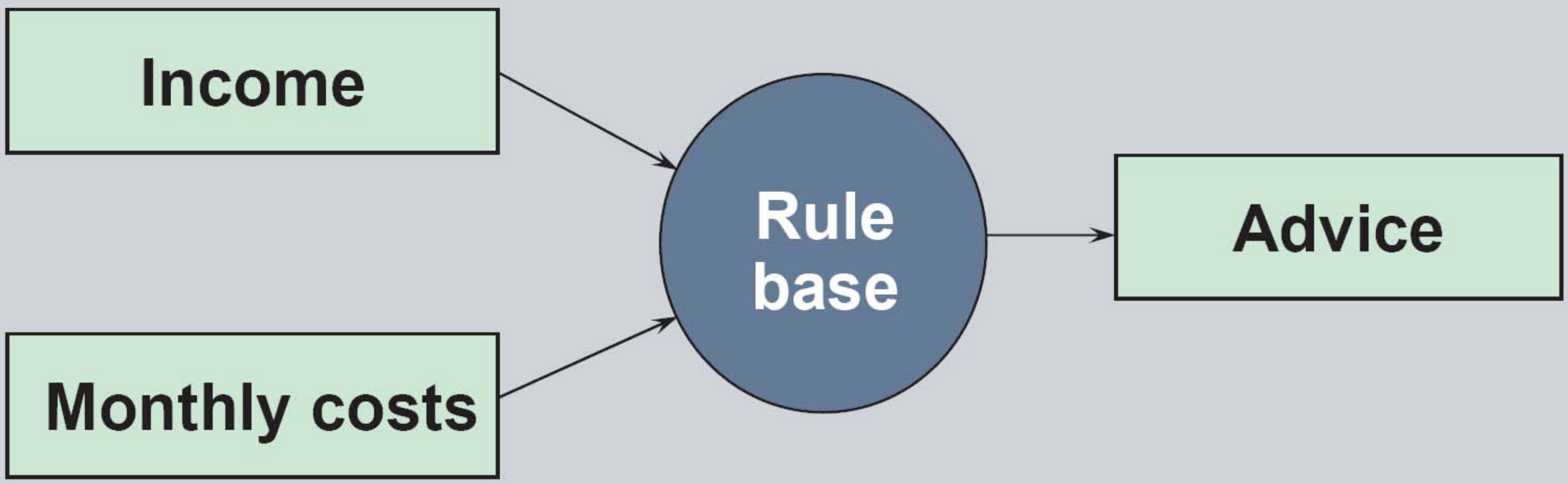
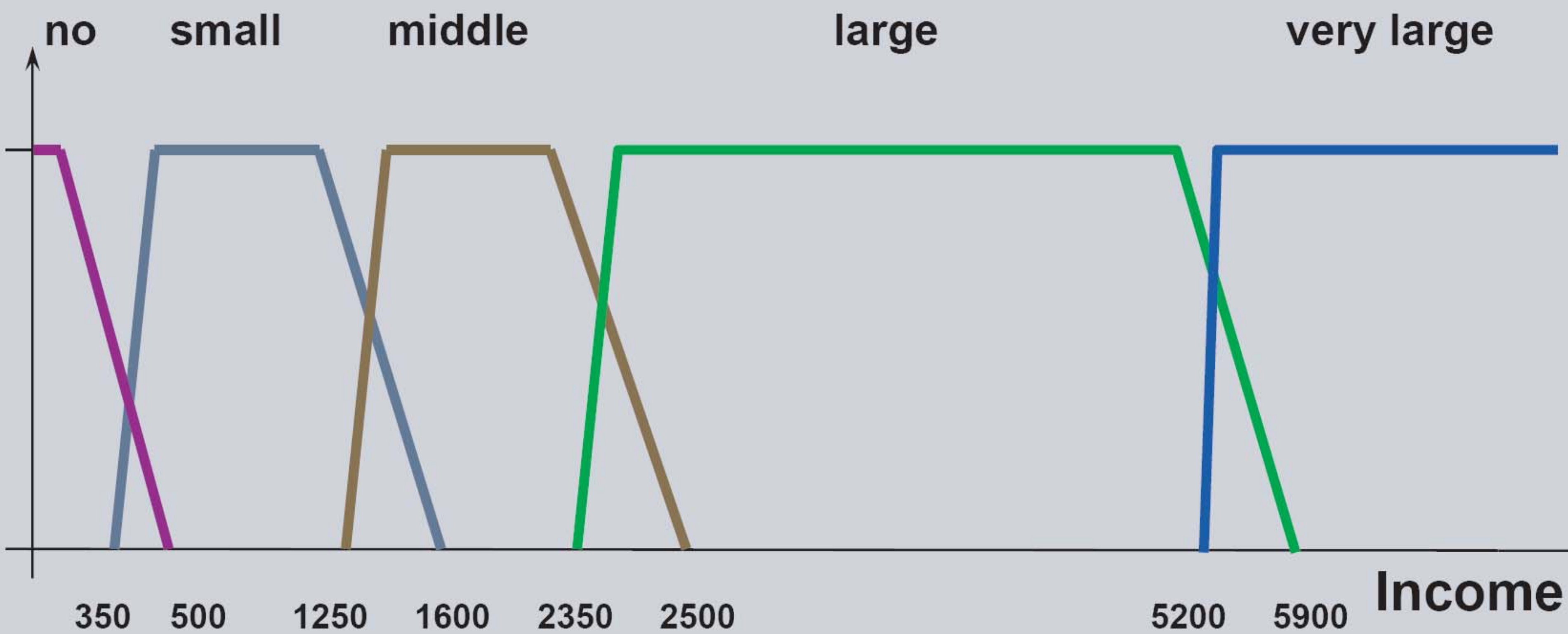
Applications of fuzzy logic

