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Overview of Fuzzy Logic

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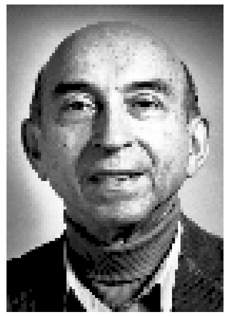
- Dr. Lotfi Zadeh, a professor of mathematics from U.C. Berkeley, proposed the fuzzy theory 1965/1967.



- Dr. Zadeh originally started his research within traditional control theory.
- He was unsatisfied with the failure of the traditional control theory to explain many phenomena such as, why a person can control a complex system that he/she cannot describe mathematically (Driving car is a good example).

Thesaurus:

- *Fuzzy*: uncertain / unclear / vague
- *Logic*: reason

Definition:

- Fuzzy logic is a mean to transform linguistic experience into mathematical information.

- Fuzziness may be related to possibility as opposed to probability.

References

Author	Nguyen, H. T. (Hung T.), 1944-
Title	**A first course in fuzzy logic / Hung T. Nguyen and Elbert A. Walker**
Publ info	Boca Raton : CRC Press, c1997

Author	Yen, John
Title	**Fuzzy logic : intelligence, control, and information / John Yen and Reza Langari**
Publ info	Upper Saddle River, N.J. : Prentice Hall, c1999

Author	Kosko, Bart
Title	**Fuzzy engineering / Bart Kosko**
Publ info	Upper Saddle River, N.J. : Prentice Hall, c1997

Author	Driankov, Dimiter
Title	**An introduction to fuzzy control / Dimiter Driankov, Hans Hellendoorn, Michael Reinfrank ; with cooperation from Rainer Palm, Bruce Graham, and Anibal Ollero ; foreword by Lennart Ljung**
Publ info	Berlin ; New York : Springer, c1996
Edition	2nd, rev. ed

Language → Mathematics

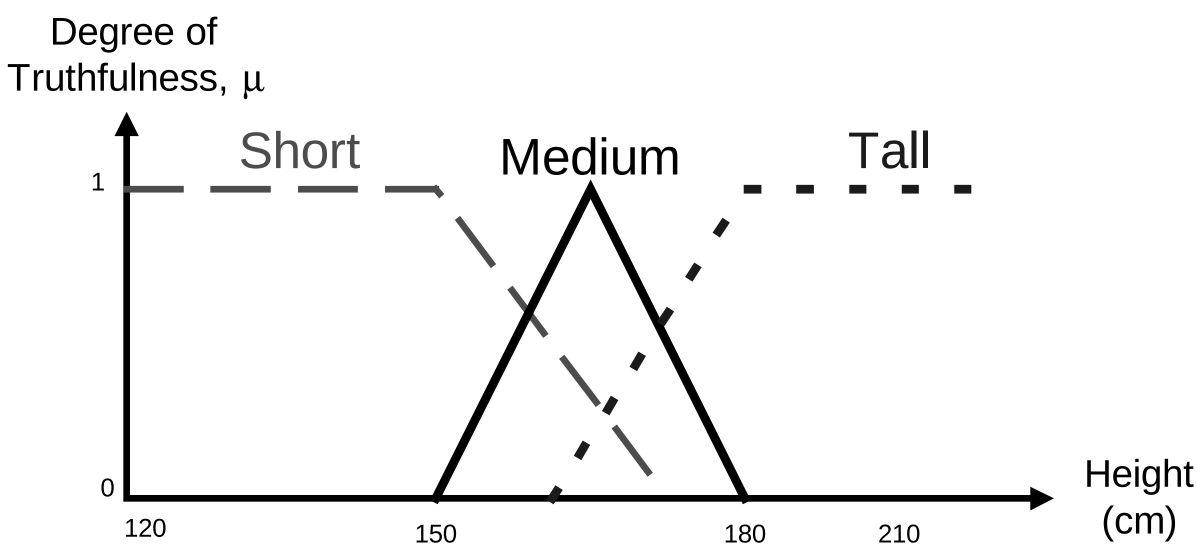
Example: Height

Height (cm)	Truthfulness
120	short (sure)
150	short (sure)
165	short (?) medium (sure) tall (?)
170	short (no way) medium (sure) tall (?)
175	short (no way) medium (?) tall (?)
180	short (no way) medium (no way) tall (sure)
.	.
.	.
.	.
.	.

Fuzzy Sets (Membership Functions):

- Membership function (fuzzy set) relates the degree of truthfulness μ (between 0,1) for a linguistic term.

