Приложение на Теорията на Размитата Логика при Моделирането на Бизнес Процеси и Вземане на Управленски Решения

Fuzzy Logic Applications to Modeling of Business Processes and Management Decision Making

Ганчо Вачков (*Gancho Vachkov*)
International Business School (IBS)
Distance Learning Center, Sofia
E-mail: gvachkov@ibsedu.bg
gancho.vachkov@gmail.com

Public Lecture

IBS
February 21st, 2018

Short Biographical Notes:

- **Education:** Control Engineer -TU-Sofia (1965);
  Ph.D. – 1978 (UCTM-Sofia)
- **Work Experience**:

- **Bulgaria**, Sofia - University of Chemical Technology and Metallurgy (1970 - 1996);

- **Japan** (1996 – 2012): Kitami Institute of Technology (1996-1998); Nagoya University (1998-2002); Kagawa University (2002-2011); Yamaguchi University (2011-2012);

- **Fiji Islands**, Suva: University of the South Pacific (USP): 2012-2013; 2014, 2015;
- **Azerbaijan**, Baku: Baku Higher Oil School (BHOS): 2016-2017.
- **Currently**: International Business School (IBS), Botevgrad; Distance Learning Center, Sofia

Work Locations on the World Map:

Map of Teaching Locations in Japan

- Kitami Institute of Technology
- Nagoya University
- Kagawa University
- Yamaguchi University

Research Interests:

- Fuzzy Logic Control and Applications
- Fuzzy and Neural Modeling – Industrial and Robotics Applications
- Data Clustering and Unsupervised Algorithms
- Intelligent Data Analysis and Evolving Systems
- Learning Algorithms and Multi-agent Methods for Optimization
- Fault Diagnosis in Industrial and Complex Systems
- Performance Evaluation and Monitoring

Outline of the Presentation

- Historical Remarks about Fuzzy Logic and Systems
- The Concept of Fuzzy Sets, Membership Functions, Membership Degree, Linguistic Variables
- Structure of the Fuzzy Rules and Fuzzy Rule Base
- Content of the Parameter Base
- General Structure of the Fuzzy Decision Making Unit (FDMU)
- Calculation Steps of the FDMU:

  Fuzzification, Fuzzy Inference and De-Fuzzification
- General Structure of the Fuzzy Logic Controller – examples
- Some Details, Considerations and **Discussions**

Historical Remarks on Fuzzy Logic and Fuzzy Systems

- Fuzzy Sets – Lotfi Zadeh (1965)
- Fuzzy Control and Applications – *E. Mamdani* (UK, 1974); *T. Yamakawa* (Japan, 1986)
- Fuzzy Modeling and Decision Making

Michio Sugeno (Japan);
Takagi-Sugeno (TS) *Fuzzy Model (1985)*

Supporting Algorithms used in Fuzzy Logic:

Learning Algorithms and Multi-agent **Optimization Algorithms**: Particle Swarm Optimization (PSO); Genetic Algorithms (GA); **Clustering Algorithms**

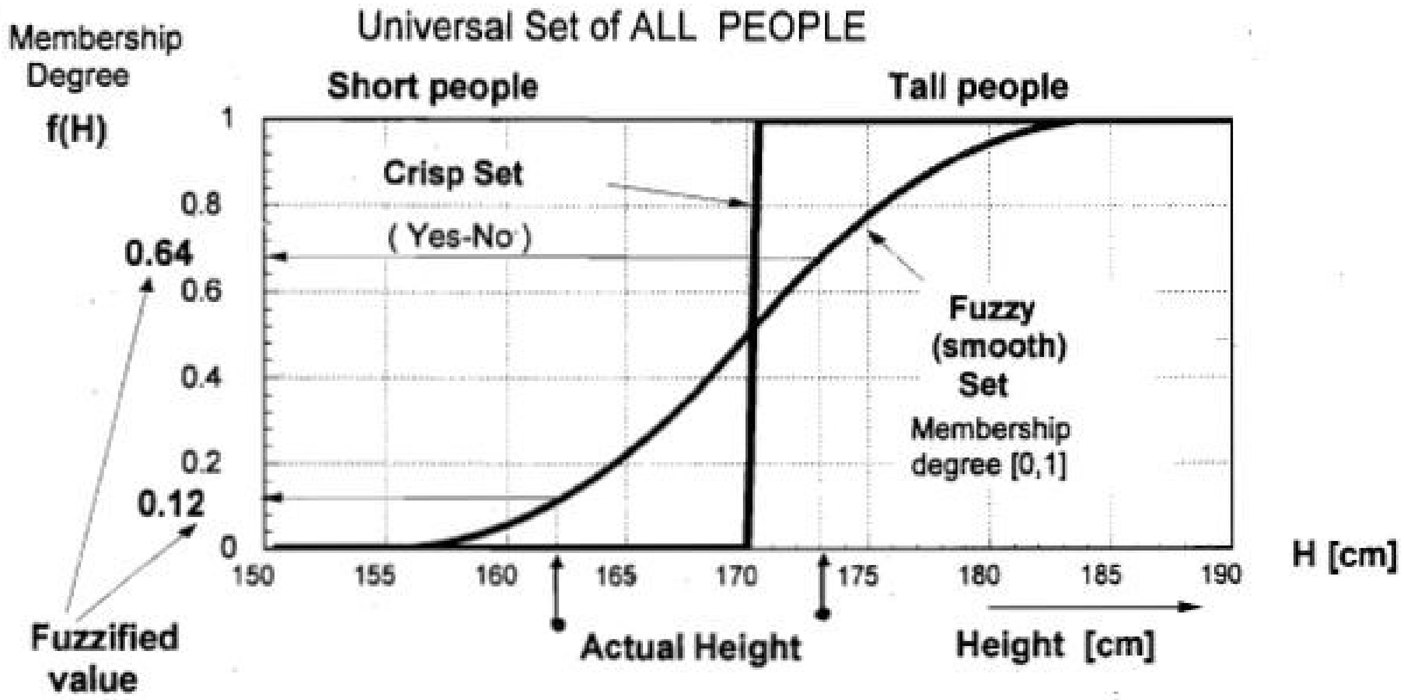
History of Fuzzy Sets

FUZZY SETS THEORY & APPLICATIONS

1965 - Lotfi ZADEH

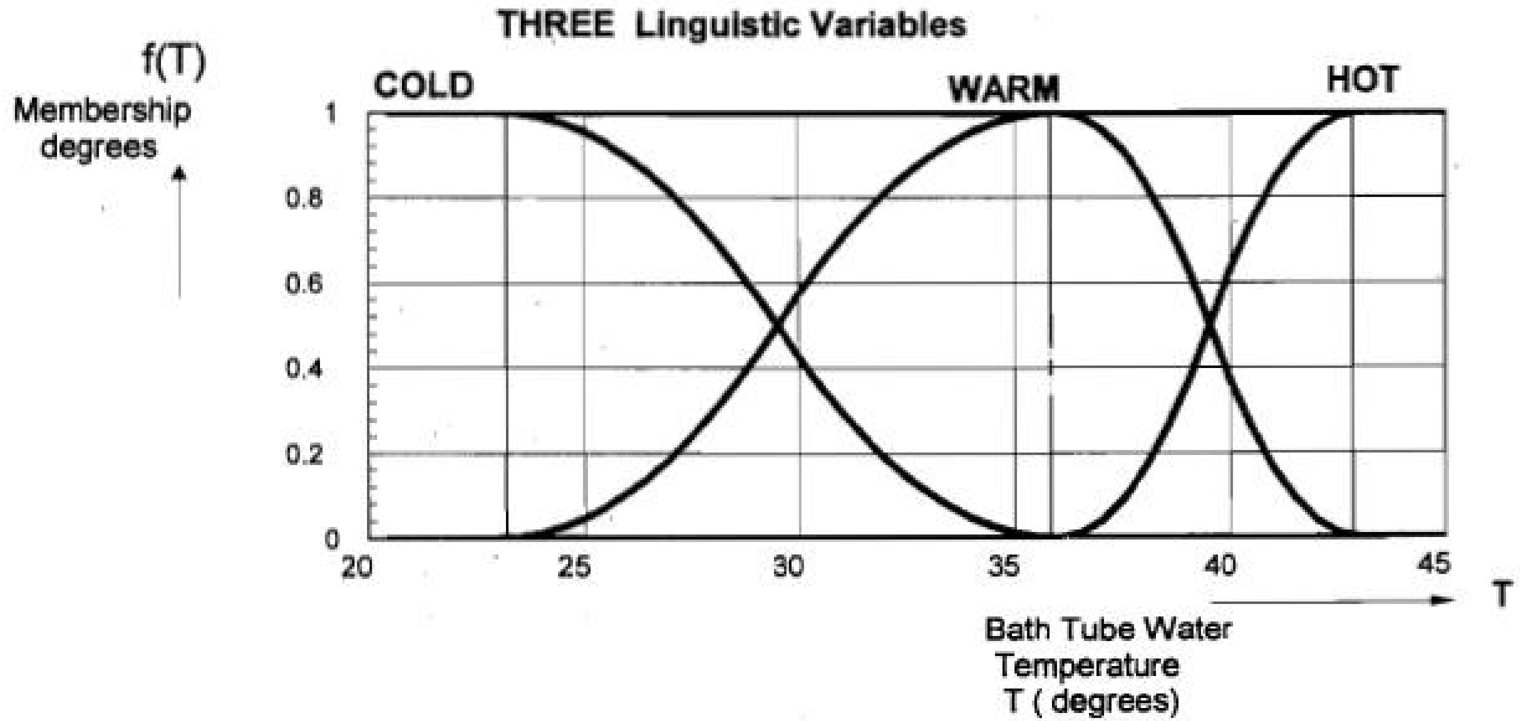
(Berkeley University, California, USA)

1974 - A. Mamdani (UK) - Fuzzy Control



Fuzzy Sets and Ordinary (Crisp) Sets

Fuzzy Sets versus the Ordinary (Crisp) Sets



Membership Function for 3 Lingusitic Variables:

Cold*, *Warm* and *Hot Bath Tube Water.

Human Experts use Fuzzy Logic and Fuzzy Rules in Decision Making

HUMANS USE **KNOWLEDGE** from the type of **HEURISTIC RULES** IN THEIR EVERYDAY LIFE TO SOLVE DIFFERENT PROBLEMS !

HUMANS DO NOT LIKE PURE MATHEMATICS !

HEURISTIC RULES ARE FROM THE TYPE :

IF < CONDITIONS> **THEN** <CONCLUSIONS>

IF < CAUSES > **THEN** < EFFECTS>

IF < ACTION> **THEN** < RESPONSE, REACTION>

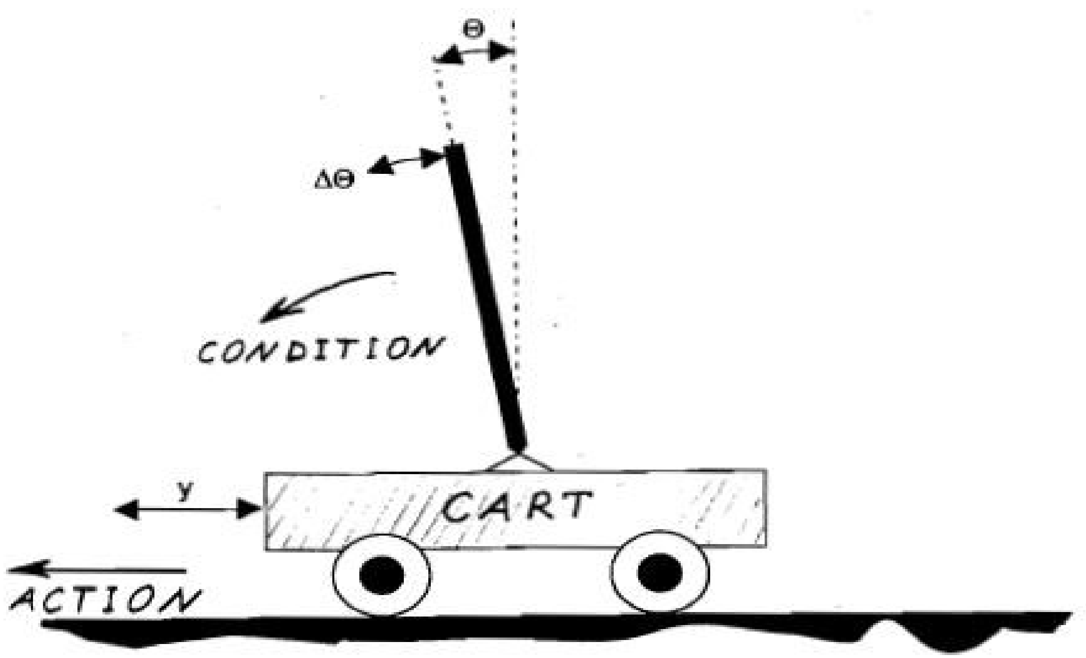
Inverted Pendulum – Typical Example of a Fuzzy Logic Control

INVERTED PENDULUM EXAMPLE

(BALANCING A BROOM STICK)

RULE: **IF** (THE STICK IS MOVING FORWARD)

THEN (MOVE the CART FORWARD)



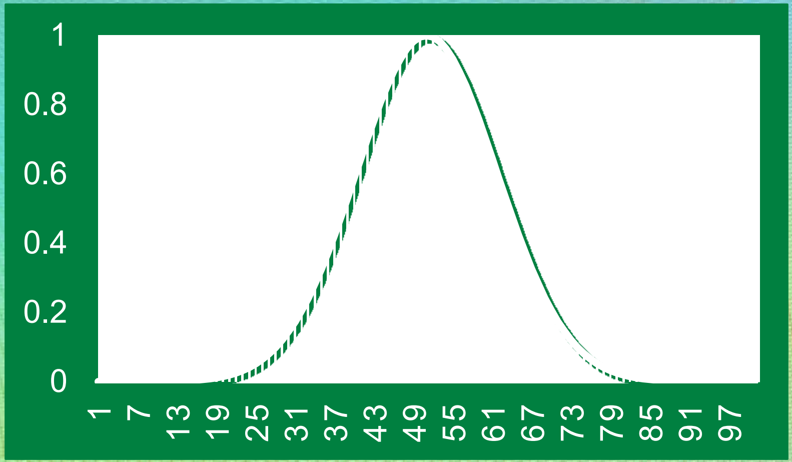
Basic Notions in Fuzzy Logic

Fuzzy Set – it corresponds to a respective predefined **Linguistic Variable** (name) with its predefined **Membership Function**

Example:

A Fuzzy Set is represented by the Linguistic Variable (name assigned by human) - ***Medium***

The respective Membership Function is assumed as smooth Gaussian Function:



Basic Notions in Fuzzy Logic (2)

Normally, each Process Variable (usually an Input of a Process or System) is observed by Human or measured by a Sensor as a real numerical value.