Loan advisory system



Monthly income



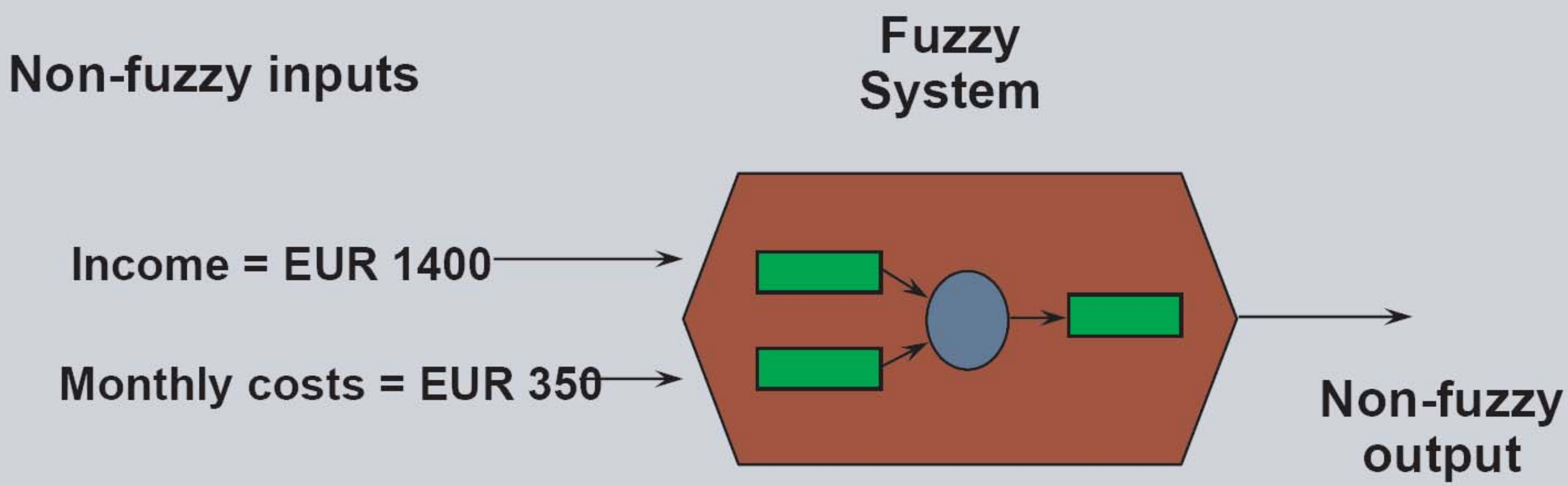
Three rules of the rule base

RULE 1
IF Income = very large AND Monthly costs = small
THEN Advice = Give Credit

RULE 2
IF Income = small AND Monthly costs = middle
THEN Advice = Boundary case

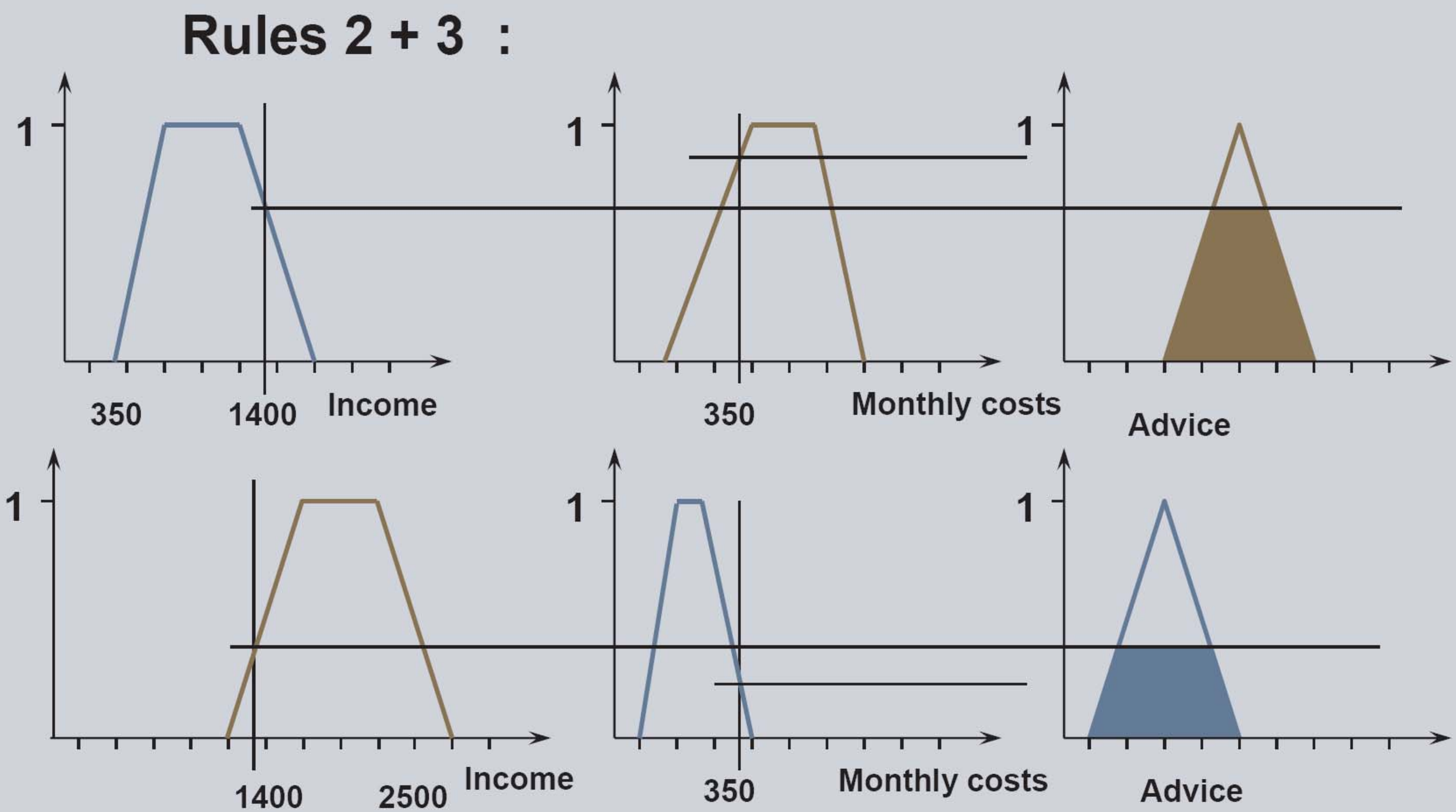
RULE 3
IF Income = middle OR Monthly costs = small
THEN Advice = Probably give credit