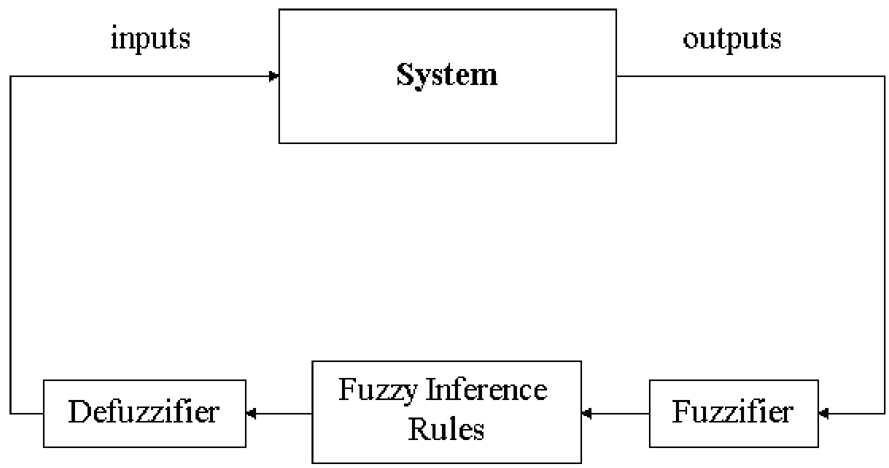
μ=0 No truth / Absolutely false / No possibility
μ=1 Full confidence / Absolutely correct / Sure thing



- The same value of a variable can be represented using more than one membership function (*check 165 cm*).
- Membership sets can be of any shape (trapezoid, triangle, gaussian, etc….)

Fuzzy Logic Controller

Fuzzy logic can be used to control systems that do not have well-defined models. Fuzzy logic controller is a feedback controller that looks like:



Fuzzifier

- The fuzzifier uses the fuzzy membership sets to define the truthfulness of a variable as shown before.

Fuzzy Inference Rules

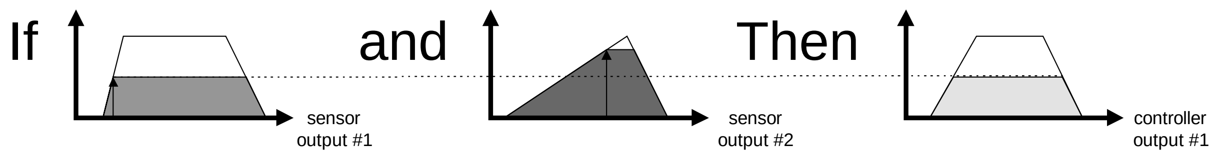
- These rules determine the actions of the controller. Each rule is in the form of:

IF {<variable #1> is <fuzzy term>}
and {<variable #2> is <fuzzy term>}
and {<variable #3> is <fuzzy term>}
and …
.
.
.
.
.
THEN
<controller input #j> is <fuzzy term>

Defuzzification:

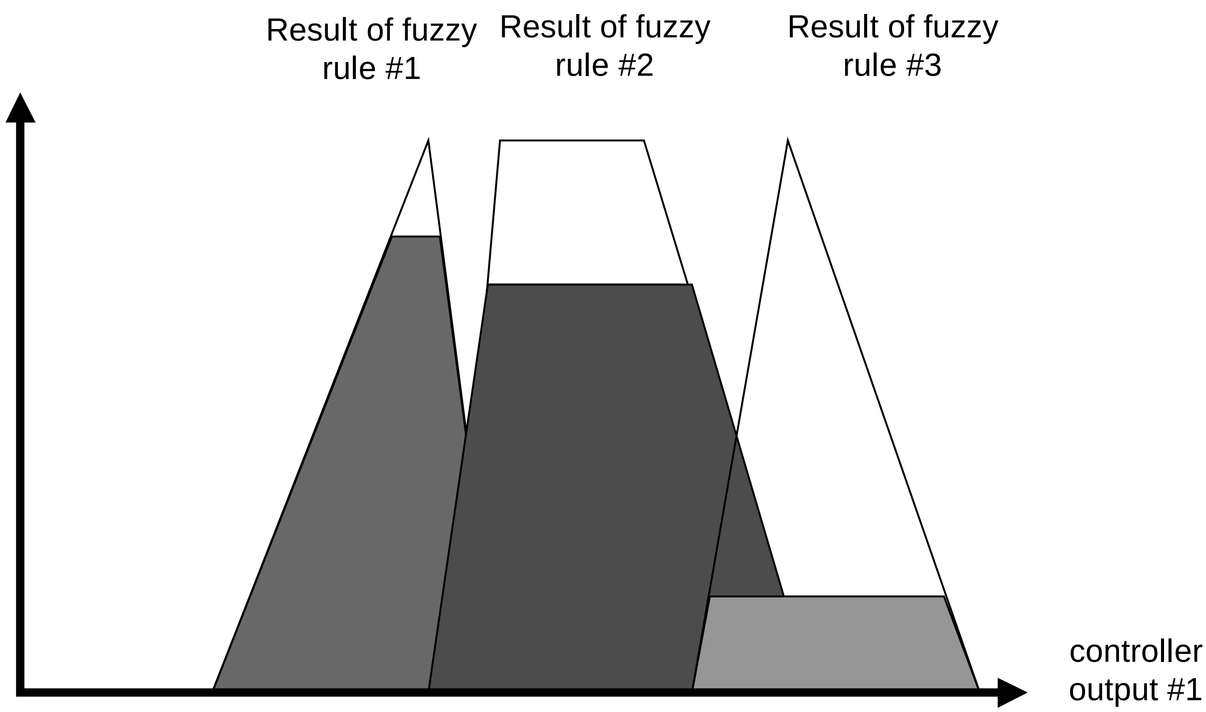
- Defuzzification starts by assigning a truth value for the control output as follows,