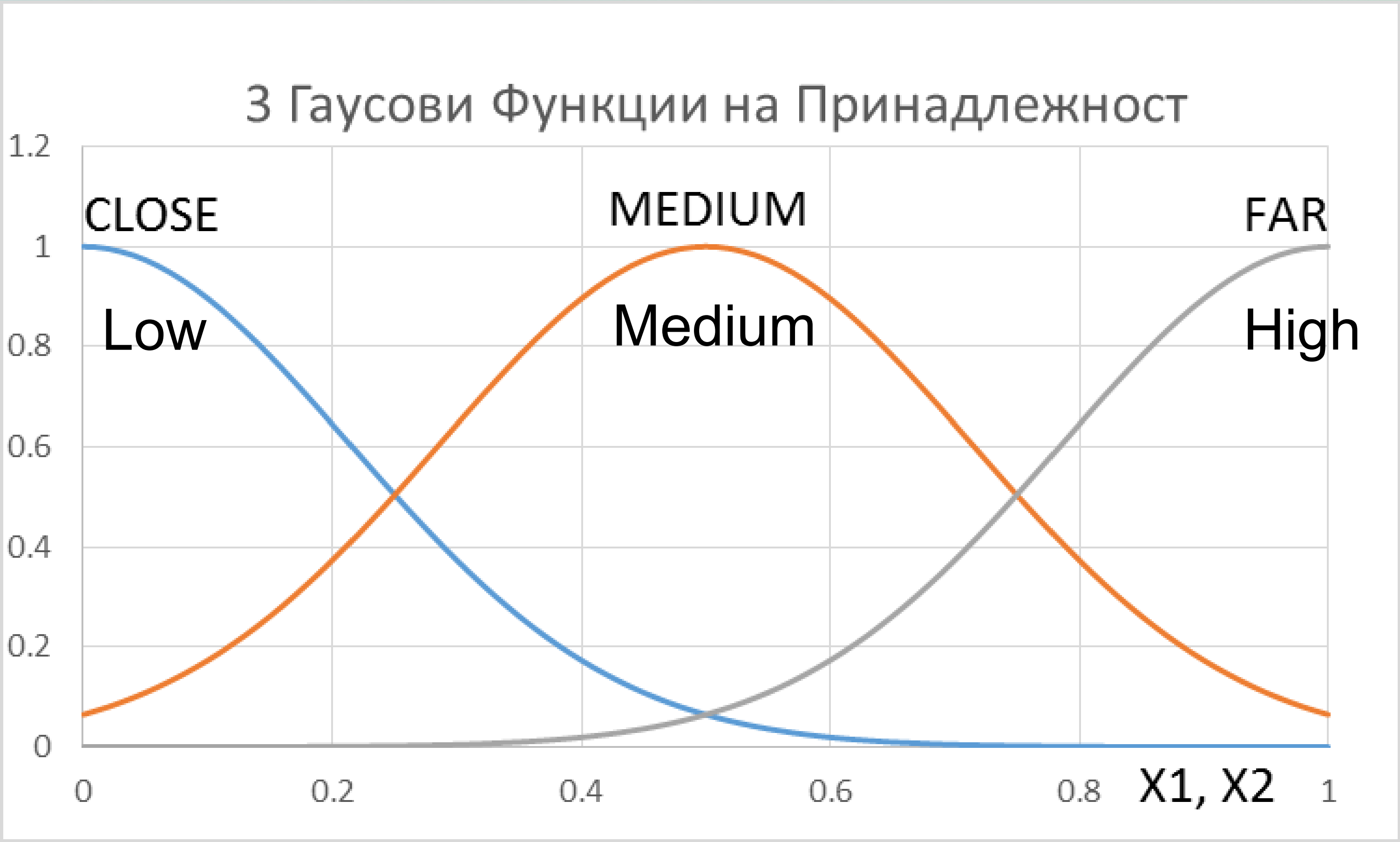
We discretize the whole range of this variable to a predefined number of Fuzzy Sets with given Linguistic Variables and their respective Membership Functions.

Example: The Real measured variable is: *Temperature* with *three Linguistic Variables:*

Low, ***Medium***, ***High***

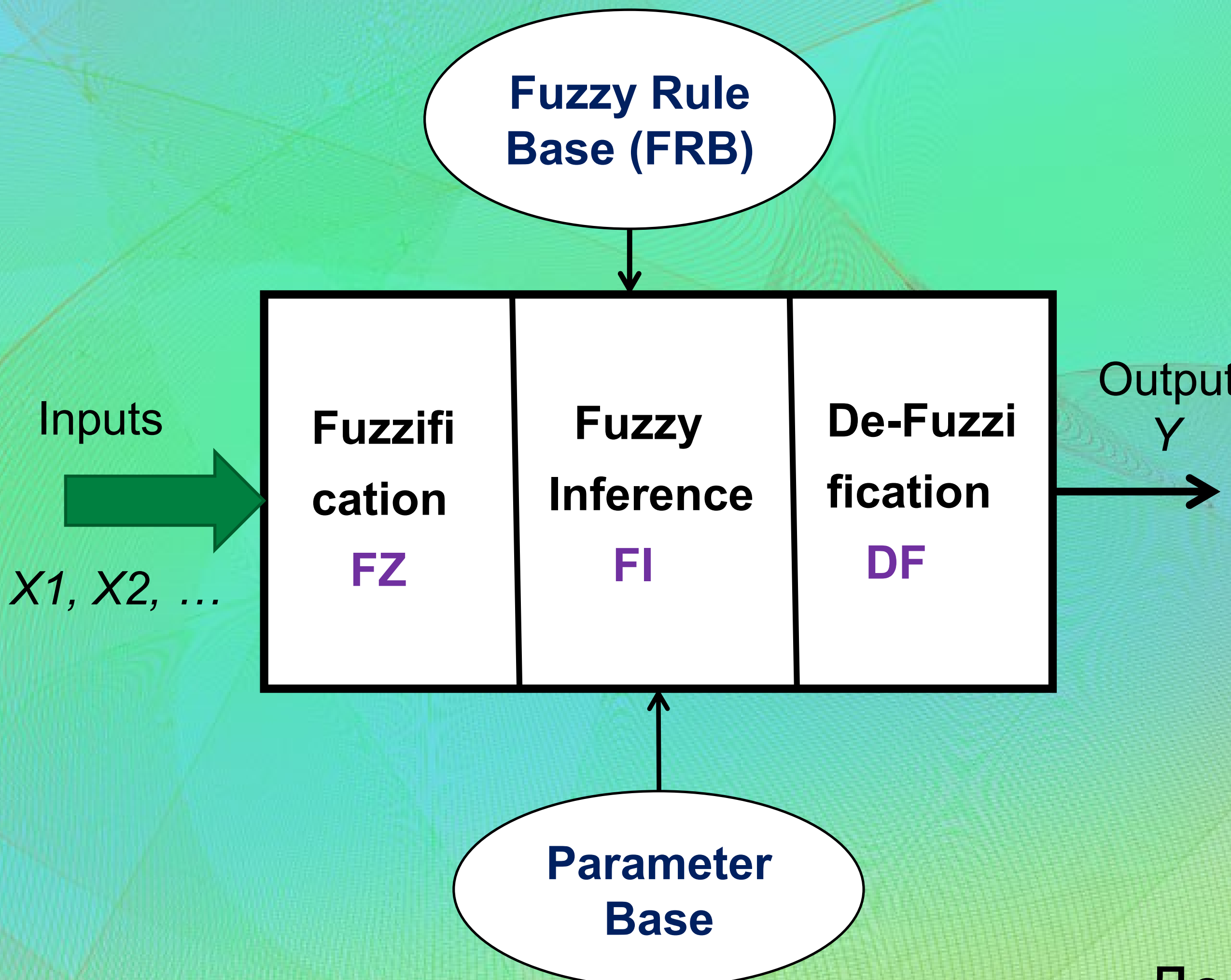
and their respective Membership Functions, assumed as **Gaussian Type.**

Three Gaussian Membership Functions assigned by Human for the Process Parameter: Temperature



Observed Process Parameter: **Temperature**

General Structure of the Fuzzy Decision Making Unit (FDMU)



Размиване

Формиране на Извод

Де-Размиване

База Размити Правила

Structure of the **Fuzzy Rule Base**

It consists of a List of Fuzzy Rules with the following **If-Then** Format:

IF (Antecedent) **THEN** Consequent

IF (Situation) **THEN** Decision

(Condition) (Action)

<u>Example</u> for a Fuzzy Rule to control the Temperature of a Boiler (Heat-Exchanger):

IF (<u>Temperature</u> is ***Low*** **AND** <u>Flowrate</u> is ***Medium***)

THEN Open ***Slightly*** the Valve (to increase the Heat)

(The Control Action)

Two types of Fuzzy Rules

1) **Fully** Linguistic Fuzzy Rules (M*amdani* type Fuzzy Rules)

IF (X1 is ***Low*** **AND** *X2* is ***Big***) **THEN** *Y* is ***Medium***

X1, X2 and *Y* are represented by Linguistic Variables

2) **Semi** Linguistic Fuzzy Rules (*Takagi-Sugeno* type of Fuzzy Rules) with **Singletons** (Real Numbers) as Output

Crisp Value

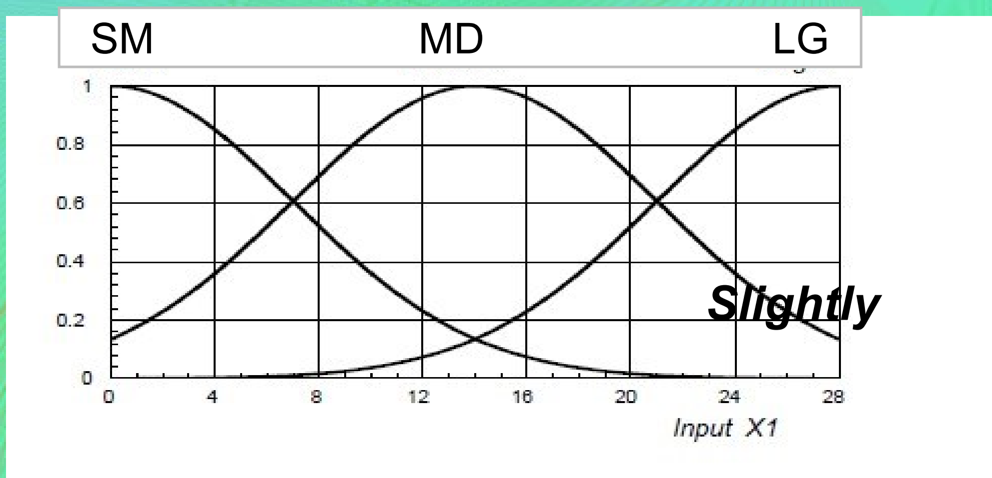
IF (X1 is ***Low*** **AND** *X2* is ***Big***) **THEN** *Y* **=** *12.50* (*Singleton*)

X1, X2 are represented by Linguistic Variables and *Y* is a real (crisp, numerical) value, called Singleton

Membership Functions

They are defined for each Input separately !