Fuzzy System

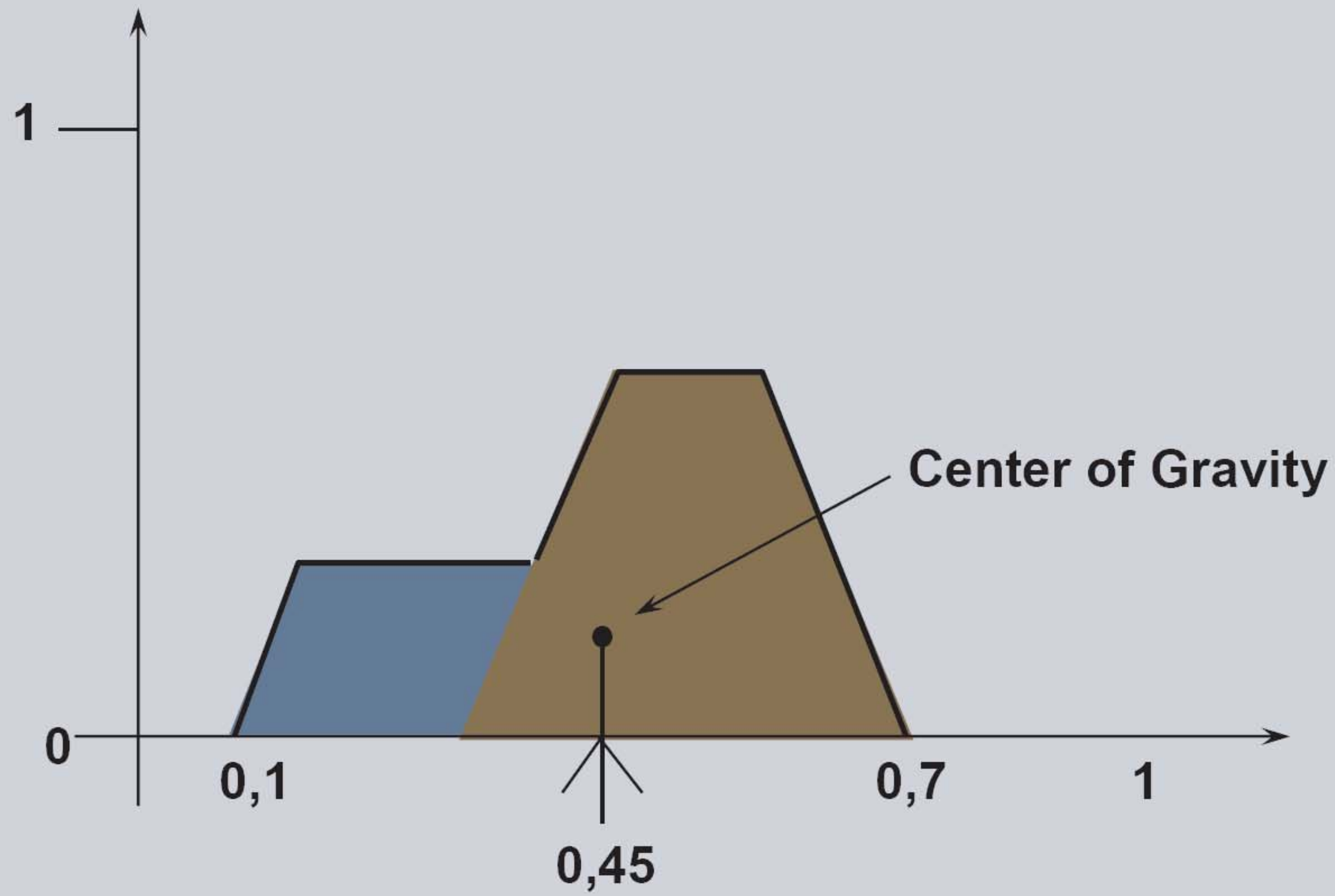


Only rules 2 en 3 can be applied.

Activating the rules



Defuzzification



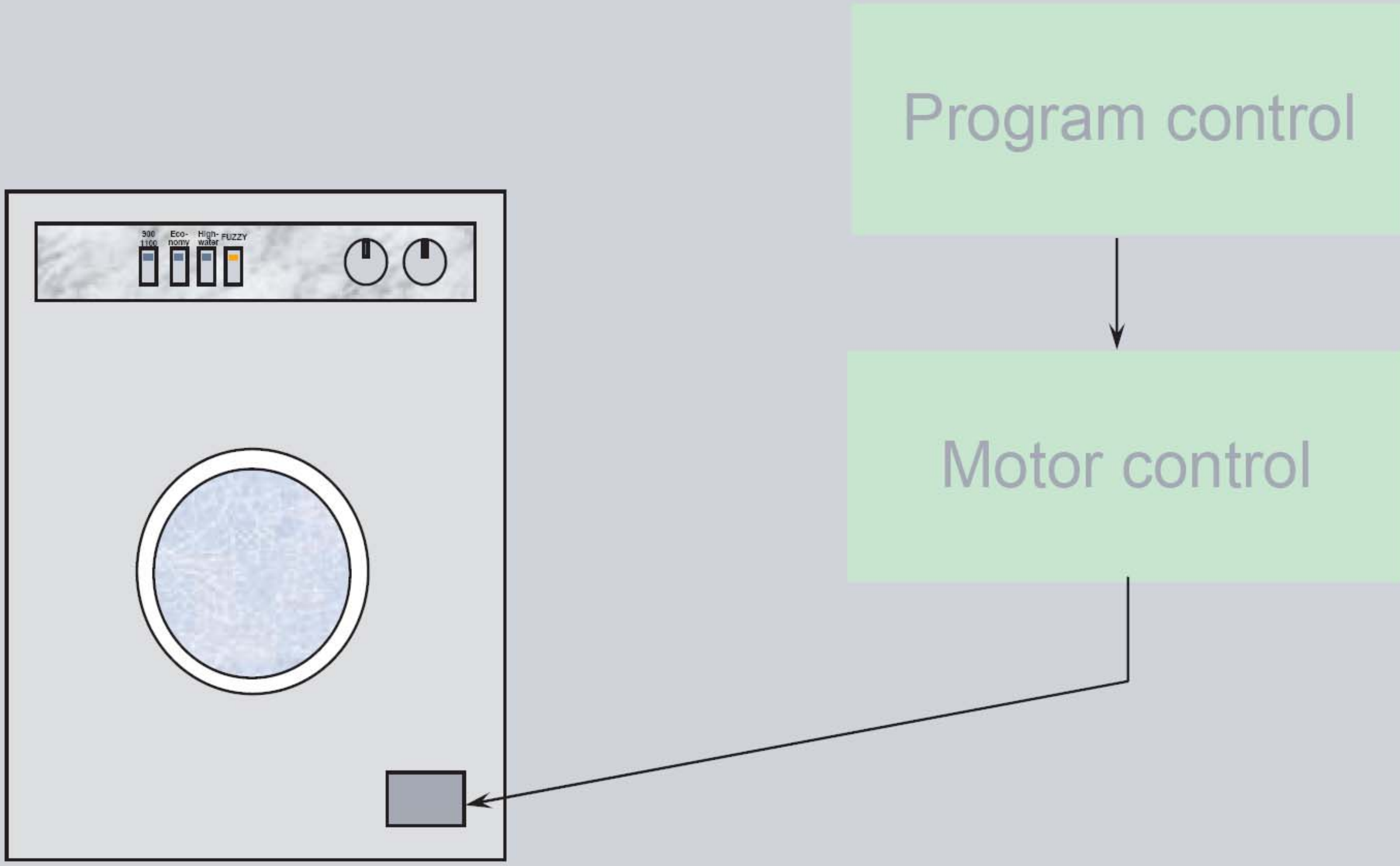
0,45 = “Boundary case"