µ(fuzzy term of control input #j) =
min(µ(fuzzy term of sensor output #1) ,
µ(fuzzy term of sensor output #2) ,
..... ,
µ(fuzzy term of sensor output #n))



- At this stage, we know two things:
  1. What fuzzy term(s) control input #j belongs to.
  2. What is the truthfulness of each of these terms.
- However, the controller input has to be a *crisp* (definitive) number.
- Different processes of defuzzifications can achieve this goal.
- We will present here the *moment of area method*:

$$x = \frac{\sum_{i=1}^{n} A_i * rcg_i}{\sum_{i=1}^{n} A_i}$$



Example

Consider the control of a vehicle,

Model:

$$F(\phi) = m\ddot{x}$$
$$\dot{x} \geq 0$$

Objectives of the controller:

- Reach a target point at x_d meters away from the starting point
- Velocity is equal to zero at the end of the motion

Variables:

Sensor Outputs:

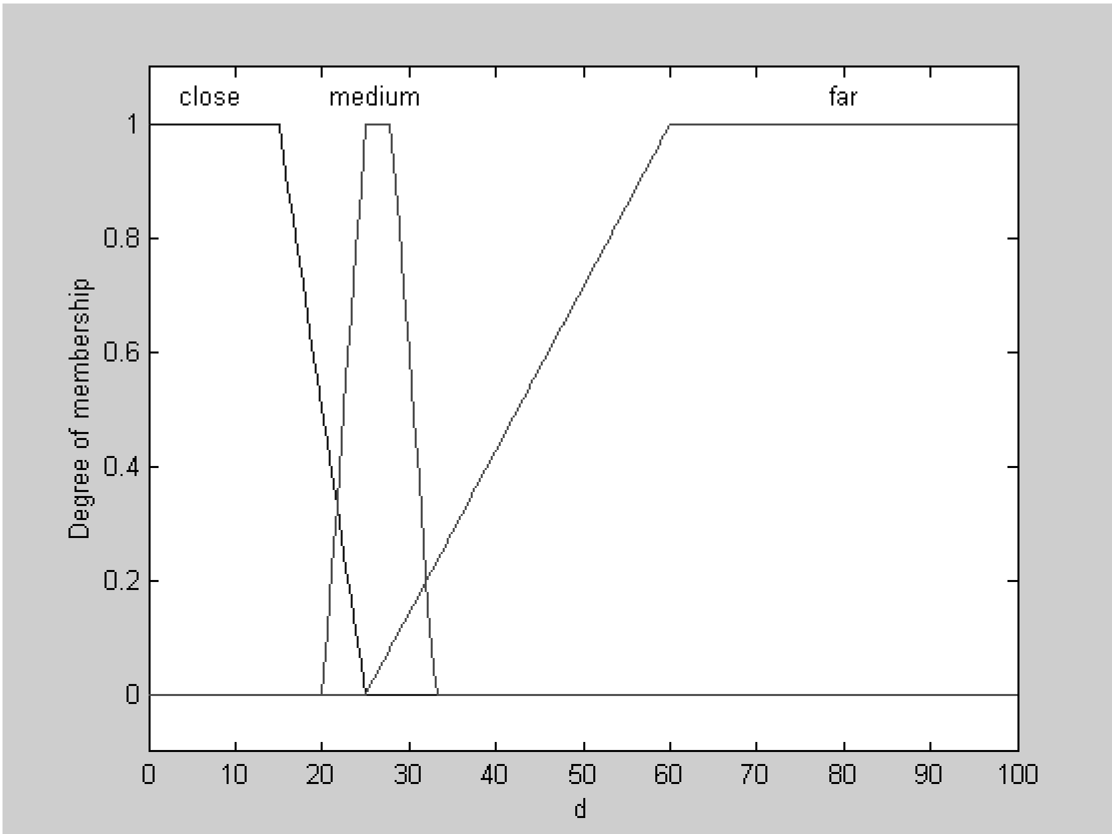
- Distance_to_target, $d=(x_d - x)$
- Velocity, v= $\dot{x}$

