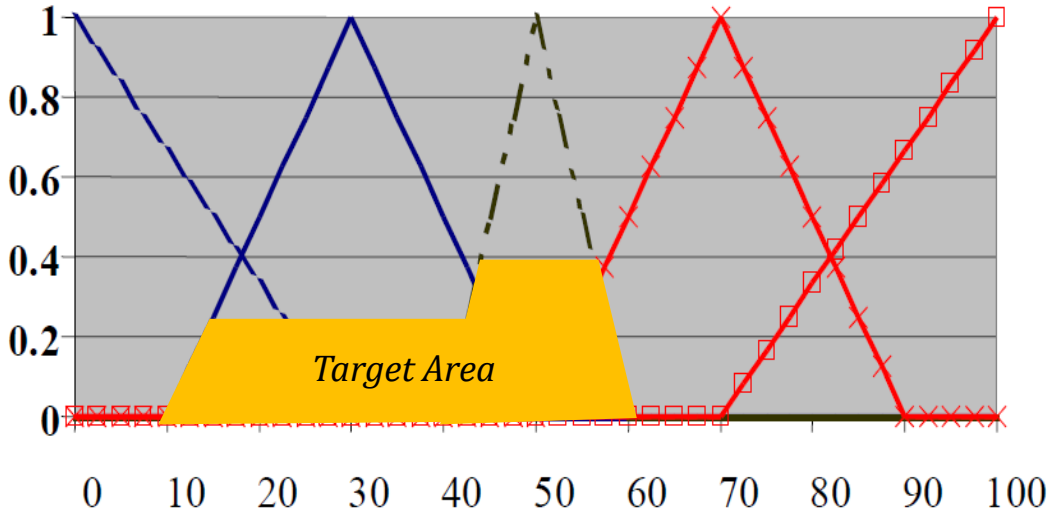
$$D_{CA}(t) = \frac{\sum_{k=1}^{n} C(z_k) z_k}{\sum_{k=1}^{n} C(z_k)}$$

$$= \frac{0.125(12.5) + 0.25(15)}{0.125 + 0.25 + 0.3 + \cdots + 0.25}$$

$$+ \frac{0.3(17.5 + 20 + \cdots + 42.5)}{0.125 + 0.25 + 0.3 + \cdots + 0.25}$$

$$+ \frac{0.4(45 + \cdots + 55) \ \ldots + 0.25(57.5)}{0.125 + 0.25 + 0.3 + \cdots + 0.25}$$

$$= 45.5\ rpm$$



What's Next?

- Evolutionary Computation

Questions?