Fuzzy logic

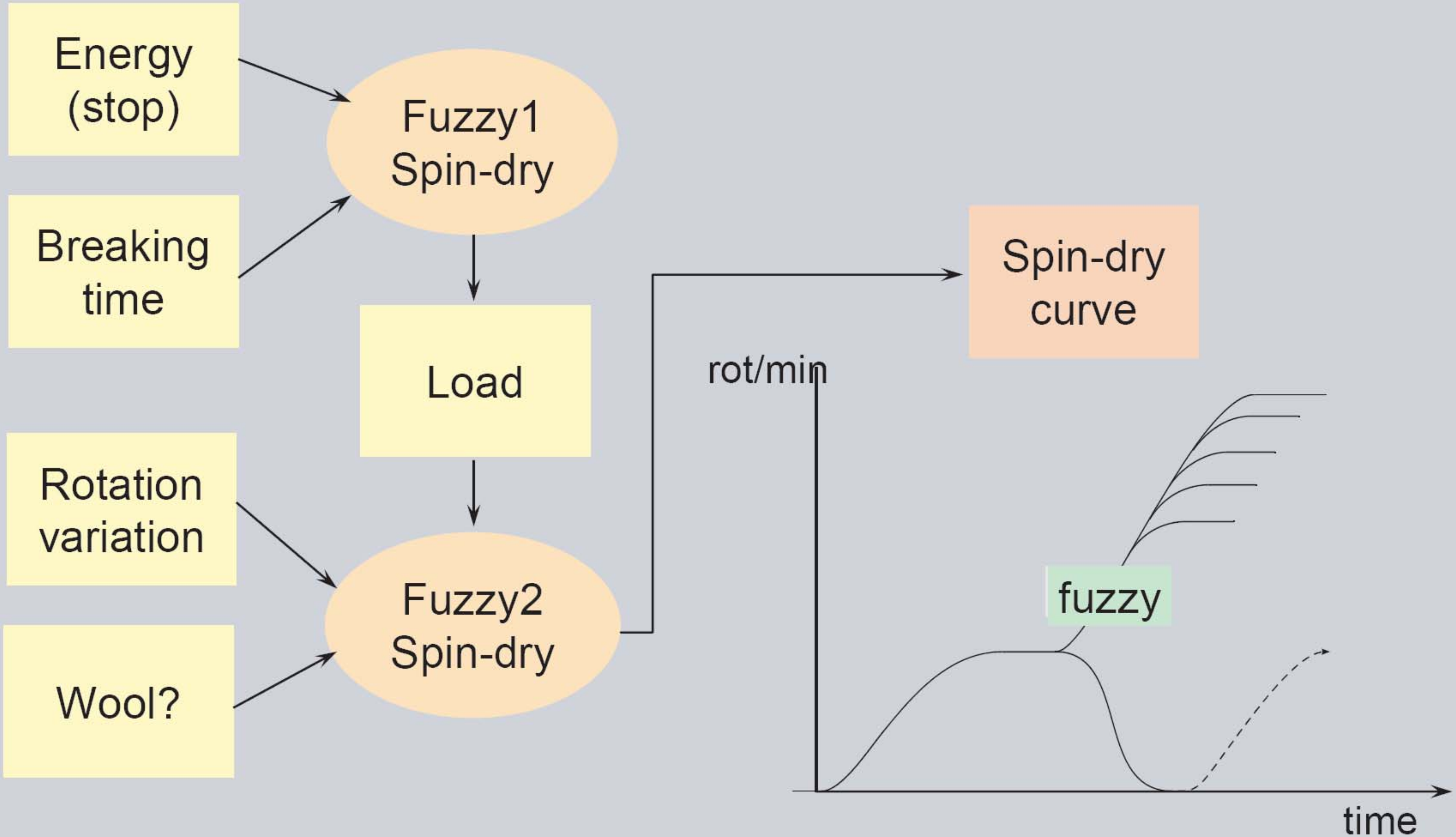
In formula

$$y_l(k) = \frac{\sum_{i=1}^{K_l} \beta_{li}(x_l)\left(\zeta_{li} y(k-1) + \eta_{li} u(k) + \theta_{li}\right)}{\sum_{i=1}^{K_l} \beta_{li}(x_l)}$$

Fuzzy washing machine with fuzzy control



The spin-dry process



Fuzzy vacuum cleaner

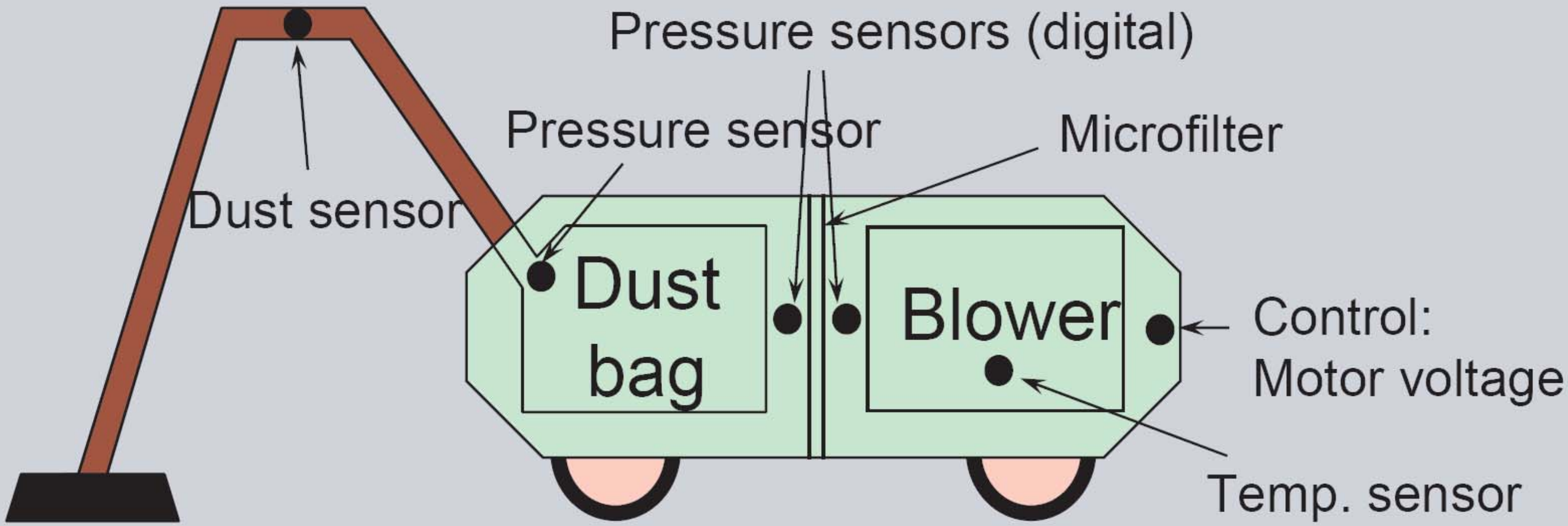
Extended Automization for a Vacuum Cleaner