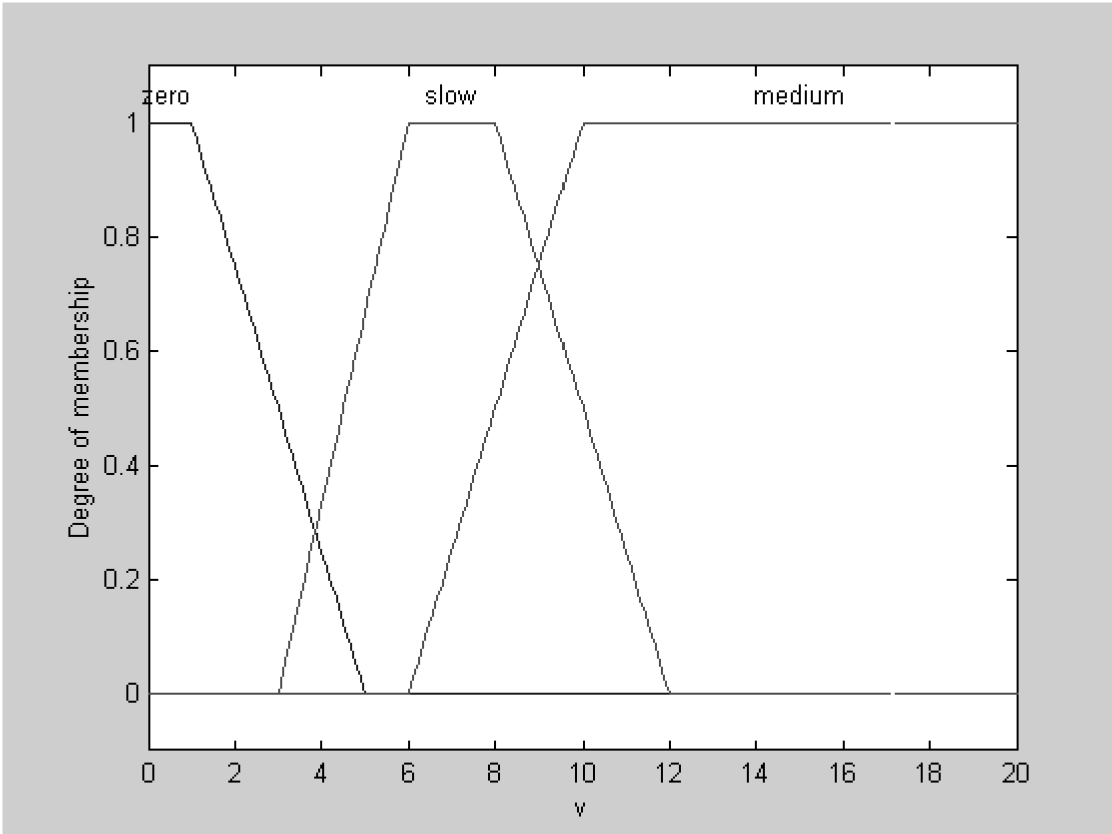
Controller input

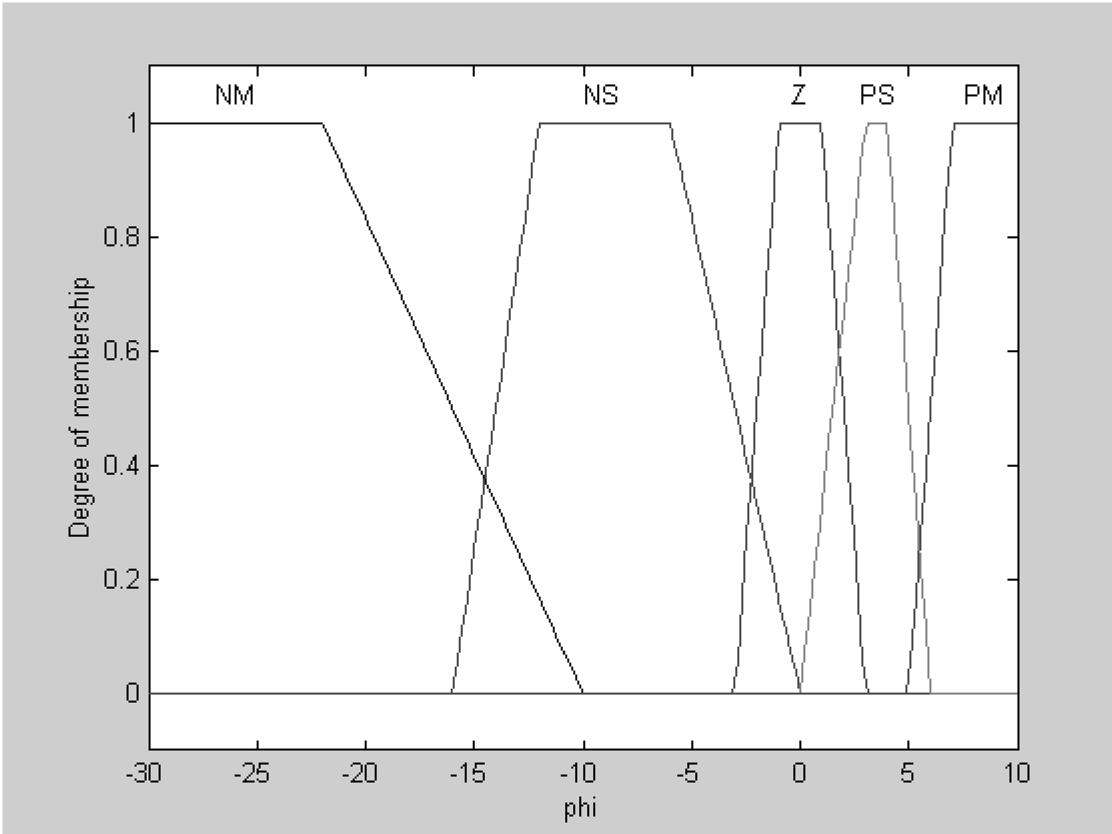
- Accelerator/Brake_angle, ϕ

Variable	**Fuzzy Terms**
d	close
	medium
	far
v	zero
	slow
	medium
ϕ	Negative Medium
	Negative Small
	Zero
	Positive Small
	Positive Medium

Fuzzy membership sets




zero
slow
medium
Degree of membership
1
0.8
0.6
0.4
0.2
0
