Reinforcement learning of fuzzy logic controllers

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What is fuzzy logic?

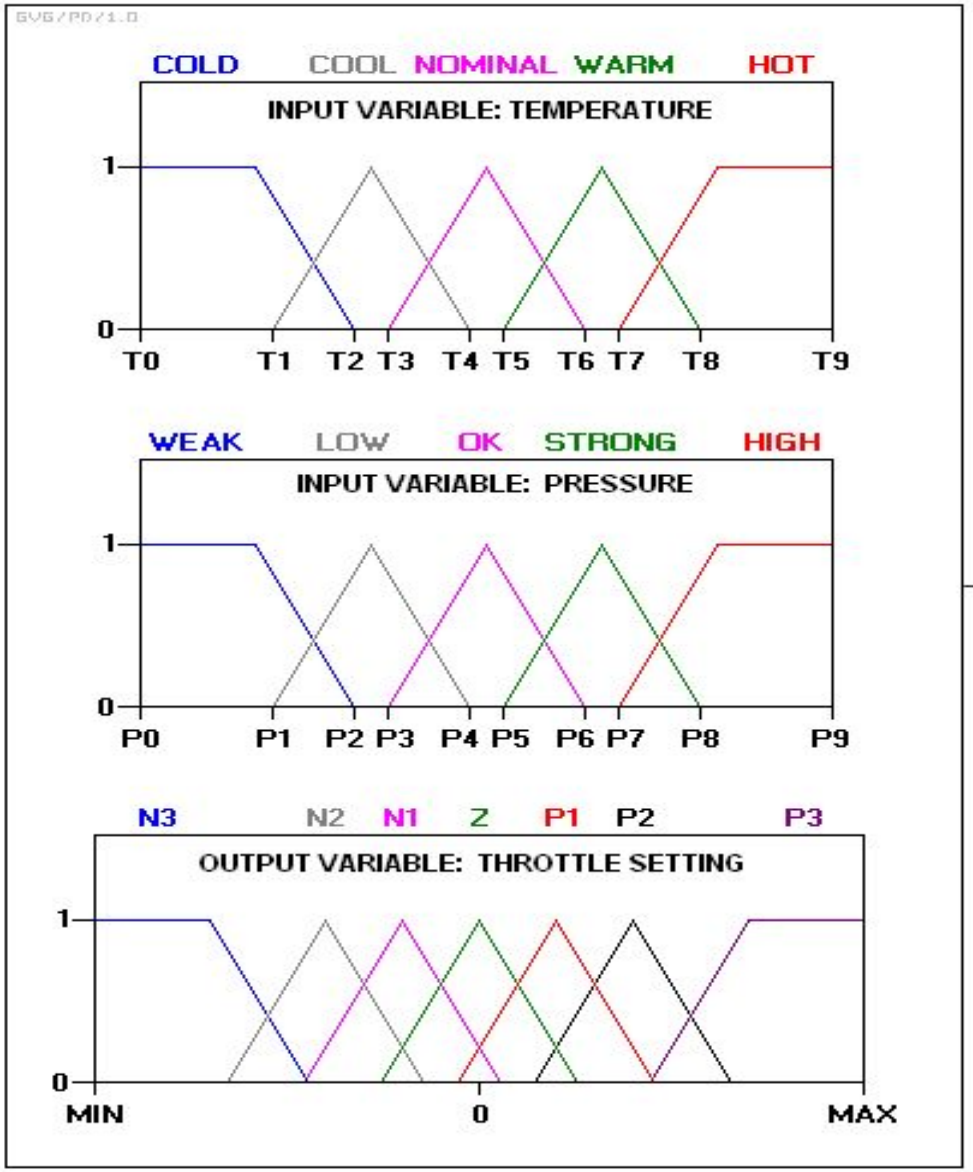
Boolean logic	Fuzzy logic
0 or 1	Between 0 and 1

Fuzzy Logic

Simple example of the logic for temperature regulator that uses a fan might look like this:

```
IF temperature IS very cold THEN stop fan
IF temperature IS cold THEN fan speed is zero
IF temperature IS warm THEN fan speed is moderate
IF temperature IS hot THEN fan speed is high
```