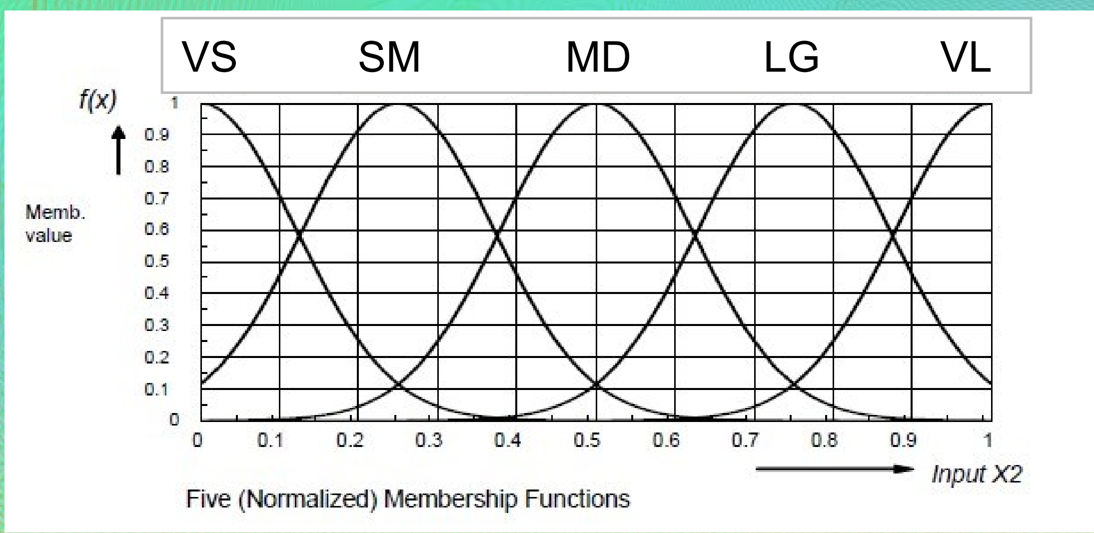
<u>Example:</u> FDMU with two Inputs *X1* and *X2* and One Output *Y*



3 Membership Functions, Defined for the Input *X1*

Small SM;
Medium MD,
Large LG

Gaussian Type (smooth) Membership Functions



Five (Normalized) Membership Functions

5 Membership Functions, defined for the Input X1

Very Small VS,
Small SM,
Medium MD,
Large LG,
Very Large VL

Fuzzy Rule Base (FRB) of the Fuzzy Decision Making Unit (FDMU)

Example:

3 X 5 = **15** Fuzzy Rules

For the Output *Y*,
The following *5* **Linguistic Variables** have been defined:

VS – Very Small
SM – Small
MD – Medium
LG – Large
VL – Very Large

X1 / X2	SM	MD	LG
VL	LG	VL	VL
LG	MD	LG	LG
MD	MD	MD	LG
SM	SM	MD	MD
VS	VS	SM	MD

Input *X2* ↑

→ Input X1

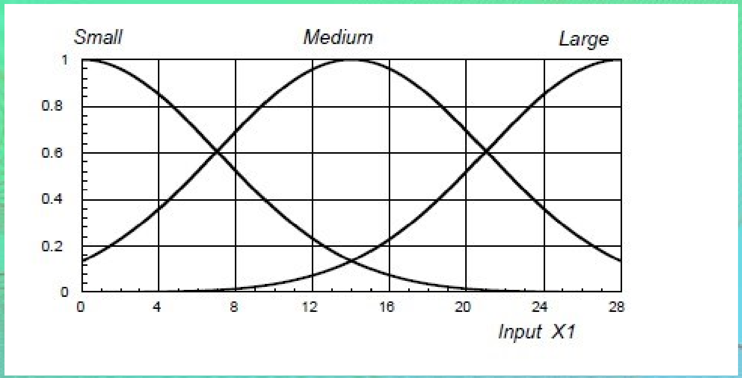
Fuzzy Rule base is created by a Human EXPERT !

Types of Membership Functions used for Fuzzy Modeling and Fuzzy Control

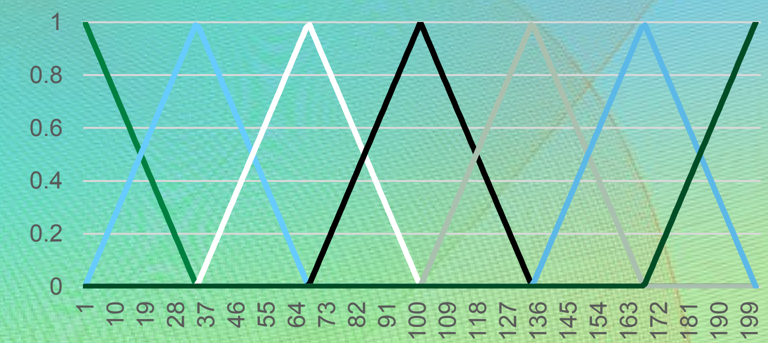
- Gaussian Membership Functions

  (mainly for Fuzzy Modeling)

$$A_i(x) = \exp\left(-\frac{(x-c_i)^2}{2\sigma_i^{\,2}}\right),\ i=1,2,\ldots,L$$



- Triangular Membership Functions (Fuzzy Control)
- Trapezoidal Membership Functions (Fuzzy Control)



- Any other type and shape, given by the Human Expert (mostly for Decision Making)

The Parameter Base

- This is the complete set of parameters that are involved in the calculation steps of the FDMU. The appropriate tuning of all these parameters (or at least part of them) is mandatory ! This tuning improves significantly the performance (desired output) of the FDMU. Otherwise the FDMU has no meaning !
- The List of these Parameters includes:

- The number of the assumed Linguistic Parameters for each Input and for the Output (level of **granulation**);
- Parameters controlling the Locations of the Membership Functions (e.g. Center, Left Boundary, Right boundary);
- Parameters controlling the Shape of the Membership functions (e.g. width, steepness etc.);
- Assumed Values of the Singletons representing the Outputs of the Fuzzy Rules.

1) Fuzzification FI (Размиване)

This is a computational step of **Mapping** (a correspondence) between a given **“crisp” numerical value** of the Input (e.g. a real measurement from a sensor) and all the respective **Membership Degrees** for all assumed Linguistic Variables for this Input.

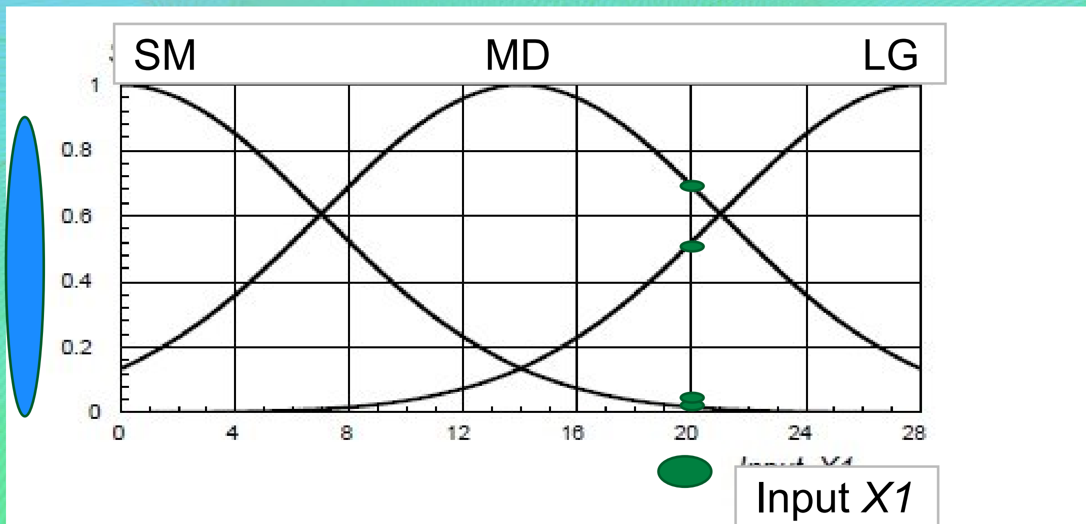
These Membership Degrees (each of them a real number between *0.0* and *1.0*) are easily calculated from the respective algebraic equations of the Membership Functions (e.g. Gaussian Function, Triangular function, Trapezoidal Function, Bell Function etc.)

In short: **Fuzzification** is a Mapping procedure of the type:

One to Many, that is:

One real value of the Input corresponds to ***L*** membership degrees, calculated from all *L* Membership Functions, defined for this Input.

Example of Fuzzification

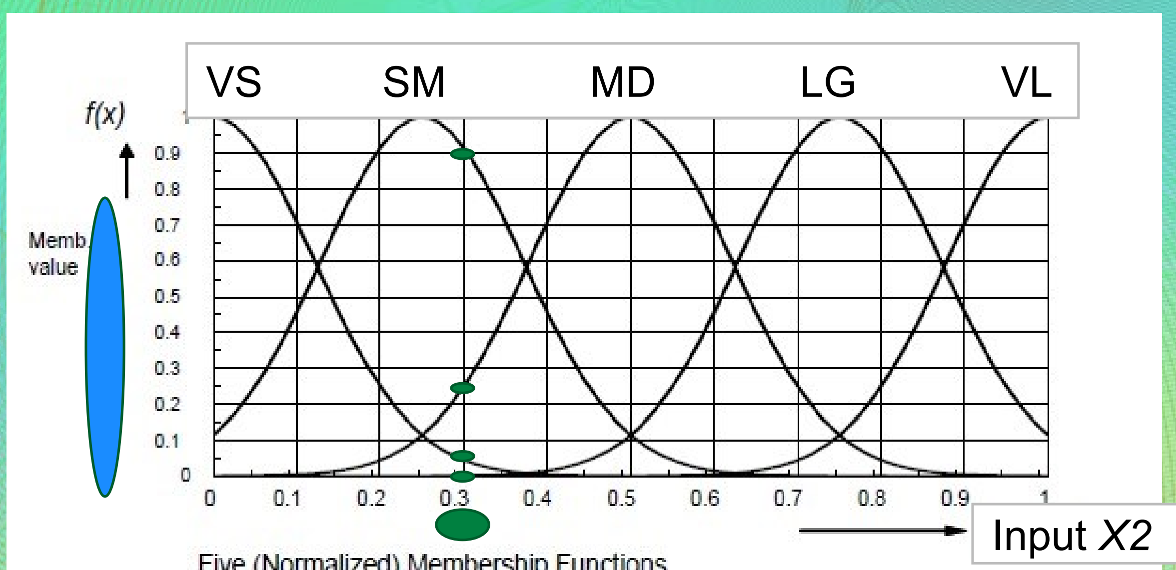


X1 = 20

L = 3

$$f_{SM} = 0.02$$
$$f_{MD} = 0.70$$
$$f_{LG} = 0.55$$

$$\sum = 1.27$$



X2 = 0.30

L = 5

$$f_{VS} = 0.04$$
$$f_{SM} = 0.90$$
$$f_{MD} = 0.25$$
$$f_{LG} = 0.00$$
$$f_{VL} = 0.00$$

$$\sum = 1.19$$

Result of the Fuzzification Step (the Mapping) for this Example:

Input 1

X1 = 20

$f_{SM} = 0.02$

$f_{MD} = 0.70$

$f_{LG} = 0.55$

Membership Degrees:

$$\sum = 1.27$$

Input 2

X2 = 0.30

$f_{VS} = 0.04$

$f_{SM} = 0.90$

$f_{MD} = 0.25$

$f_{LG} = 0.00$

$f_{VL} = 0.00$

Membership Degrees:

$$\sum = 1.19$$

2) Fuzzy Inference

Computation Steps
(Формиране на Извод)

This is the first part of the process of Fuzzy Decision Making. The aim is to calculate the so called Truth Value *Tv* of each Fuzzy Rule from the Fuzzy Rule Base (FRB).

The *Tv* is also called: Strength, Firing Degree, Activation Degree. Note that in the Fuzzy Sets concept, we are dealing with not only the two crisp cases 0.0 and 1.0 like:

Tv = 0.0 → The Fuzzy Rule is not Activated (not true)

Tv = 1.0 → The Fuzzy Rule is fully Activated (true)

but also with all intermediate values, in which the Activation Degree is a real number between *0.0* and *1.0*, for example:

Tv = 0.7 → The Fuzzy Rule is strongly Activated (i.e. this Rule is quite true) or

Tv = 0.3 → The Fuzzy Rule is a little Activated (not very true)

Different Operations of the Fizzy Inference

There are two main operations in the Fuzzy Inference procedure:

Min Operation and *Product Operation*

(as explained below)

The ***Product Operation*** is most frequently used, because it is more sensitive to any changes in the inputs *X1* and *X*2.