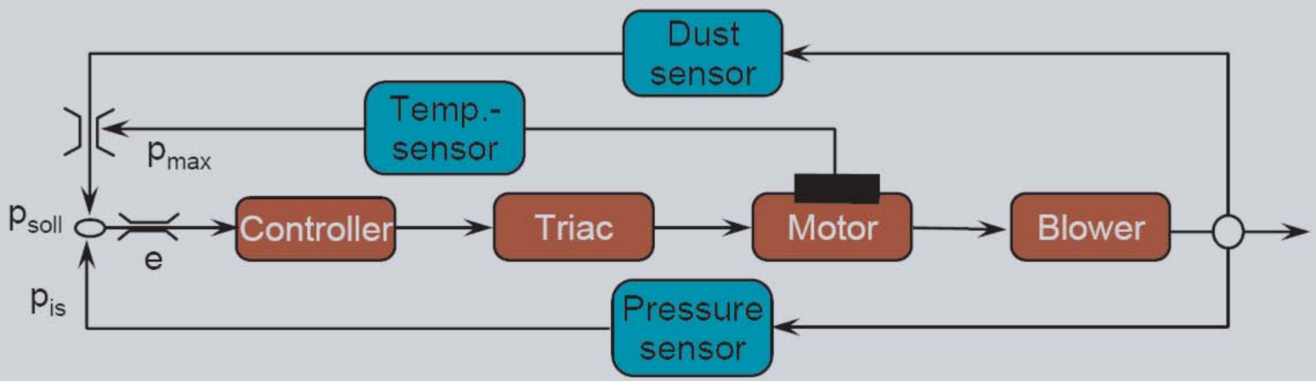
- Realization of the control with Fuzzy
- Good performance

Realized Modules

- Pressure control
- Control by dust sensor
- Filter change and blockage diagnosis

Fuzzy vacuum cleaner with pressure control and control by dust sensor





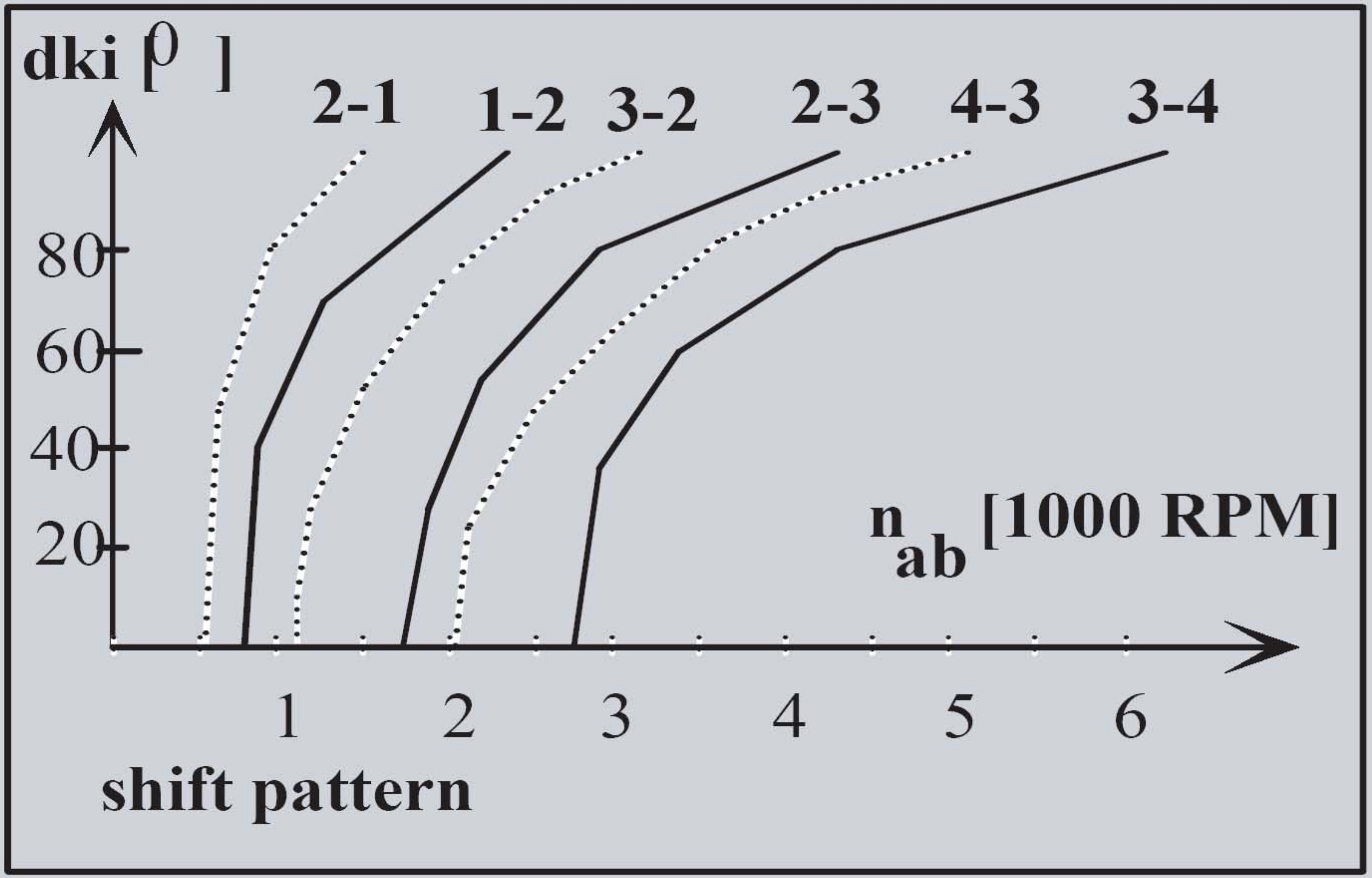
Automatic transmission system

Development of a logical system for an Automatic Transmission System with respect to

