Fuzzy logic

Developing Fuzzy Expert Systems

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Fuzzy Expert System Development Process

1. Specify the problem; define linguistic variables.
2. Determine fuzzy sets.
3. Bring out and construct fuzzy rules.
4. Encode the fuzzy sets, fuzzy rules and procedures to perform fuzzy inference into the expert system.
5. Evaluate and tune the system.

Example: Air Conditioner

1a. Specify the problem

Air-conditioning involves the delivery of air, which can be warmed or cooled and have its humidity raised or lowered.

An air-conditioner is an apparatus for controlling, especially lowering, the temperature and humidity of an enclosed space. An air-conditioner typically has a fan which blows/cools/circulates fresh air and has a cooler. The cooler is controlled by a thermostat. Generally, the amount of air being compressed is proportional to the ambient temperature.

1b. Define linguistic variables

- Ambient *Temperature*
- Air-conditioner Fan *Speed*

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2. Determine Fuzzy Sets

Fuzzy sets can have a variety of shapes.

However, a triangle or a trapezoid can often provide an adequate representation of the expert knowledge, and at the same time, significantly simplifies the process of computation.

Fuzzy sets are defined both for input and output variables!

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Example: Air Conditioner

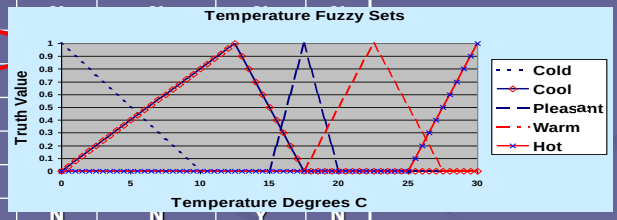
2. Determine Fuzzy Sets: Temperature

$0<\mu(T)<1$

$\mu(T)=0$

$\mu(T)=1$

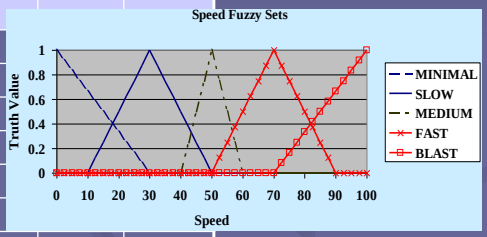
Temp (ºC).	COLD	COOL	PLEASANT	WARM	HOT
0	Y*				
5	Y				
10	N				
12.5	N				
15	N				
17.5	N				
20	N	N	N	Y	N
22.5	N	N	N	Y*	N
25	N	N	N	Y	N
27.5	N	N	N	N	Y
30	N	N	N	N	Y*



Example: Air Conditioner

2. Determine Fuzzy Sets: Fan Speed

Rev/sec (RPM)	MINIMAL	SLOW	MEDIUM	FAST	BLAST
0	Y*	N	N		
10	Y	N	N		
20	Y	Y	N		
30	N	Y*	N		
40	N	Y	N		
50	N	N	Y*		
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*



3. Bring out and construct fuzzy rules

- To accomplish this task, we might ask the expert to describe how the problem can be solved using the fuzzy linguistic variables defined previously.
- Required knowledge also can be collected from other sources such as books, computer databases, flow diagrams and observed human behaviour.

Example: Air Conditioner

RULE 1: IF *temp* is *cold* THEN *speed* is *minimal*
RULE 2: IF *temp* is *cool* THEN *speed* is *slow*
RULE 3: IF *temp* is *pleasant* THEN *speed* is *medium*
RULE 4: IF *temp* is *warm* THEN *speed* is *fast*
RULE 5: IF *temp* is *hot* THEN *speed* is *blast*

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4. Encode the fuzzy sets, fuzzy rules and procedures to perform fuzzy inference into the expert system

To accomplish this task, we may choose one of two options:

- to build our system using a programming language such as C/C++ or Pascal, or
- to apply a fuzzy logic development tool such as MATLAB Fuzzy Logic Toolbox or Fuzzy Knowledge Builder.

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5. Evaluate and tune the system

- The last, and the most laborious, task is to evaluate and tune the system. We want to see whether our fuzzy system meets the requirements specified at the beginning.
- **Evaluation of the system** output is performed for test situations on the several representative values of input variables. Fuzzy Logic development tools often can generate surface to help us evaluate and analyze the system's performance.
- **Tuning of the system** consists of reviewing, adding and/or changing the membership functions and rules in order to increase the performance of the system.

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Example: Air Conditioner

5a. Evaluate the system

Consider a temperature of 16°C, use the system to compute the optimal fan speed.