Therefore the Product Operation is the preferred choice not only for Fuzzy Control applications, but also for various Fuzzy Modeling Applications

The Two Operations to calculate the Truth Value *Tv of a given Fuzzy Rule*:

1. ***Min*** Operation

$$Tv = min\{f_{X1}, f_{X2}\}$$

2. ***Product*** Operation

$$Tv = f_{X1} \times f_{X2}$$

f_{X1} for Small (**SM**)

f_{X2} for Medium (**MD**)

Here $0.0 \le f_{X1} \le 1.0$ and $0.0 \le f_{X2} \le 1.0$

are the calculated fuzzy membership degrees for the two linguistic variables (one for the Input *X1* and another for the Input X2) that participate in this Fuzzy Rule

Example: IF{*X1* is **SM** AND *X2* is **MD**} THEN Y is MD

Calculating the Truth Values of the Fuzzy Rules for given Inputs of *X1* and *X2:*

X1 = 20 and *X2 = 0.30*

A) Min Operation

Fuzzy Rule: IF(*X1* is **LG** AND *X2* is **MD**) THEN *Y* is LG

$$f_{LG} = 0.55; \quad f_{MD} = 0.25; \quad Tv = min\{0.55,\, 0.25\} = \mathit{0.25}$$

Fuzzy Rule: IF(*X1* is **MD** AND *X2* is **SM**) THEN *Y* is MD

$$f_{MD} = 0.70; \quad f_{SM} = 0.90; \quad Tv = min\{0.70,\, 0.90\} = \mathit{0.70}$$

B) Product Operation

Fuzzy Rule: IF(*X1* is **LG** AND *X2* is **MD**) THEN *Y* is LG

$$f_{LG} = 0.55; \quad f_{MD} = 0.25; \quad Tv = 0.55 \times 0.25 = \mathit{0.1375}$$

Fuzzy Rule: IF(*X1* is **MD** AND *X2* is **SM**) THEN *Y* is MD

$$f_{MD} = 0.70; \quad f_{SM} = 0.90; \quad Tv = 0.70 \times 0.90 = \mathit{0.6300}$$

Activation *Tv* of All Fuzzy Rules for the Inputs: *X1 = 20* and *X2 = 0.3*

Assumed Singletons** (Consequents) of the Fuzzy Rules**):

VS = 0.5; SM = 1.5; MD = 3.0; LG = 5.0; VL = 8.0

Activation Levels of All Rules:
Tv [*0.0* ←→ *1.0*]

X1 / X2	SM	MD	LG
VL	0.0	0.0	0.0
LG	0.0	0.0	0.0
MD	0.005	0.175	**0.1375**
SM	0.018	**0.630**	0.495
VS	0.0008	0.028	0.022

Singletons of all Fuzzy Rules
(the Consequents)

X1 / X2	SM	MD	LG
VL	**5.0**	**8.0**	**8.0**
LG	**3.0**	**5.0**	**5.0**
MD	**3.0**	**3.0**	**5.0**
SM	**1.5**	**3.0**	**3.0**
VS	**0.5**	**1.5**	**3.0**

Computation Steps

3) Defuzzification (Де-Размиване)

This is the third (final) computation step and the *second part* of the decision making procedure of the FDMU.

Defuzzification is a process, in which the final decision (final output) of the FDMU is represented

as a crisp (real) value *Y for any* furher use (for example: for real *Control Output)*.

This is done by a kind of **Aggregation** of all the local outputs of all Fuzzy Rules in the FRB.

The idea is that all fuzzy rules contribute to some degree (between *0.0* and *1.0*) to the final decision and we have to blend their local solutions in order to produce the Global one.

Defuzzification (2)

The semi-linguistic type of Fuzzy Rules have Linguistic variables as Antecedents and Singletons (real values) as Consequents. They are currently the most often used type of Fuzzy Rules. Especially, the famous *Takagi-Sugeno* (TS) Fuzzy Models and TS Fuzzy Controllers use these types of Fuzzy Rules.

Fuzzy Rule i: **IF** (X1 is ***Low*** **AND** *X2* is ***Big***) **THEN**
Yi **=** *10.0* (Singleton) ← Local Output of this Fuzzy Rule

If the case of Semi-Lingustic Fuzzy Rules for Fuzzy Control or Fuzzy Modeling, the following **Weighted Average** Defuzzification method is used to calculate the final output from the FDMU:

The **Weighted Average Method** for Defuzzification (Метод на претегленото средно)

$$Y = \frac{\sum_{i=1}^{L} y_i Tv_i}{\sum_{i=1}^{L} Tv_i}$$

The final Real Output from the Fuzzy Decision Making Unit (FDMU)

L – Number of All Fuzzy Rules in the Fuzzy Rule Base

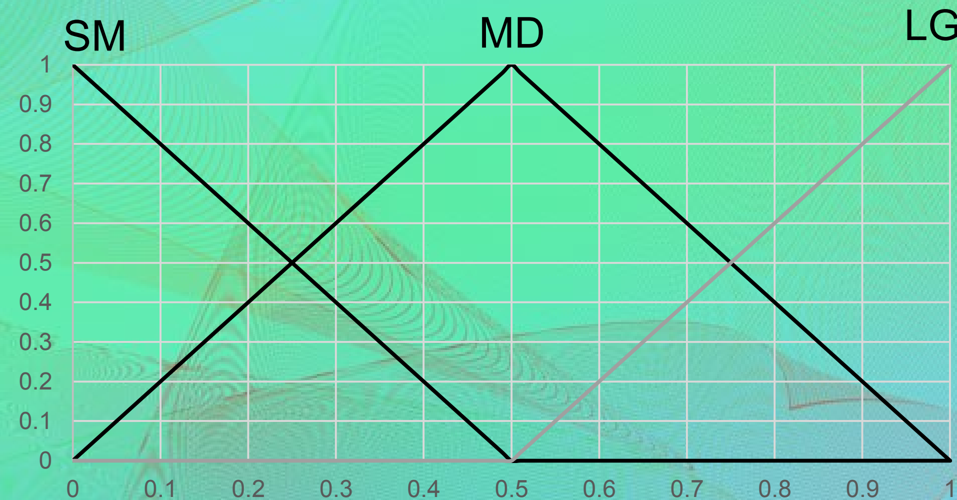
$y_i,\ i=1,2,...,L$ – The Consequents (Singletons) of all Fuzzy Rules

$Tv_i,\ i=1,2,...,L$ – The Activation Degrees (Truth Values) of all Fuzzy Rules

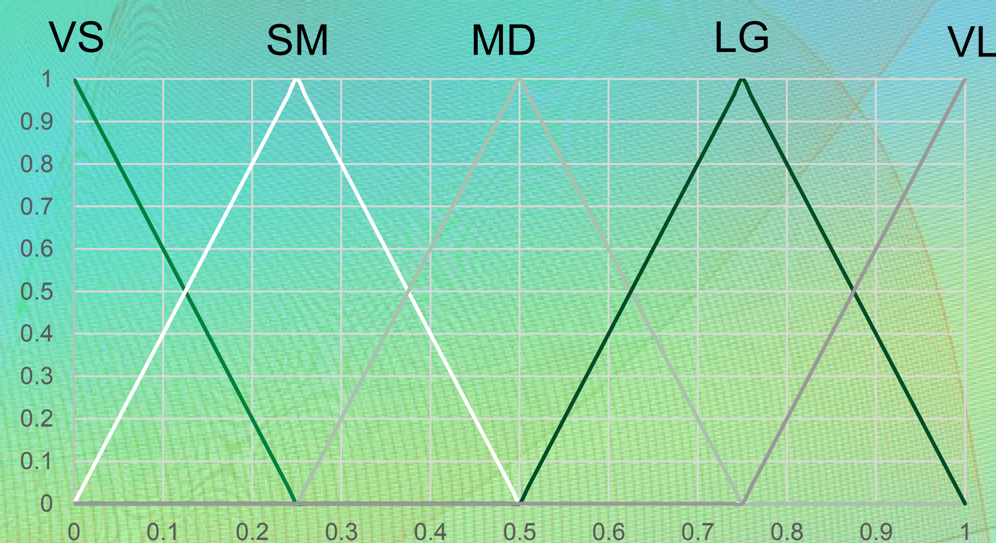
Note: In the particular case of using <u>Triangular Membership Functions</u> for all inputs that <u>overlap</u> at a membership degree *0.5*, the denominator is always *1.0* and can be omitted (Why?). This is the often case in designing the **Fuzzy Logic Controllers**

Example of using Normalized Triangular Membership Functions that overlap at a Membership Degree of *0.5*

Input1 with
3 Membership
Functions



For any given pairs of Inputs *X1* and *X2*, only **4** Fuzzy Rules from the FRB will be activated ! **Why** ?



Input2 with
5 Membership
Functions

L = 3 x 5 = 15 Fuzzy Rules

The Fuzzy Controller as a FDMU How does it work?

- This is a special (concrete) type of Fuzzy Decision Making Unit (FDMU) with *Two-Inputs* and *One-Output*, as follows:
- Input *X1* is the *Current Error:* $E(k) = R(k) - Y(k)$
- Input *X2* is the Change-of-Error*:* $DE(k) = E(k) - E(k-1)$
- The Output *Y* is the Change-of-Output: $DU(k)$

  k represents the current sampling time instance
- The calculated Control Action of the Fuzzy Controller at this current sampling *k* will be:

$$U(k) = U(k-1) + DU(k)$$

Fuzzy Rule Base for a Standard (Feed-Back) Fuzzy Controller

Example

Type 7-7-7

PL – Positive Large
PM – Positive Medium
PS – Positive Small
ZR – Zero
NS - Negative Small
NM – Negative Medium
NL – Negative Large

	PL	ZR	PS	PS	PM	PL	PL	PL
	PM	NS	ZR	PS	PM	PM	PM	PL
	PS	NM	NS	ZR	PS	PS	PM	PL
Change of Error: DE(k)	*ZR*	NL	NM	NS	ZR	PS	PM	PL
	NS	NL	NM	NS	NS	ZR	PS	PM
	NM	NL	NM	NM	NM	NS	ZR	PS
	NL	NL	NL	NL	NM	NS	NS	ZR
Error: E(k)		*NL*	*NM*	*NS*	*ZR*	*PS*	*PM*	*PL*

Linguistic Variables for Input 1 (*Error*): **7**

Linguistic Variables for Input 2 (*Change-of-Error*): **7**

Linguistic Variables for the Output (Change-of-Output): **7**

FRB Represents the Expert Knowledge About Control

Control Surface of a 7-7-7 type Fuzzy Controller with different parameter settings: (1)

Membership Functions for the ***Error:***

-1.00 -0.3333 -0.1111 0.0 +0.1111 +0.3333 +1.0

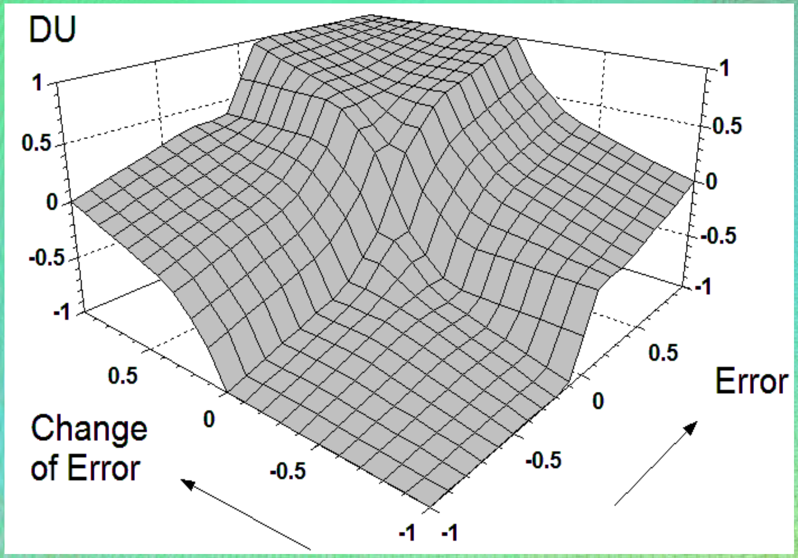
Membership Functions for the ***Change-of-Error***:

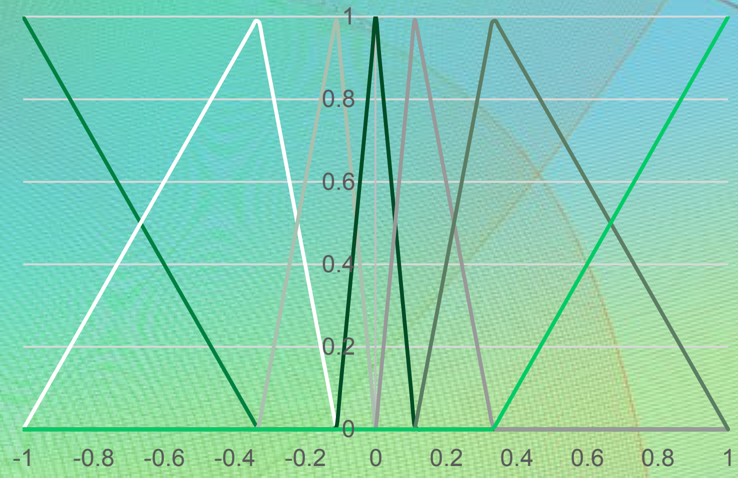
-1.00 -0.3333 -0.1111 0.0 +0.1111 +0.3333 +1.0

Output with 7 Singletons:

-1.0; -0.6666; -0.3333; 0.0; 0.3333; 0.6666; +1.0;

Version1





Control Surface of a 7-7-7 type Fuzzy Controller with different parameter settings: (2)