0
2
4
6
8
10
12
14
16
18
20
v


NM
NS
Z
PS
PM
Degree of membership
1
0.8
0.6
0.4
0.2
0
-30
-25
-20
-15
-10
-5
0
5
10
phi

Fuzzy rules:

IF {<Distance_to_target> is <close>}and {<Velocity> and <medium>} THEN <Accelerator/Brake_angle> is <Negative Medium>

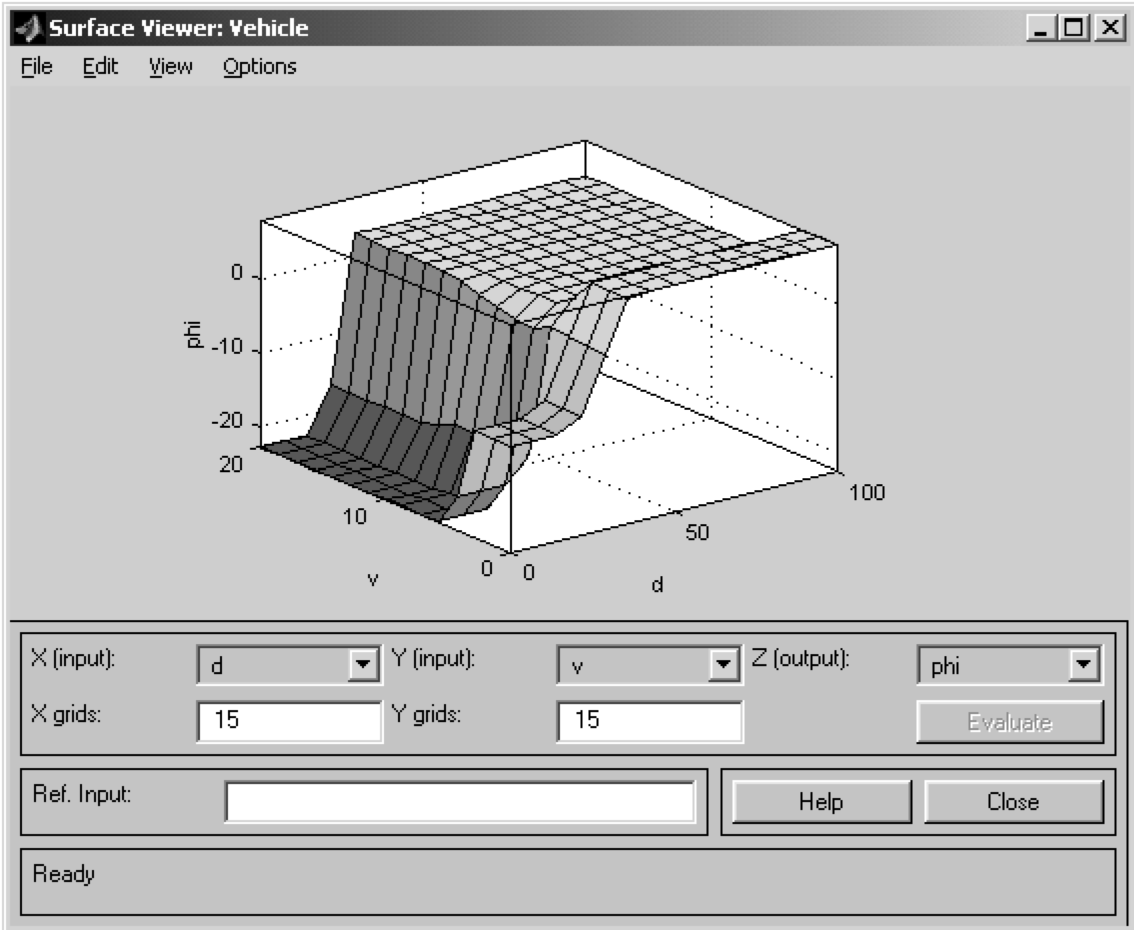
All these rules can be combined in one Table as follows,