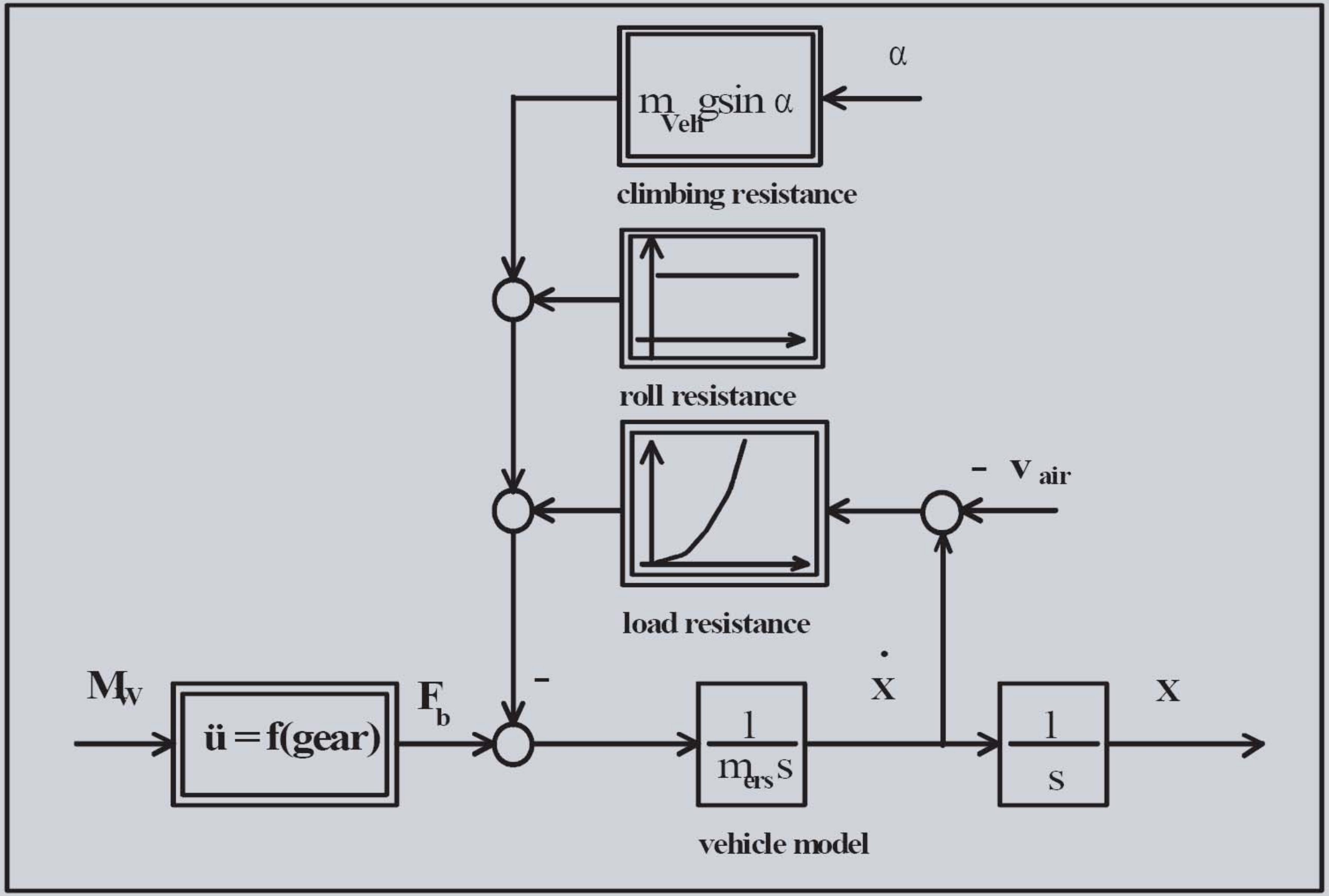
- different drivers
  - Sportily, …, defensive

- Driving situations
  - Overtaking
  - Curves
  - Mountains
  - City, Land, Highway
- Working conditions
  - Motor temperature
  - Load of the vehicle