Membership Functions for the ***Error:***

-1.00 -0.666 -0.333 0.0 +0.333 +0.666 +1.0

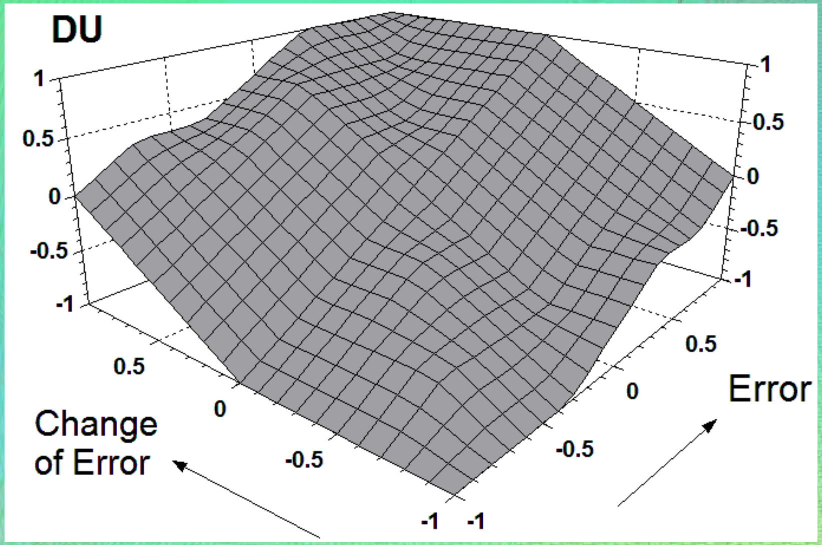
Membership Functions for the ***Change-of-Error***:

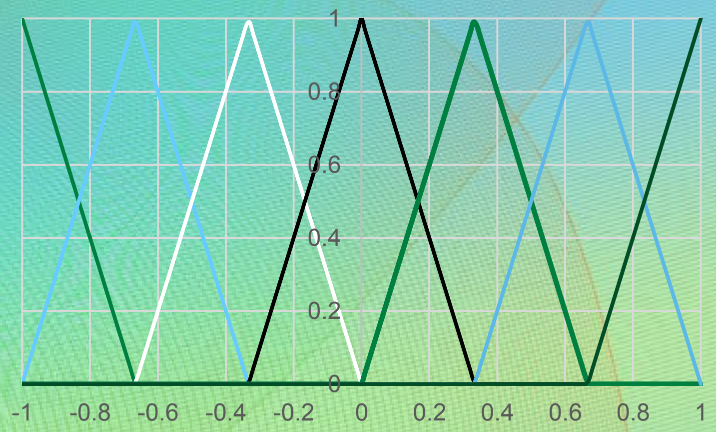
-1.00 -0.666 -0.333 0.0 +0.333 +0.666 +1.0

Output with 7 Singletons:

-1.0; -0.666; -0.333; 0.0; 0.333; 0.666; +1.0;

Version2





Control Surface of a 7-7-7 type Fuzzy Controller with different tunings: (3)

Membership Functions for the ***Error:***

-1.00 -0.333 -0.111 0.0 +0.111 +0.333 +1.0

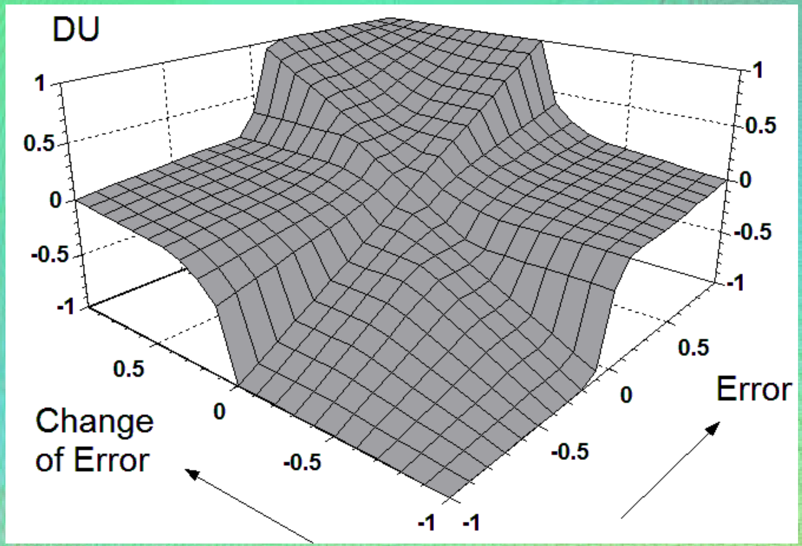
Membership Functions for the ***Change-of-Error***:

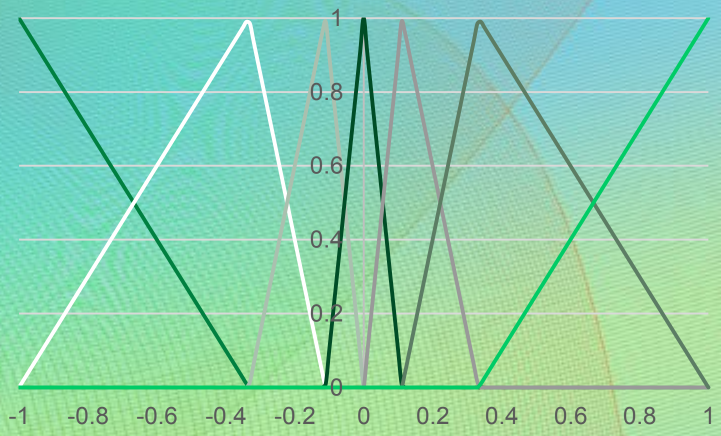
-1.00 -0.333 -0.111 0.0 +0.111 +0.333 +1.0

Output with 7 Singletons:

-1.0; -0.333; -0.111; 0.0; 0.111; 0.333; +1.0;

Version3





Control Surface of a 7-7-7 type Fuzzy Controller with different tunings: (4)

Membership Functions for the ***Error:***

-1.00 -0.900 -0.700 0.0 +0.700 +0.900 +1.0

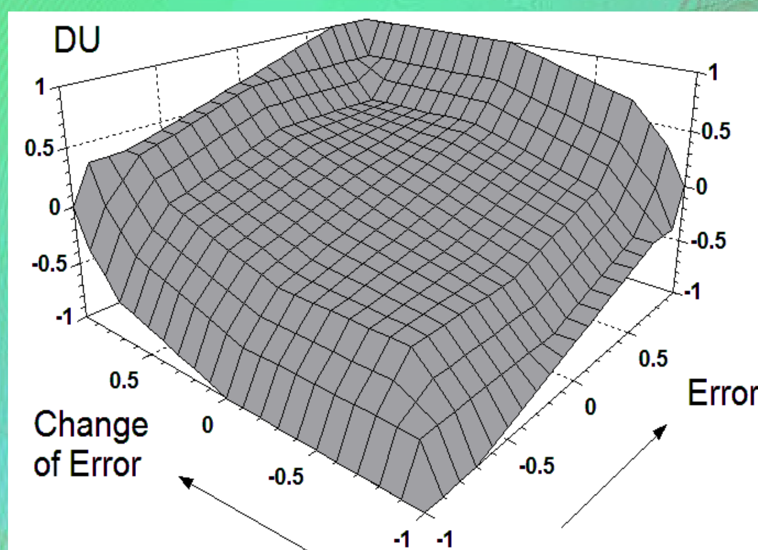
Membership Functions for the ***Change-of-Error***:

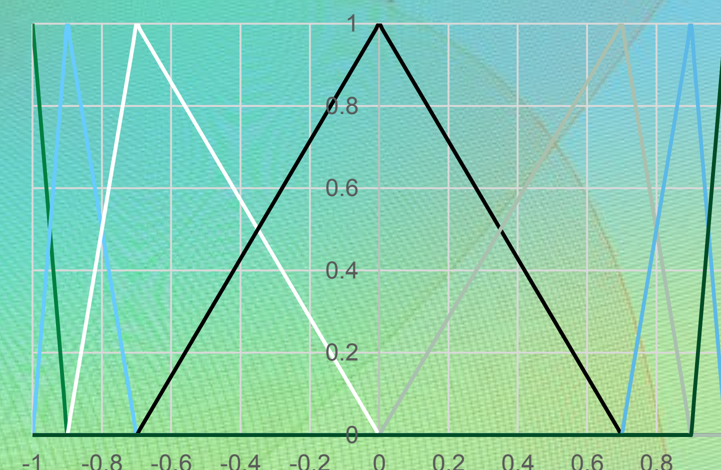
-1.00 -0.900 -0.700 0.0 +0.700 +0.900 +1.0

Output with 7 Singletons:

-1.0; -0.666 -0.333; 0.0; 0.333; 0.666; +1.0;

Version4





Main Characteristics and Tuning Issues of the Fuzzy Logic Controller (FC, FLC)

- The FC has a highly flexible and nonlinear structure that works as Universal Approximator. This property has been proven theoretically and means that the FC is able to approximate any kind of nonlinearity (in the Plant or in the Controller itself) with any predefined accuracy. This is the FC's **strongest merit**, compared to many other controllers and control methods. .
- The (FC) contains quite many parameters that ffect its performance. So, **precise tuning** of the FC is required for achieving good results. This is a challenging task that can be solved by using some of the recent Multi-Agent Methods for Optimization, such as GA, PSO, ACO and others.

Simplified Two-stage Tuning (Optimization) of the Fuzzy Controller

This is a strategy that gives satisfactory (not necessarily global optimal) results and consists of the following two consequtive steps:

- **Structure Optimization**. It includes tuning the number of Linguistic Variables for each Input, the number of the Singletons (Consequents, Outputs) of the Fuzzy Rules in the FRB.
- **Parameter Optimization**. It includes tuning all parameters in the Parameter Base for a given fixed state of the Structure parameters.
- Obviously this often leads to local optimum solutions, but in many cases they are considered as satisfactory practical solutions.

Summary: the Merits and Demerits of the Fuzzy Logic Controller

+

- Fuzzy Logic is an excellent tool for Fuzzy Logic Control of any type of complex and high nonlinear plants.
- Such Controller does not require detailed knowledge about the Process Dynamics

-

- However, the Fuzzy Controller has **many** parameters that should be properly tuned. This is a big hurdle and challenging task that requires the use of good Optimization tool.

- **So, keep trying !**

Discussions, Questions and some Answers

We have so far understood that the Fuzzy Logic calculations are based on the existence of a Fuzzy Rule Base.

Q) How to obtain the Fuzzy Rule Base?

A) From a Human Expert in the respective area (Interview);

Q) What will happen if there are several (many) Experts and their opinion (decision making) differs from each other ?

A) There will be several different solutions to the same problem, produced by the respective Fuzzy Rule Bases;

Q) How to create a Fuzzy Rule Base, IF there so NO Expert to tell the Rules (e.g. in the case of a New Process)?

A) Well, this is a problem that can be solved by using available Data from the operation of the real process (<u>from Data to Knowledge</u>);

END of the Fuzzy Logic Preliminaries

New Questions ?

Some Ideas for Interesting Applications of Fuzzy Logic (e.g. in Robotics, Business, etc.) ?

Tired ?
Need a Short Break ?

A) Applications of the Fuzzy Logic in the Robotics Area (Mobile Robots Navigation)

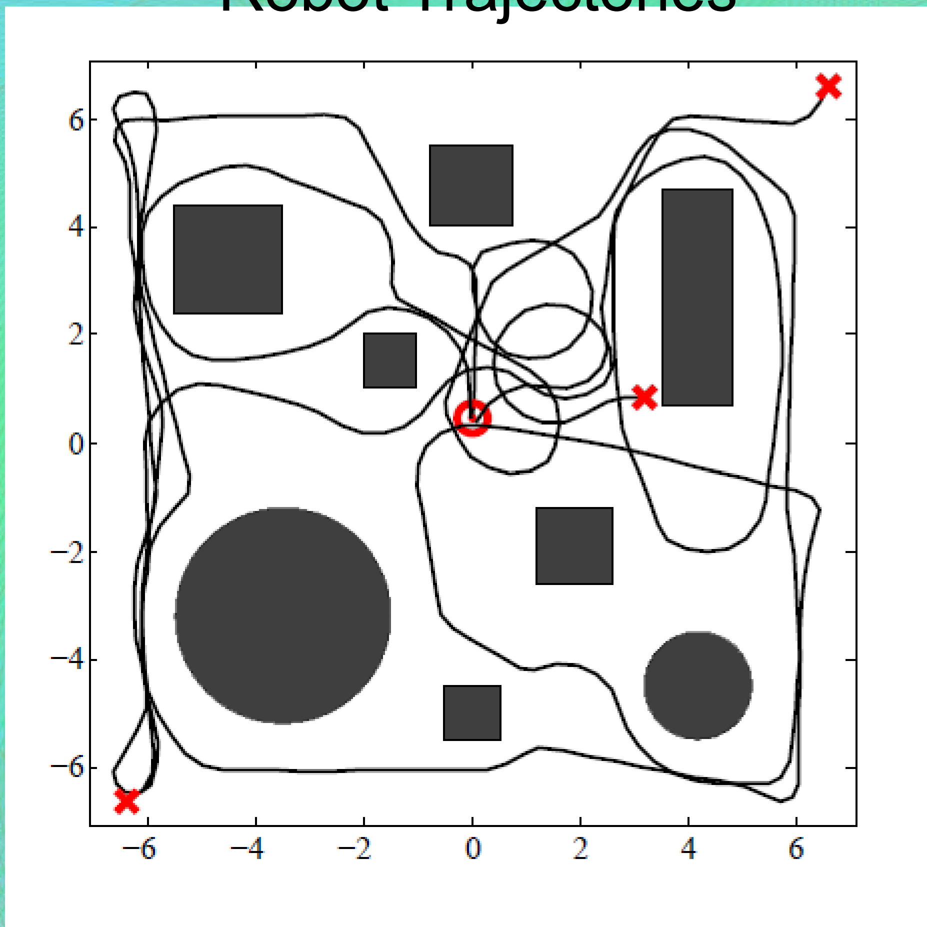
Solving the Obstacle Avoidance Problem in Robotics by using Fuzzy Logic Controller