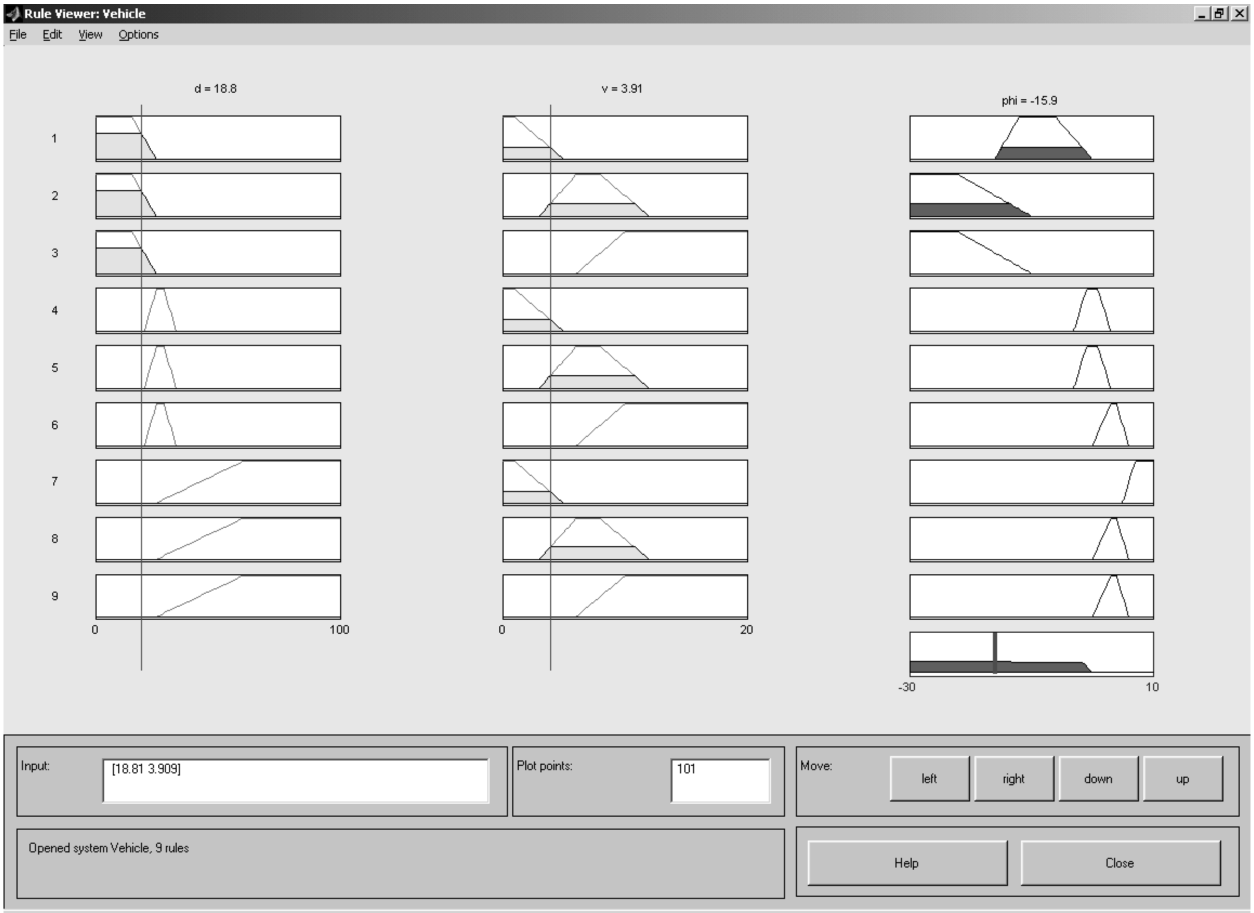
<u>Fuzzy Rules for the Autonomous Vehicle Controller</u>