The input and output variables map into the following fuzzy set:



Example of rules:

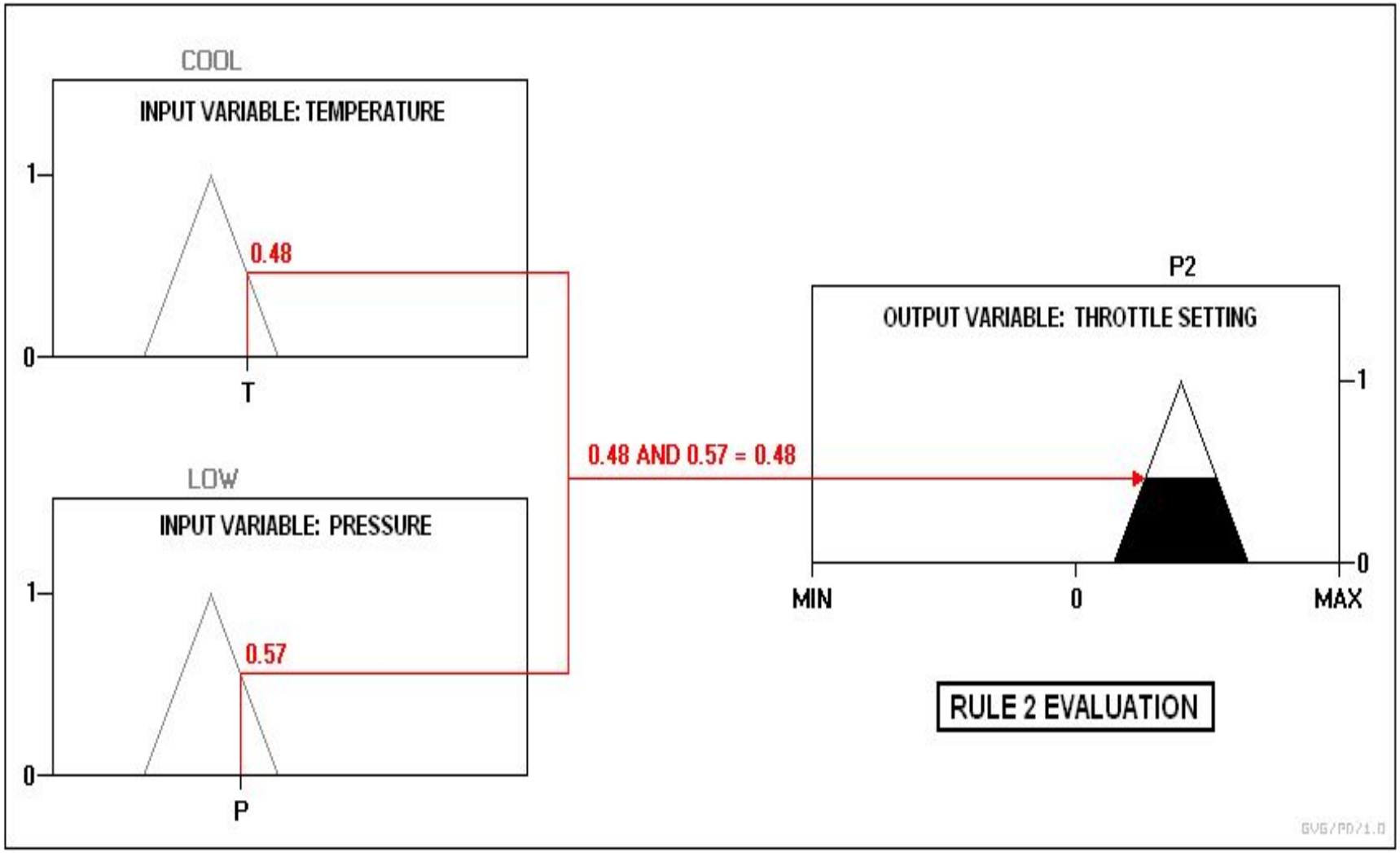
The rule set includes such rules as:

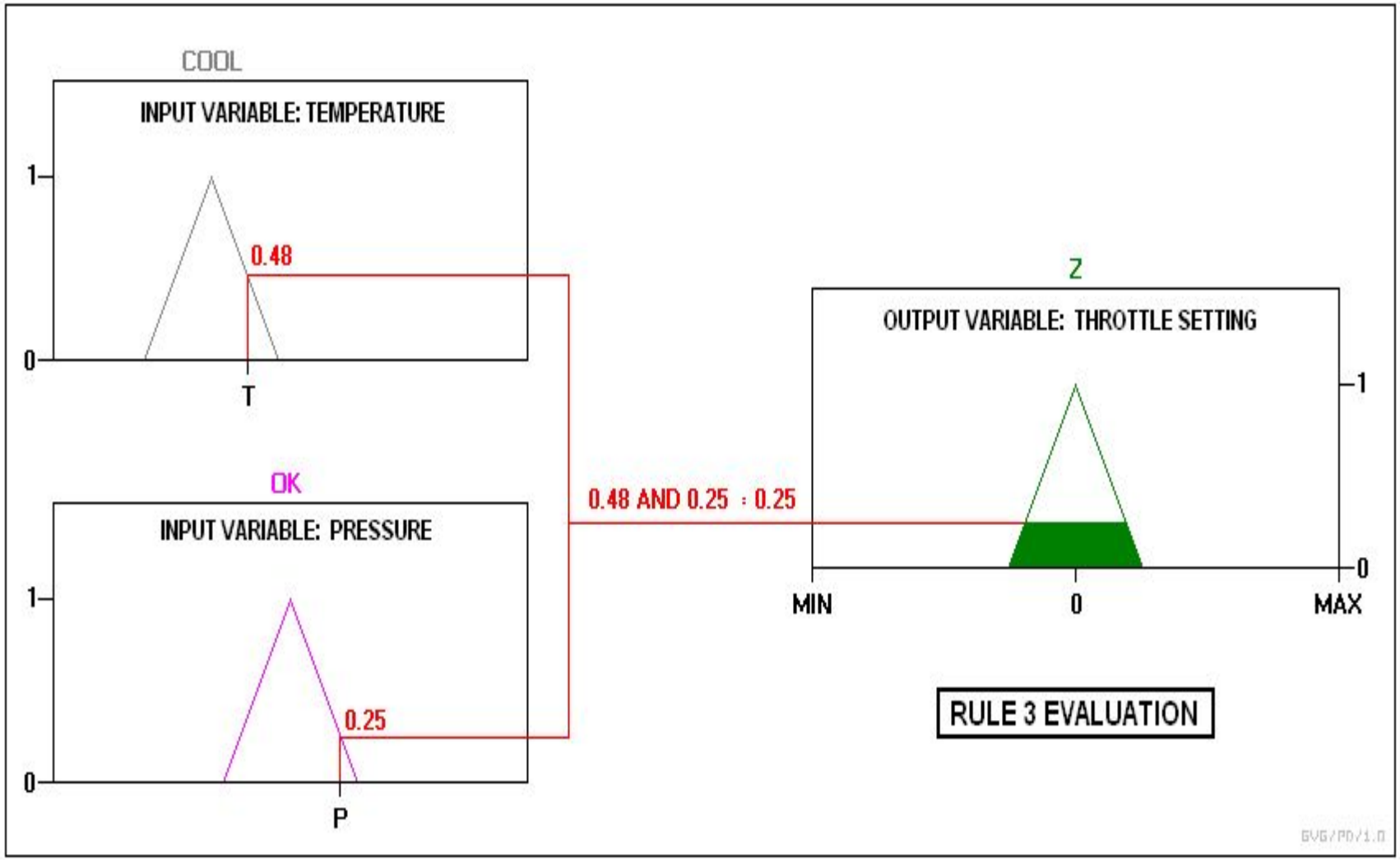
```
rule 1:  IF temperature IS cool AND pressure IS weak,
         THEN throttle is P3.
```

```
rule 2:  IF temperature IS cool AND pressure IS low,
         THEN throttle is P2.
```