Statement of the Problem:

Tuning of the Fuzzy Controller of a Mobile Robot for Obstacle Avoidance in unknown (unstructured) Environment

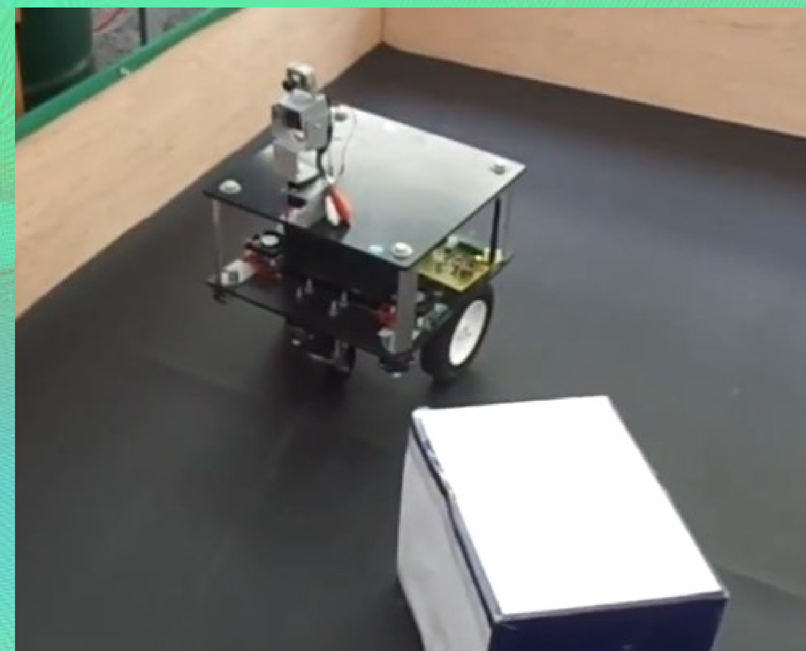
The Obstacle Avoidance Problem

Robot Trajectories



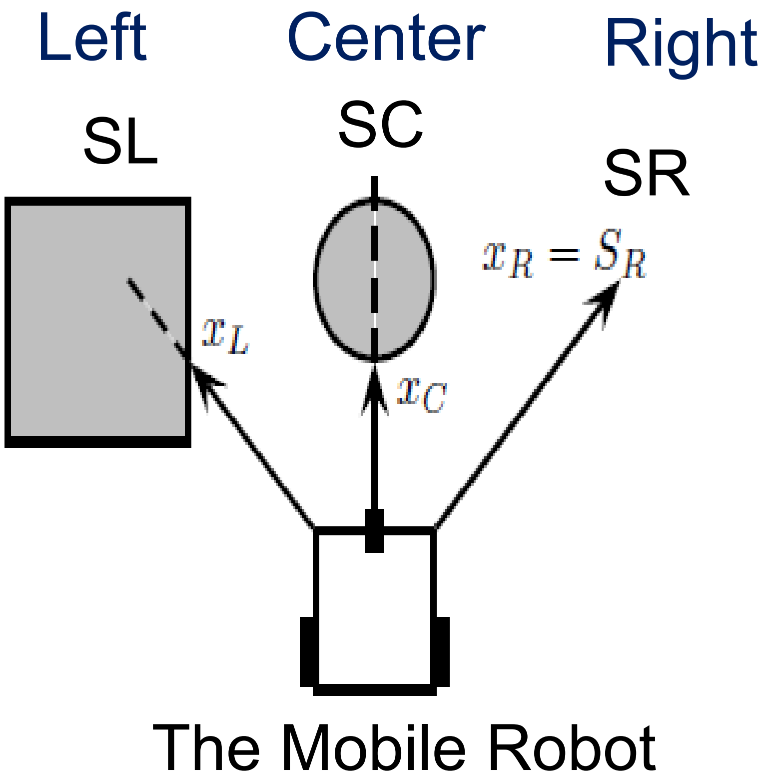
Static Obstacles

Experiments



Environment

Configuration of Three Distance Sensors



- Three distance sensors
- Two pointing at an angle of 45 degrees
- One pointing straight
- Range of the sensor is S_R

Basic Assumptions:

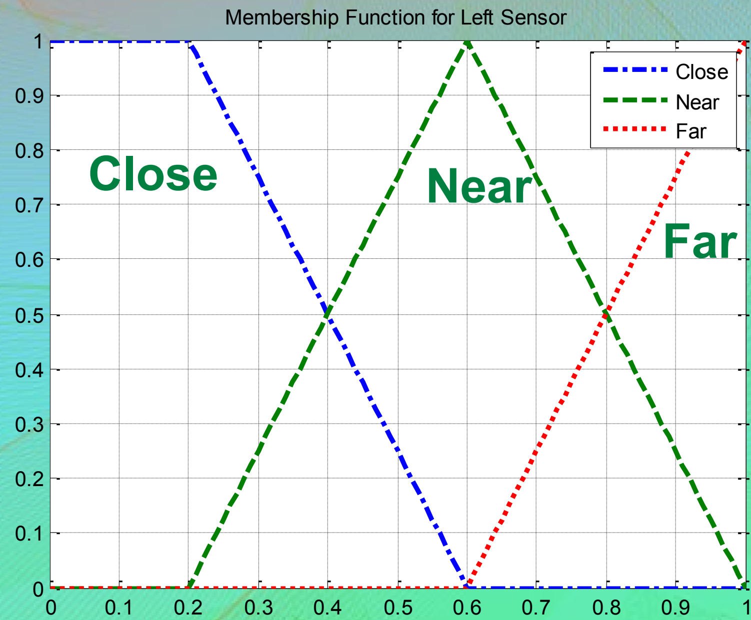
- 3 Sensors for measuring the Proximity are used:
  Left (LS), Middle(MS) and Right (RS)

- Fuzzy Rule Base with Semi-Linguistic Fuzzy Rules with ***Singletons*** (*Takagi-Sugeno* type) is used;

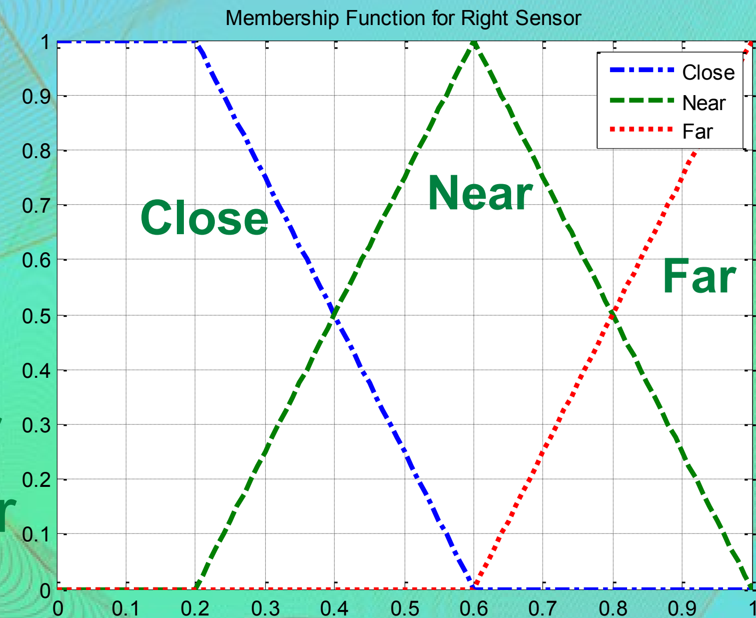
The Fuzzy Rule Structure:

IF (**Left Sensor** shows ***Far*** AND
Middle Sensor shows ***Near*** AND
Right Sensor shows ***Close***)
THEN
Change-of-the-steering Action is: ***Negative Small***
(Singleton)

Three Triangular Membership Functions assumed for Each Sensor

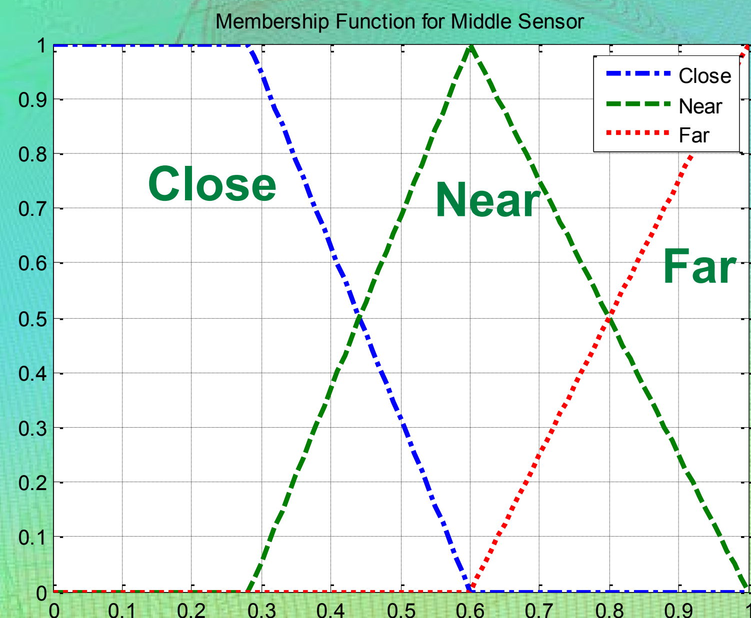


Left Sensor Input: *X1*



Right Sensor

Input: *X3*



Middle Sensor Input: *X2*

3 Linguistic Variables used:

F – *Far*;

N – *Near*;

C – *Close*

The Outputs of the Fuzzy Rules are **Singletons** (Numerical Values, Voltage, PWM)

<u>Linguistic Expressions of the Singletons:</u>

NB – Negative Big; **NM** – Negative Medium; **NS** – Negative Small

ZR – Zero

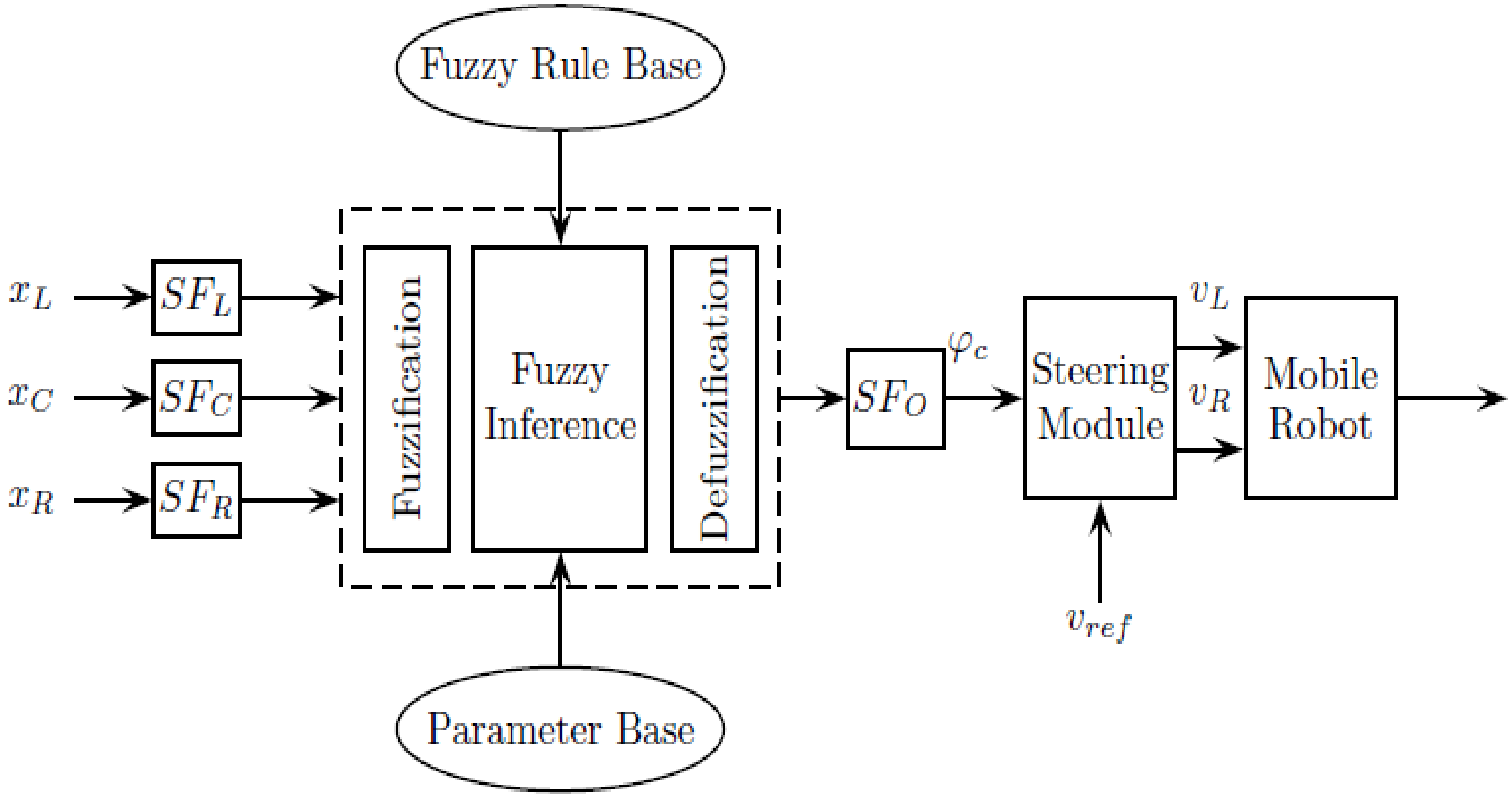
PS – Positive Small; **PM** – Positive Medium; **PB** – Positive Big