Distance → Velocity ↓	C	M	F
Z	NS	Z	PM
S	NM	Z	PS
M	NM	PS	PS

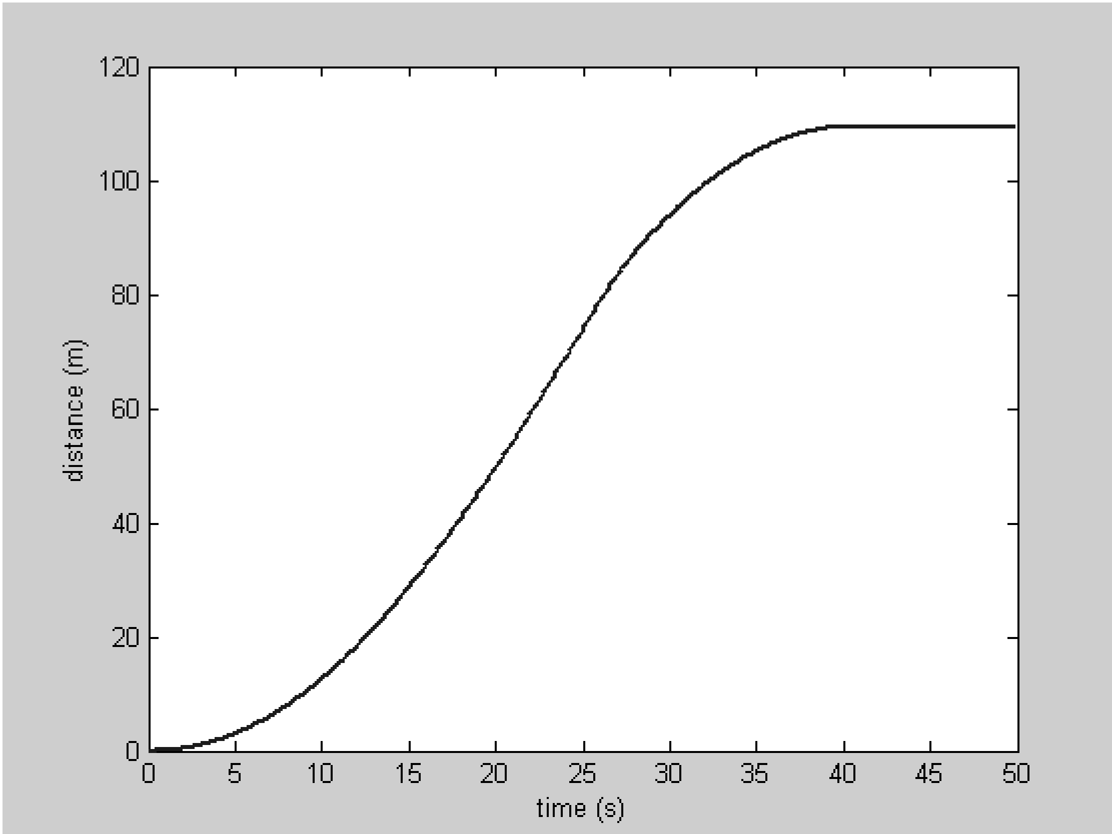
Note:

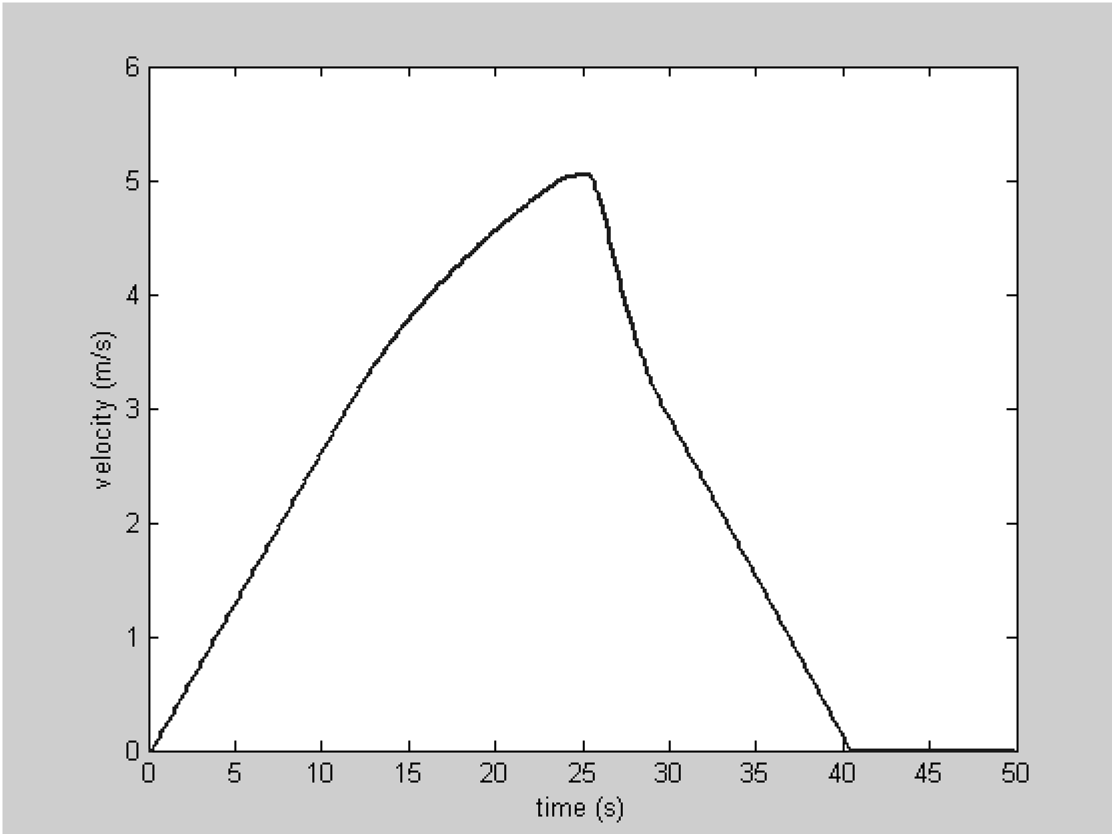
C = close　　B = big　　S = small
M = medium　　Z = zero
P = positive　　N = negative