RECALL: Operation of a fuzzy expert system:

- **Fuzzification:** determination of the degree of membership of crisp inputs in appropriate fuzzy sets.
- **Inference:** evaluation of fuzzy rules to produce an output for each rule.
- **Aggregation:** combination of the outputs of all rules.
- **Defuzzification:** computation of crisp output

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Example: Air Conditioner

- **Fuzzification**

→ **Affected fuzzy sets: COOL and PLEASANT**

$\mu_{COOL}(T) = -T/5 + 3.5$
$= -16/5 + 3.5$
$= 0.3$

$\mu_{PLSNT}(T) = T/2.5 - 6$
$= 16/2.5 - 6$
$= 0.4$

Temp=16	μ_{COLD}	μ_{COOL}	$\mu_{PLEASANT}$	μ_{WARM}	μ_{HOT}
	0	0.3	0.4	0	0

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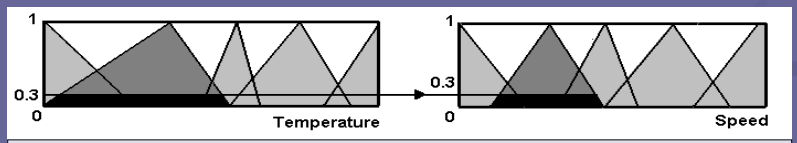
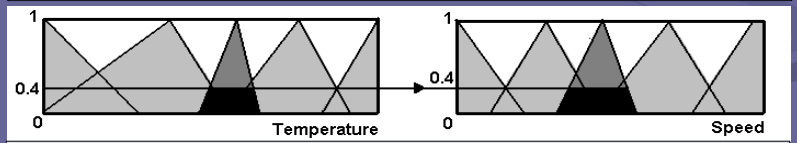
Example: Air Conditioner

- **Inference**

RULE 1: IF *temp* is *cold* THEN *speed* is *minimal*
RULE 2: IF *temp* is *cool* THEN *speed* is *slow*
RULE 3: IF *temp* is *pleasant* THEN *speed* is *medium*
RULE 4: IF *temp* is *warm* THEN *speed* is *fast*
RULE 5: IF *temp* is *hot* THEN *speed* is *blast*



RULE 2: IF ***temp*** is ***cool*** (0.3) THEN ***speed*** is ***slow*** (0.3)



RULE 3: IF ***temp*** is ***pleasant*** (0.4) THEN ***speed*** is ***medium*** (0.4)

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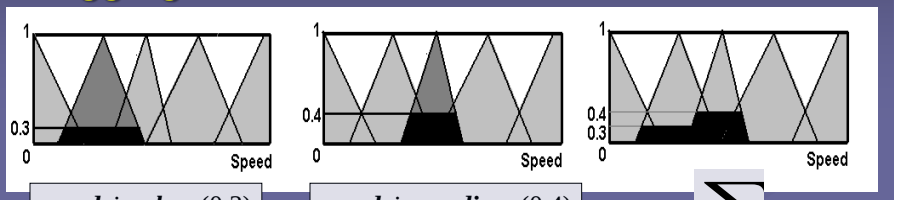
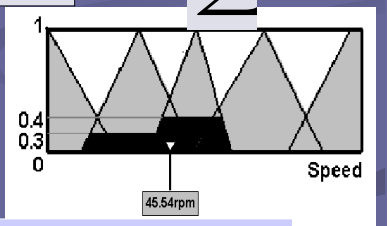
Example: Air Conditioner

- **Aggregation**



speed is ***slow*** (0.3) + ***speed*** is ***medium*** (0.4) → Σ

- **Defuzzification**



$$\text{COG} = \frac{0.125(12.5) + 0.25(15) + 0.3(17.5+20+\ldots+40+42.5) + 0.4(45+47.5+\ldots+52.5+55) + 0.25(57.5)}{0.125 + 0.25 + 0.3(11) + 0.4(5) + 0.25} = 45.54\text{rpm}$$

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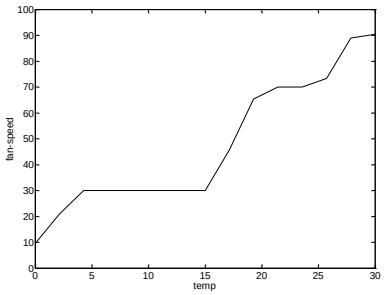
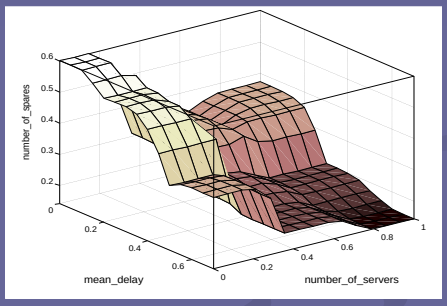
Input – Output Plot



Example: Air Conditioner one input – one output gives nonlinear transfer characteristic



More general example: two inputs – one output gives 3D transfer surface

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5b. Tune fuzzy system to improve performance

1. Review input and output variables, and if required redefine their universes.
2. Review the fuzzy sets:
   - revise shapes of the fuzzy sets. In most cases, fuzzy systems are highly tolerant of a shape approximation.
   - provide sufficient overlap between neighbouring sets. It is suggested that triangle-to-triangle and trapezoid-to-triangle fuzzy sets should overlap between 25% to 50% of their bases.
   - if required, define additional sets on the universe of discourse. Wide fuzzy sets may cause the fuzzy system to perform roughly.
3. Review the existing rule base:
   - examine for opportunities to write hedge rules to capture the pathological behaviour of the system.
   - if required, add new rules to the rule base.
   - adjust the rule execution weights. Most fuzzy logic tools allow control of the importance of rules by changing a weight multiplier.
4. Modify engine methods (AND, OR, implication, aggregation, defuzzification).

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