We assume that All Singletons values are within the Range: [*-1.0*, *+1.0*]

<u>Numerical Expressions of the Singletons:</u>

NB	NM	NS	ZR	PS	PM	PB
-1	-0.67	-0.33	0	0.33	0.67	1

Proposed Fuzzy Controller Structure



3D Fuzzy Rule Base For Obstacle Avoidance

3 x 3 x 3 = 27 Fuzzy Rules

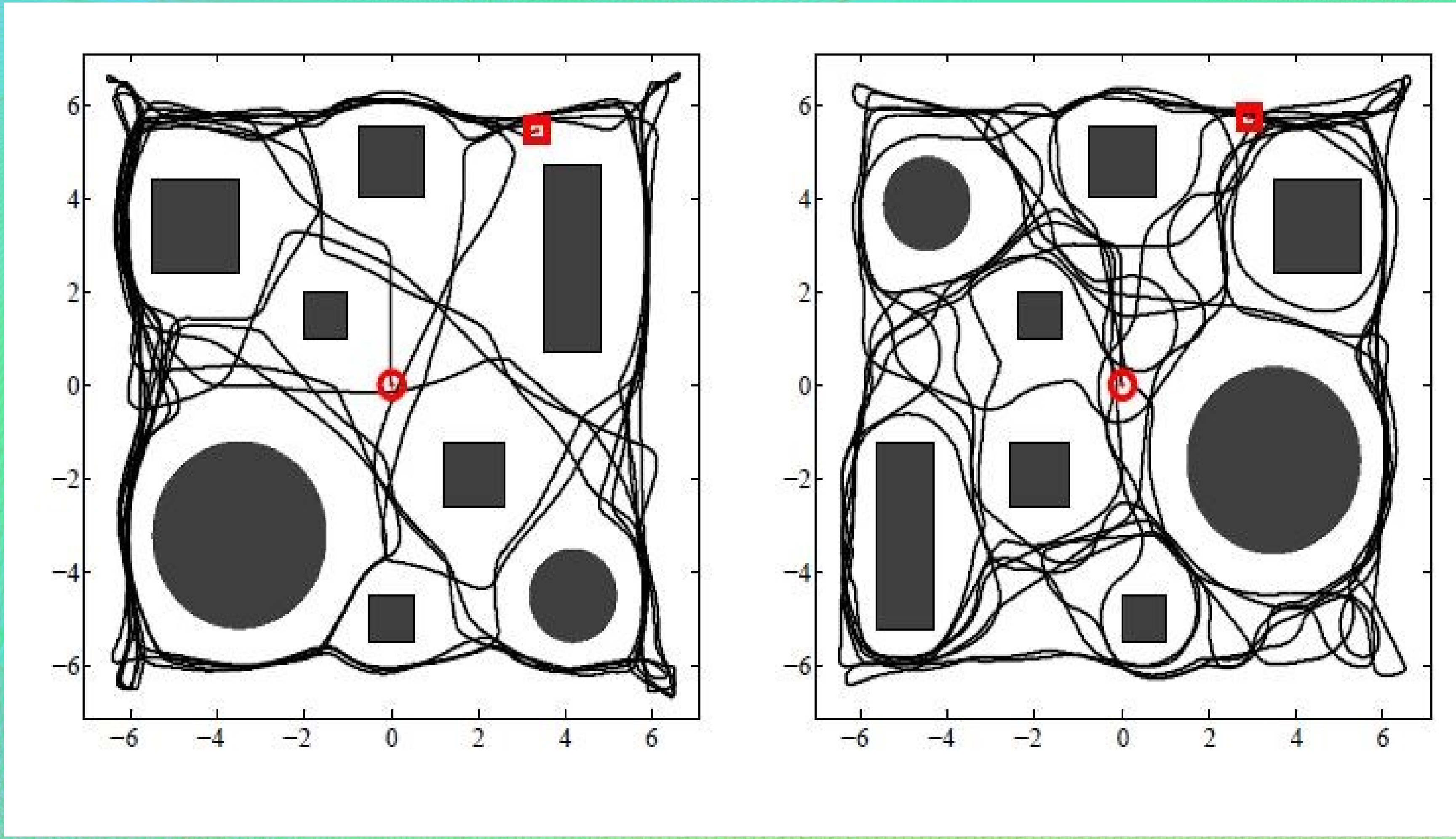
Outputs of the Fuzzy Rules:

NS – Negative Small;
PS – Positive Small;
ZR – Zero;
NM – Negative Medium;
PM – Positive Medium;

Fuzzy Rule	Left Sensor	Middle Sensor	Right Sensor	OUTPUT
1	F	F	F	R3{NS, ZR, PS}
2	F	F	N	R1{NM}
3	F	F	C	R1{NB}
4	F	N	F	R2{NM, PM}
5	F	N	N	R1{NM}
6	F	N	C	R1{NM}
7	F	C	F	R2{NB, PB}
8	F	C	N	R1{PB}
9	F	C	C	R1{NB}
10	N	F	F	R1{PM}
11	N	F	N	R2{NM, PM}
12	N	F	C	R1{NB}
13	N	N	F	R1{PM}
14	N	N	N	R2{NM, PM}
15	N	N	C	R1{NB}
16	N	C	F	R1{NB}
17	N	C	N	R2{NB, PB}
18	N	C	C	R1{NB}

Fuzzy Rule	Left Sensor	Middle Sensor	Right Sensor	OUTPUT
19	C	F	F	R1{PB}
20	C	F	N	R1{PB}
21	C	F	C	R2{NB, PB}
22	C	N	F	R1{PM}
23	C	N	N	R1{PB}
24	C	N	C	R2{NB, PB}
25	C	C	F	R1{PB}
26	C	C	N	R1{PB}
27	C	C	C	R2{NB, PB}

Simulations Results from the Robot Performance in Different Environments

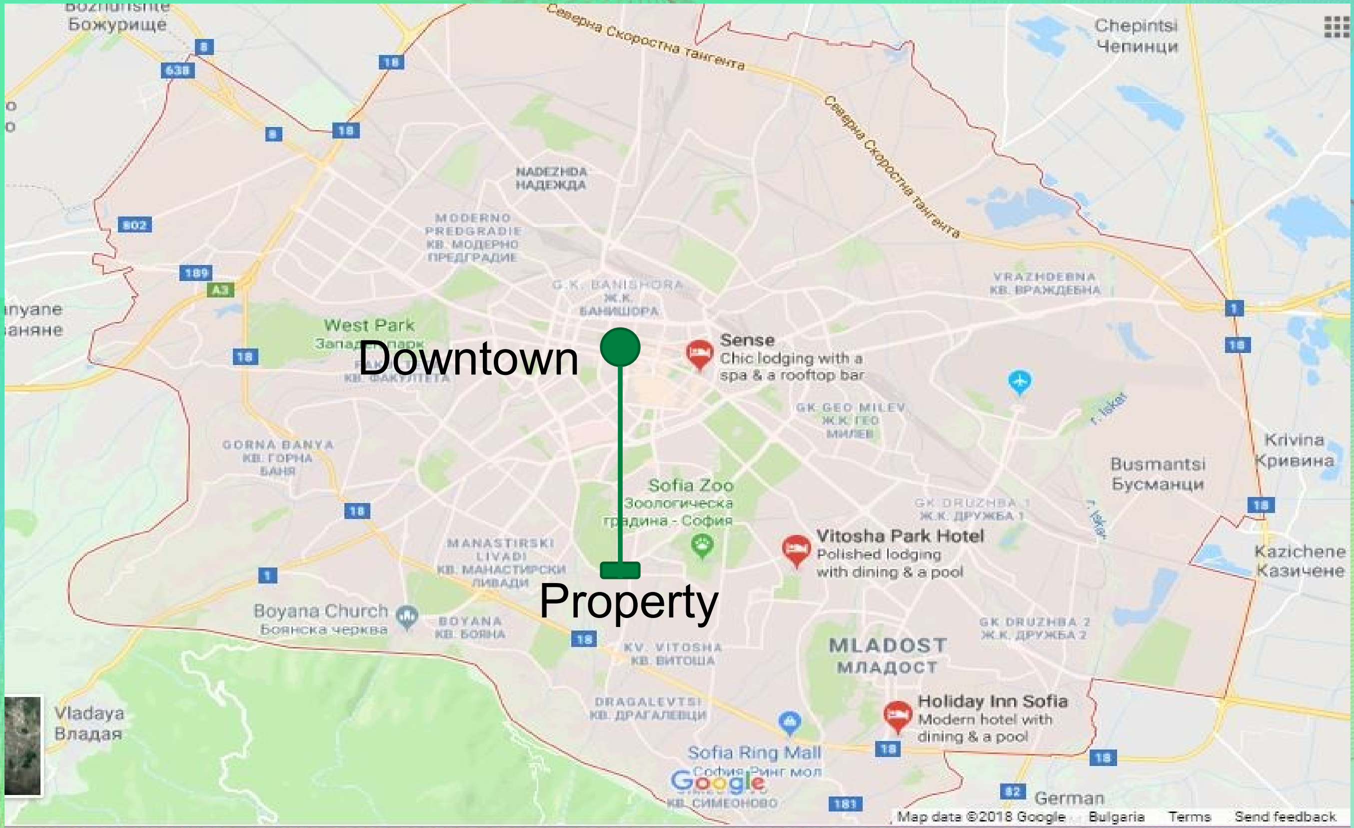


Obstacle Avoidance of the Mobile Robot

B) Fuzzy Logic Application in the Area of Decision Making in the **Real Estate Business**

The Task: Fuzzy Decision Making for estimation of the Selling Price of a Property (Apartment) within a given City Location

The City area of Sofia



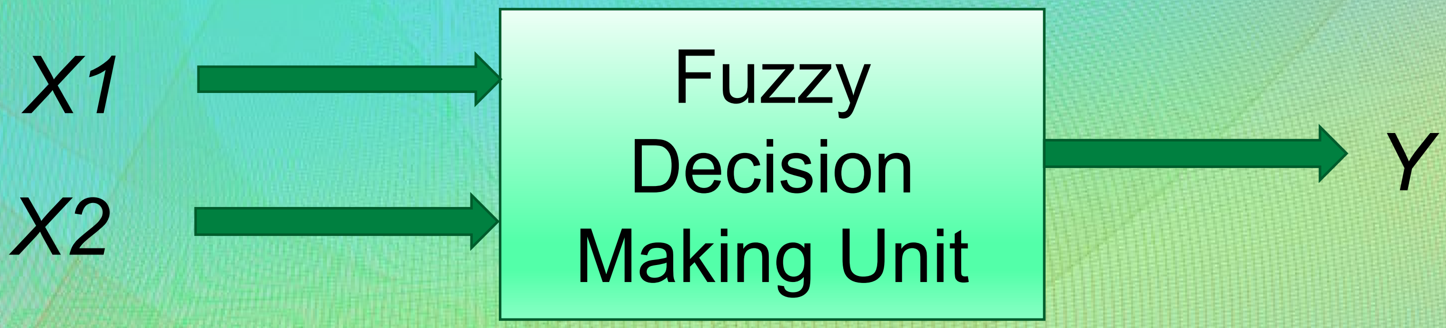
Construction of the Fuzzy Rules and respective Parameters

IF(*Input1* is ***A*** AND *Input2* is ***B***) **THEN** *Output* is ***C***

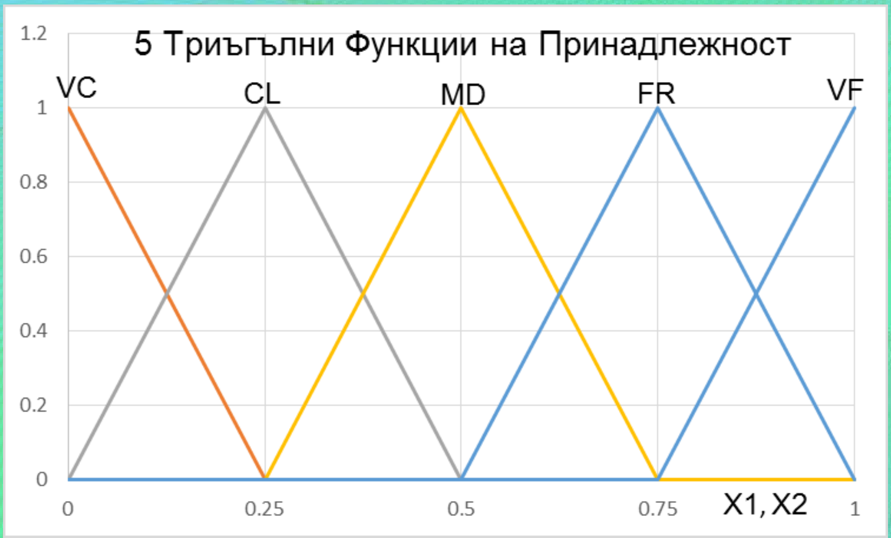
Input1 – Distance from Downtown to the Property