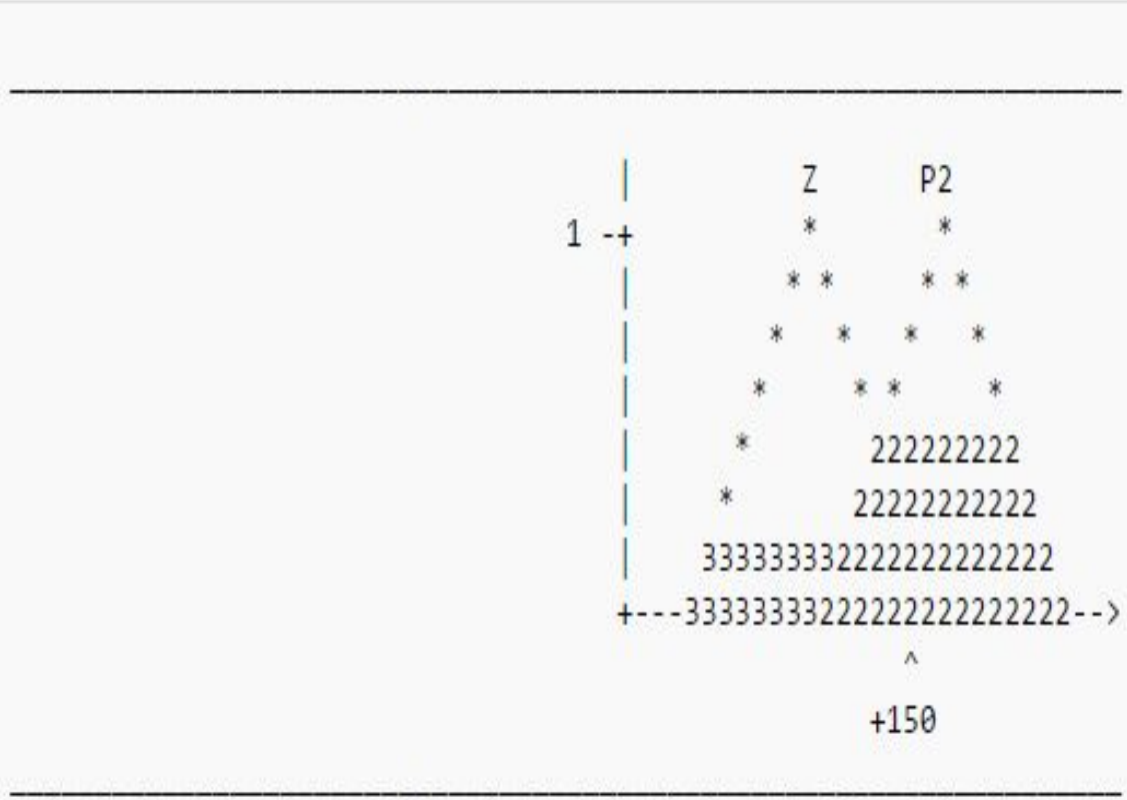
```
rule 3:  IF temperature IS cool AND pressure IS ok,
         THEN throttle is Z.
```

```
rule 4:  IF temperature IS cool AND pressure IS strong,
         THEN throttle is N2.
```


COOL
INPUT VARIABLE: TEMPERATURE
1
0
0.48
T
LOW
INPUT VARIABLE: PRESSURE
1
0
0.57
P
0.48 AND 0.57 = 0.48
P2
OUTPUT VARIABLE: THROTTLE SETTING
1
0
MIN
0
MAX
RULE 2 EVALUATION
GVG/PD/1.0


COOL
INPUT VARIABLE: TEMPERATURE
1
0
0.48
T
OK
INPUT VARIABLE: PRESSURE
1
0
0.25
P
0.48 AND 0.25 = 0.25
Z
OUTPUT VARIABLE: THROTTLE SETTING
1
0
MIN
0
MAX
RULE 3 EVALUATION
GVG/PD/1.0