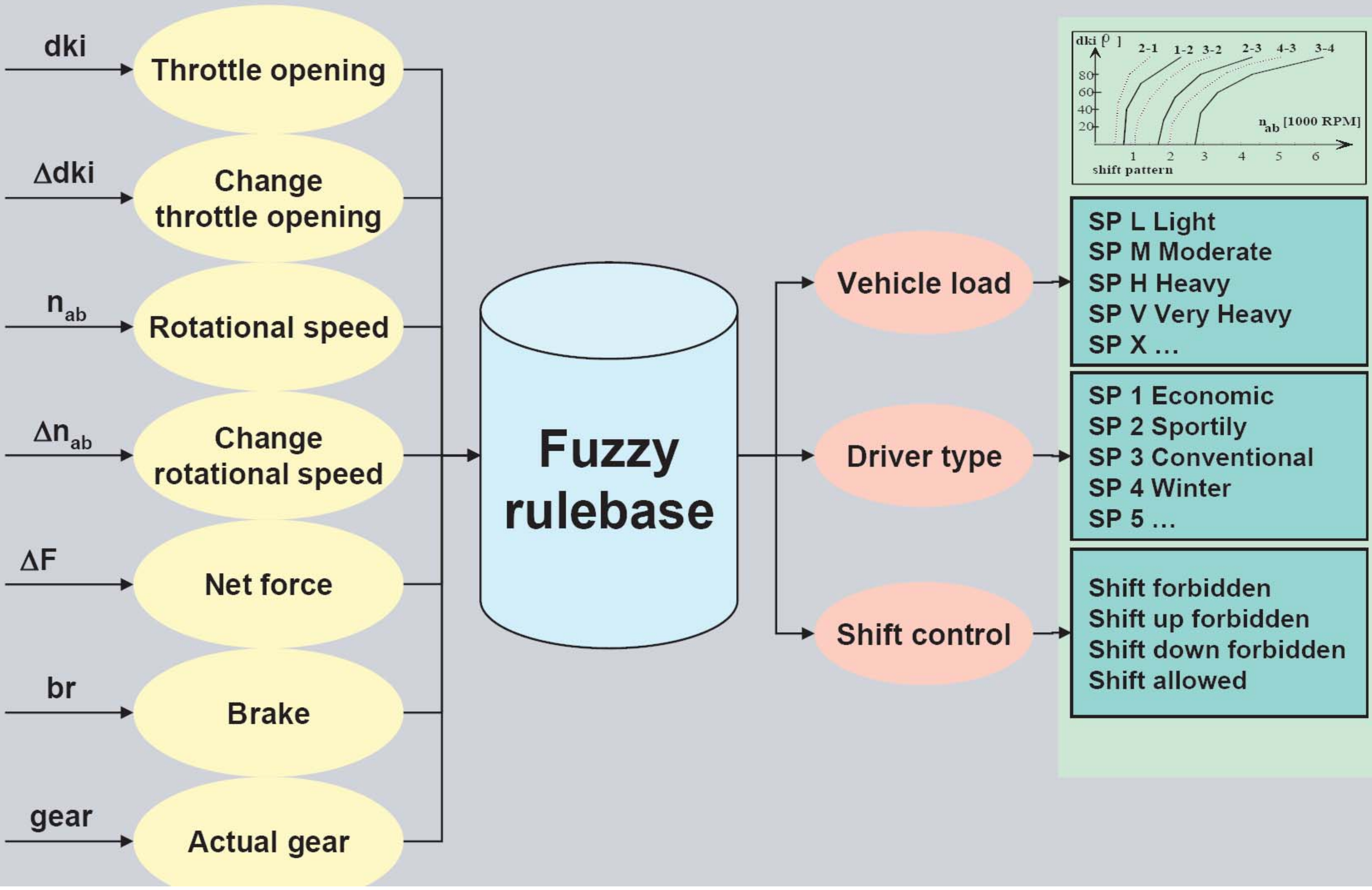
Shift patterns



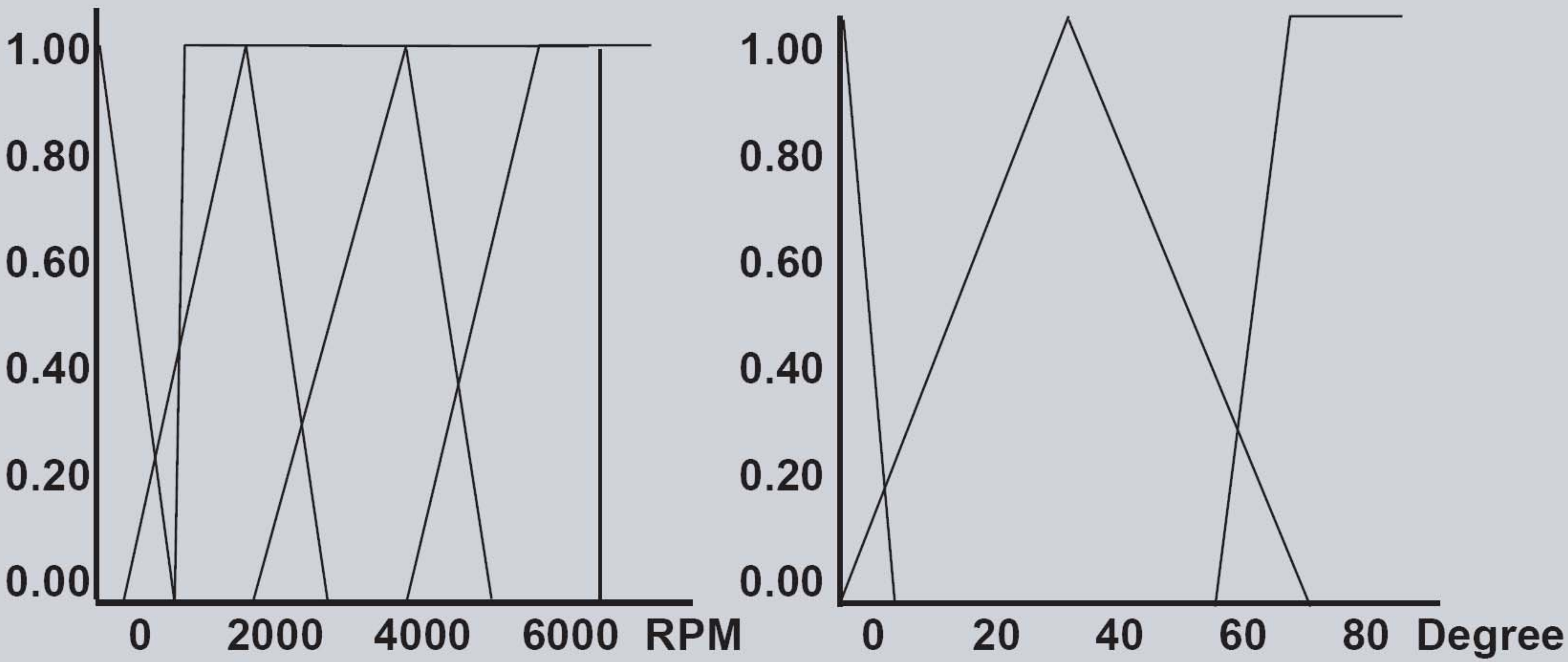
Simple modeling of the vehicle and resistances



Automatic transmission system - fuzzy system



Membership functions for Wheel rotation [RPM] and Gas pedal [degree]



Some rules

Rule1: IF D F IS negative THEN load = downhill

Rule2: IF D F IS negative AND brake IS pressed THEN load = downhill

Rule3: IF D F IS positive AND brake IS unpressed AND throttle IS open THEN load=uphill