Surface Viewer: Vehicle
File
Edit
View
Options
phi
0
-10
-20
20
10
v
0
0
50
100
d
X (input):
d
Y (input):
v
Z (output):
phi
X grids:
15
Y grids:
15
Evaluate
Ref. Input:
Help
Close
Ready

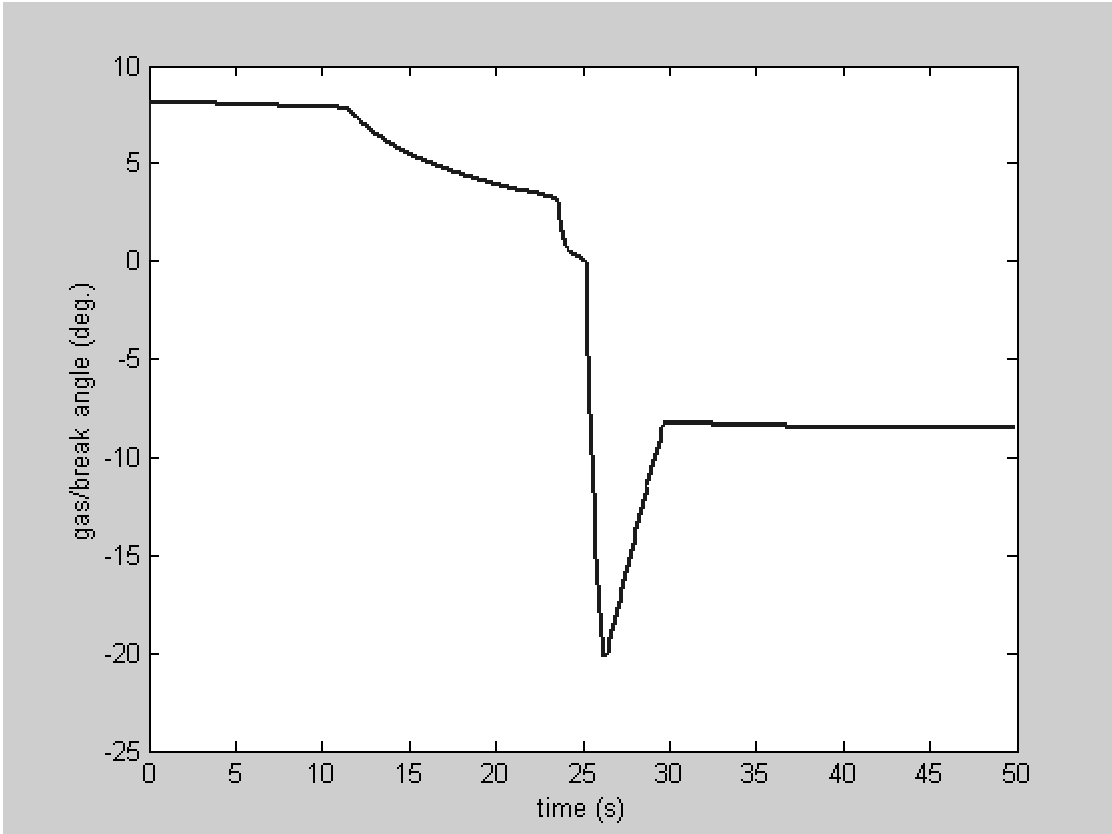

Rule Viewer: Vehicle
File
Edit
View
Options
d = 18.8
v = 3.91
phi = -15.9
1
2
3
4
5
6
7
8
9
0
100
0
20
-30
10
Input:
[18.81 3.909]
Plot points:
101
Move:
left
right
down
up
Opened system Vehicle, 9 rules
Help
Close

Results





velocity (m/s)
time (s)
0
1
2
3
4
5
6
0
5
10
15
20
25
30
35
40
45
50


10
5
0
-5
-10
-15
-20
-25
gas/break angle (deg.)
0
5
10
15
20
25
30
35
40
45
50
time (s)