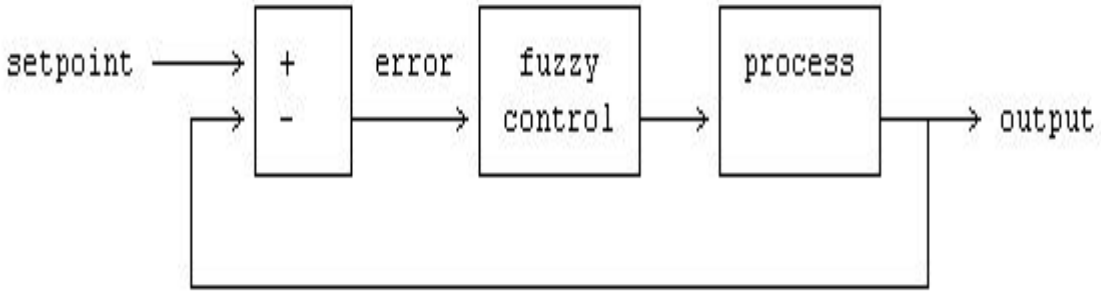
The two outputs are then defuzzified through centroid defuzzification:



The output value will adjust the throttle and then the control cycle will begin again to generate the next value .

Building a fuzzy controller [edit]

Consider implementing with a microcontroller chip a simple feedback controller:



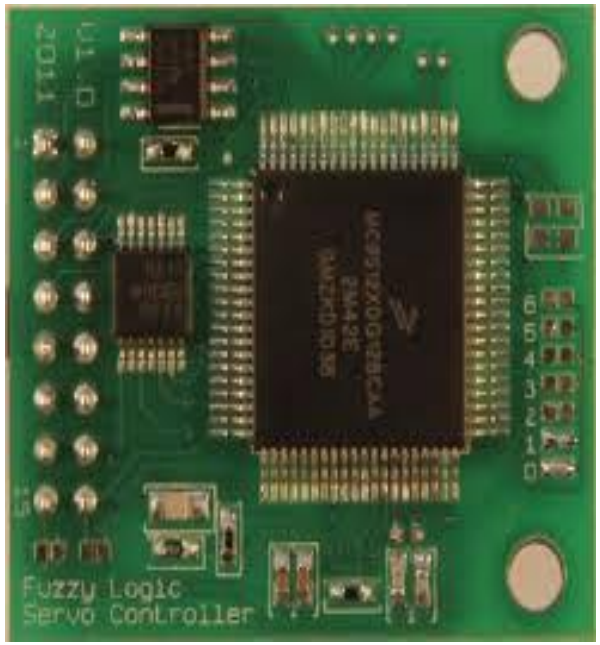
A fuzzy set is defined for the input error variable "e", and the derived change in error, "delta", as well as the "output", as follows:

```
LP:  large positive
SP:  small positive
ZE:  zero
SN:  small negative
LN:  large negative
```

There are three types of scheme:

1. FLC – Fuzzy Logic Controllers
2. NN – Neural Networks
3. RL – Reinforcement Learning

	GOOD	NOT GOOD
FLC	Small set	Fuzzy rules
NN and RL	Unfussy rules	Large set

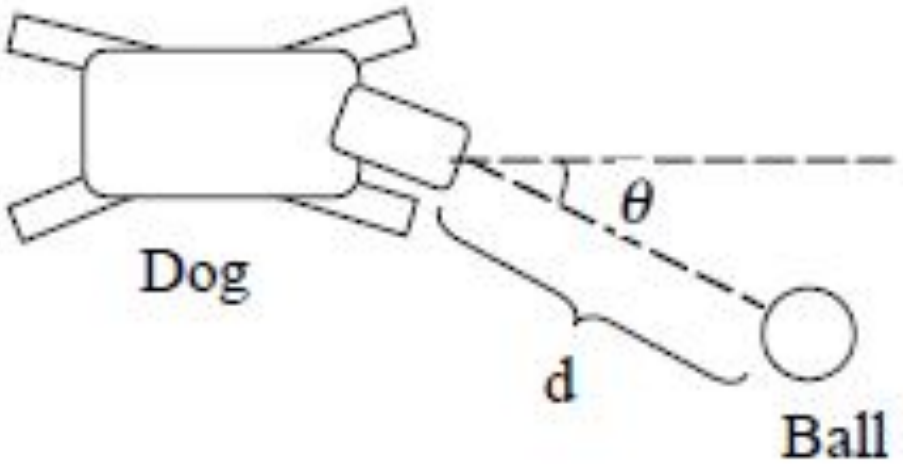


Because of small set of rules, FLC scheme is more suitable than NN or RL control schemes.