Input2 – Distance from the nearest Metro Station to the Property

Output – The selling Price of the Property



5 Assumed Membership Functions for the Inputs *X1* and *X2*



<u>Triangular</u> (Sharp) Membership Functions

<u>Gaussian</u> (Smooth) Membership Functions

VC – Very Close **CL** – Close **MD** – Medium

FR – Far **VF** – Very Far

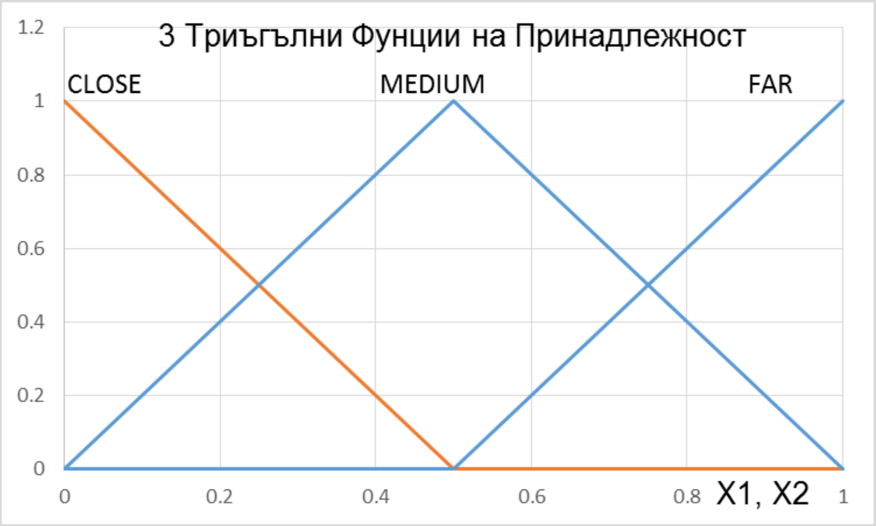
Fuzzy Rule Base of 5 x 5 = **25** Fuzzy Rules generated by the Expert (the Dealer) in Case of 5 Membership Functions for *X1* and *X2*

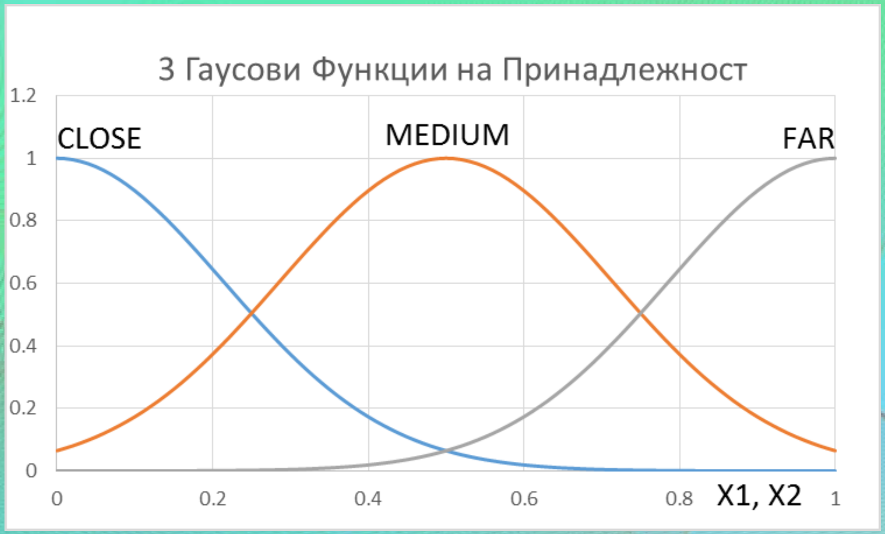
Very Far		**0.7**	**0.6**	**0.5**	**0.4**	**0.4**
Far		**0.8**	**0.7**	**0.6**	**0.5**	**0.4**
Medium		**0.9**	**0.8**	**0.7**	**0.6**	**0.5**
Close		**0.9**	**0.8**	**0.8**	**0.7**	**0.6**
Very Close		**1.0**	**0.9**	**0.8**	**0.7**	**0.6**
X2	**X1**	Very Close	Close	Medium	Far	Very Far

Maximal Price (the most expensive property)

Relative Price

3 Assumed Membership Functions for the Inputs *X1* and *X2*





<u>Triangular</u> (Sharp) Membership Functions

<u>Gaussian</u> (Smooth) Membership Functions

CL – Close **MD** – Medium **FR** – Far

Fuzzy Rule Base of 5 x 3 = **15** Fuzzy Rules generated by the Expert (the Dealer) in Case of 5 Membership Functions for X1 and 3 Membership Functions for *X2*

Far		**0.7**	**0.6**	**0.5**	**0.4**	**0.4**
Medium		**0.9**	**0.8**	**0.7**	**0.6**	**0.5**
Close		**1.0**	**0.9**	**0.8**	**0.7**	**0.6**
X2	**X1**	Very Close	Close	Medium	Far	Very Far

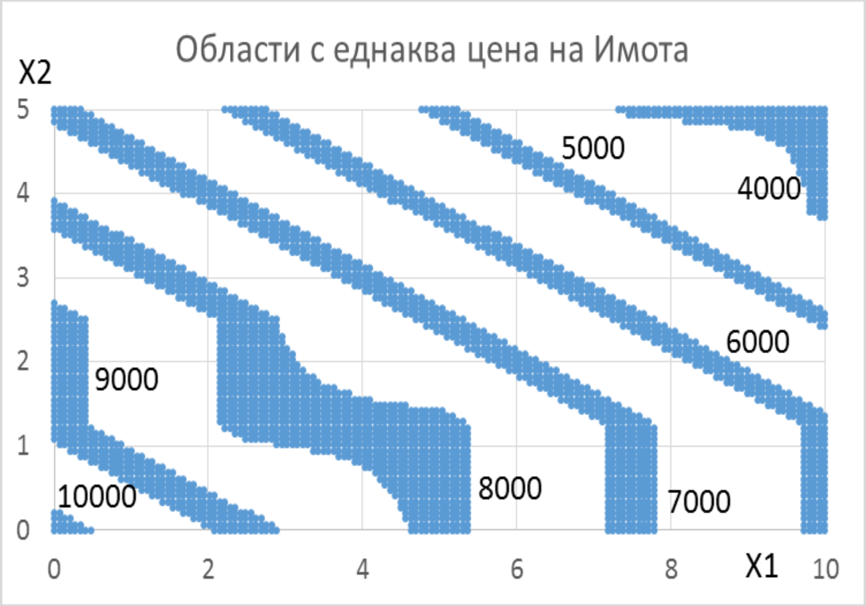
Relative Price

Maximal Price (the most expensive property)

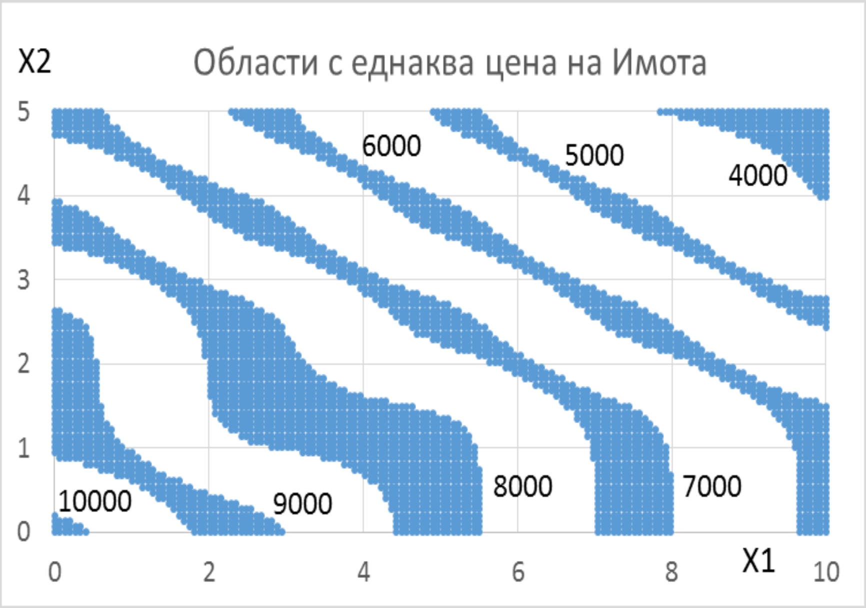
Results from the Fuzzy Decision about the Price of the Property:

Fuzzy Rule Base with 5 x 5 = 25 Fuzzy Rules

Areas with equal prices of the property
in the different parts of the City



Triangular Membership Functions

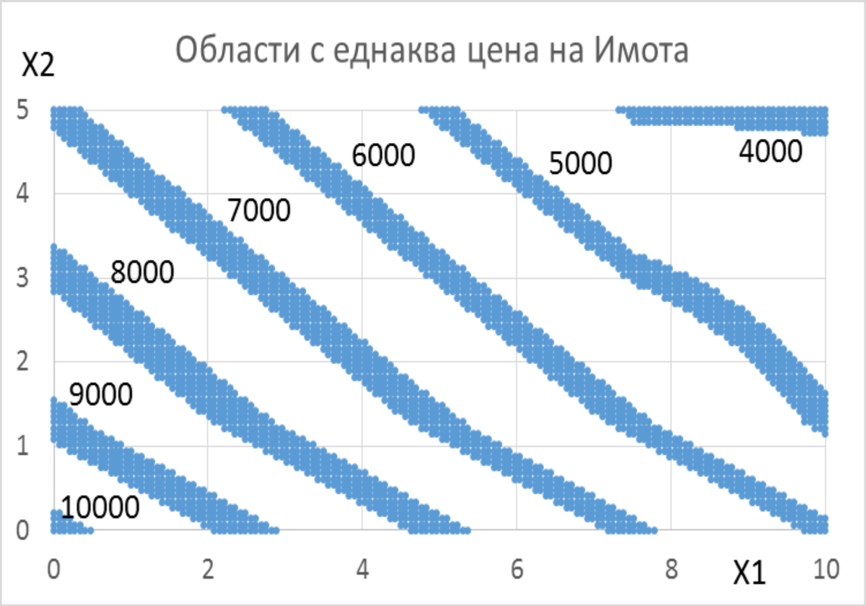


Gaussian Membership Functions

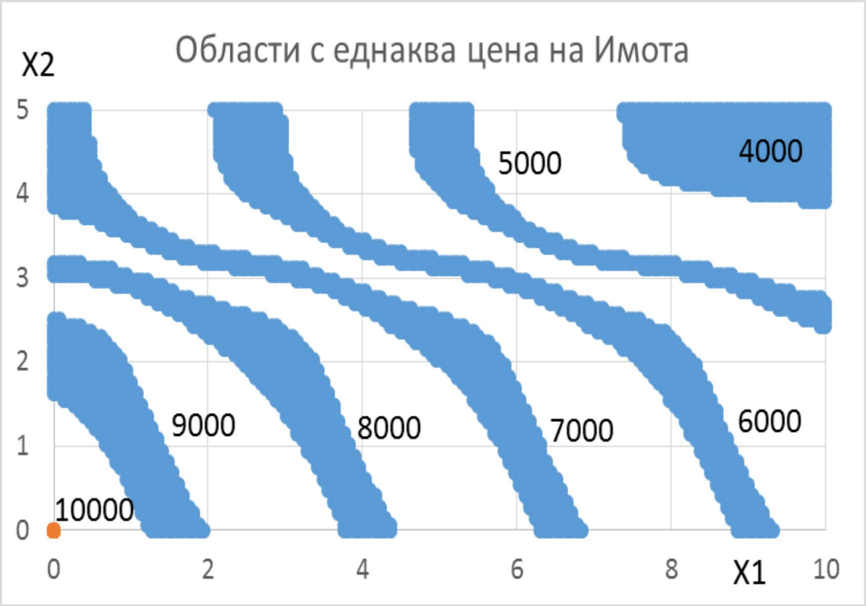
Results from the Fuzzy Decision about the Price of the Property:

Fuzzy Rule Base with 5 x 3 = 15 Fuzzy Rules

Areas with equal prices of the property in the different parts of the City



Triangular Membership Functions



Gaussian Membership Functions

Discussions and Concluding Remarks:

- The Fuzzy Decision makes it possible to combine different factors (input parameters) that influence the selling price of the property.
- <u>The problem</u> is: how many input parameters to include? Obviously two only parameters (*X1* and *X2*) are insufficient to make a realistic decision about price !
- <u>However</u>, increasing the number of the input parameters creates another problem, related to the construction of the Fuzzy Rule Base. FRB is growing in size (number of rules) <u>exponentially</u> (combinatorial explosion) !
- The accurate tuning of the parameters of the Membership Functions is mandatory for good results !

Thank you !

The Fuzzy Concept:
Precision is not true !
The truth is not precise !