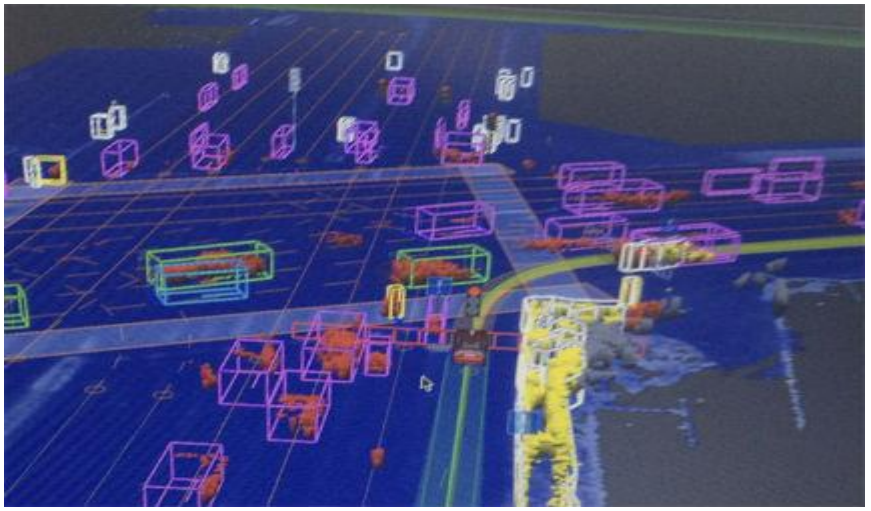
FLC

For Sony legged robots, the output action is the discrete command set, each of which can make the robot move single steps in different directions.

A reactive control scheme is employed for Sony legged robots to approach the ball in a game. There are two state variables: the orientation relative to the ball represented by θ and the distance to the ball by *d*, which are important for this behavior due to the lack of global co-ordination.



The input state vector is $S = [s1, s2]T = [\theta, d]T$. This behavior is to control the robot to approach the ball by taking action such as *MOVE FORWARD, LFFT FORWARD, RIGHT FORWARD, LEFT TURN*, or *RIGHT TURN,* which are provided by low-level walking software.



$$\mu_{F_n^j}(s_n) = \begin{cases} \max\left[0, \dfrac{d - s_n}{d - c}\right] & s_n > c \\ \max\left[0, \dfrac{s_n - a}{b - a}\right] & s_n < b \\ 1 & \text{otherwise} \end{cases} \quad (1)$$

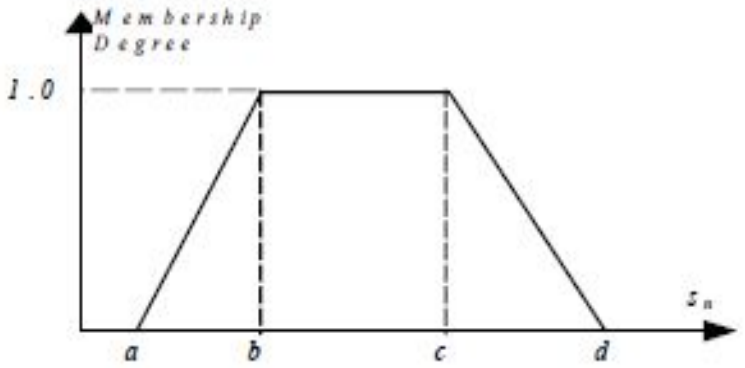


Figure 2. Membership function of a fuzzy set.

We define *F(j, n)* as the *j*-th fuzzy set *(j=1…ln)* and *ln* the number of fuzzy sets for the input state variable s*n*. A quadruple of *(a,b,c,d)* is used to represent the triangle or trapezoid membership function of the fuzzy set as shown in figure 2 where *b = c* for triangle shape. The output action *a* is the crisp value that can be seen as a fuzzy singleton *cm (m=1…M)* in a FLC.

Experimental results

The experimental results show the FLC can be learned by the proposed reinforcement learning scheme.

Thank you for attention!