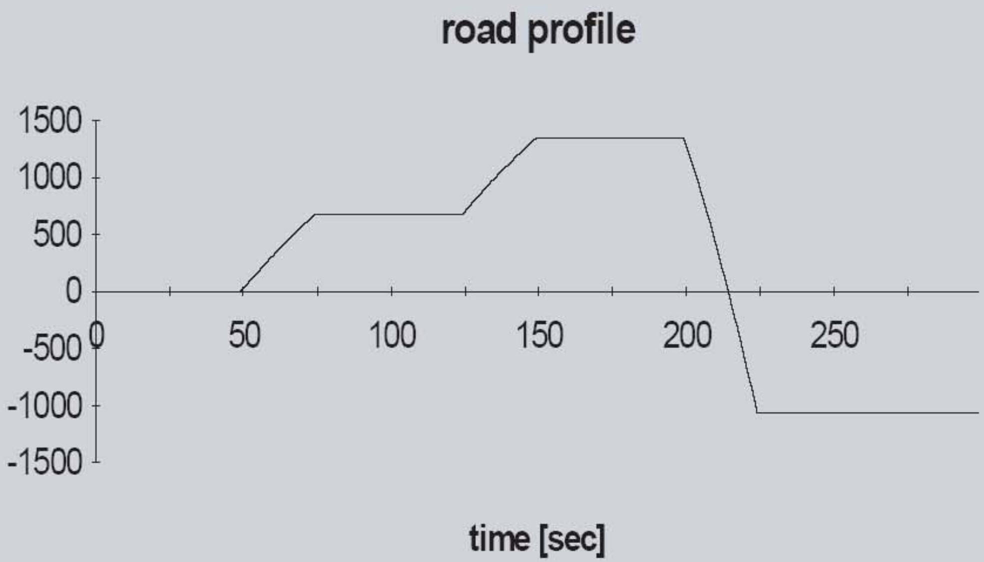
Rule4: IF throttle IS wide_open AND D n IS NOT positive AND n IS NOT high THEN load=downhill

Rule5: IF gear IS gear1 THEN shift=shiftdown_forbidden

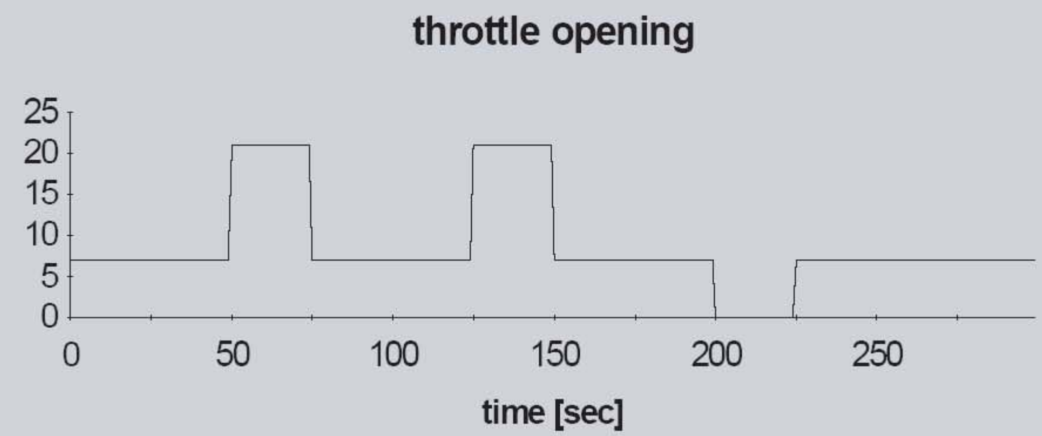
Rule6: IF D F IS negative AND brake IS pressed THEN shift=shiftup_forbidden

Model of the Driver and the Environment

Road profile:

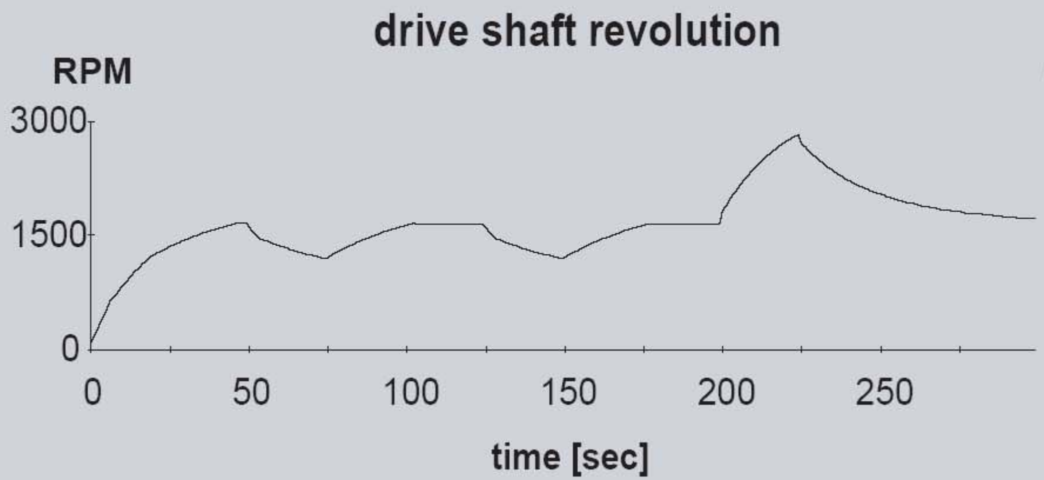


Driver model:



Vehicle velocity and conventional shift pattern

Vehicle velocity:

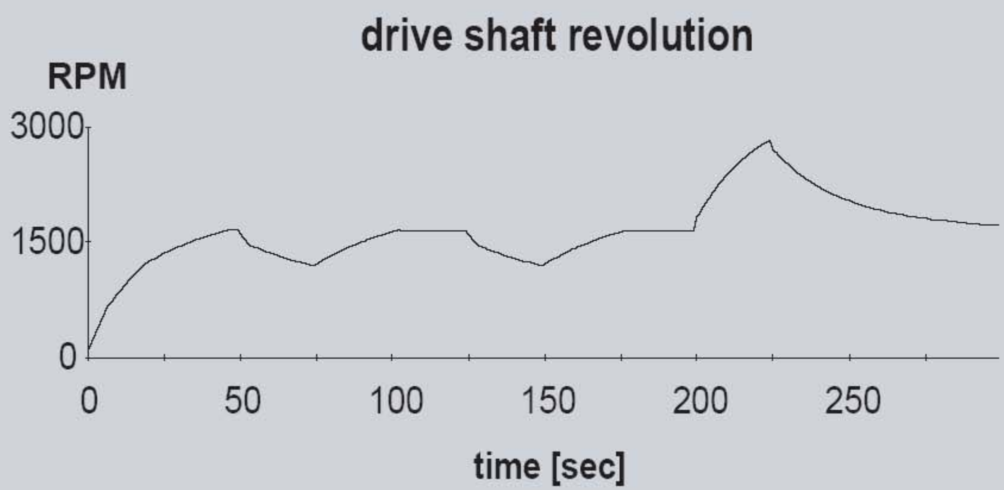


Conventional shift behaviour:

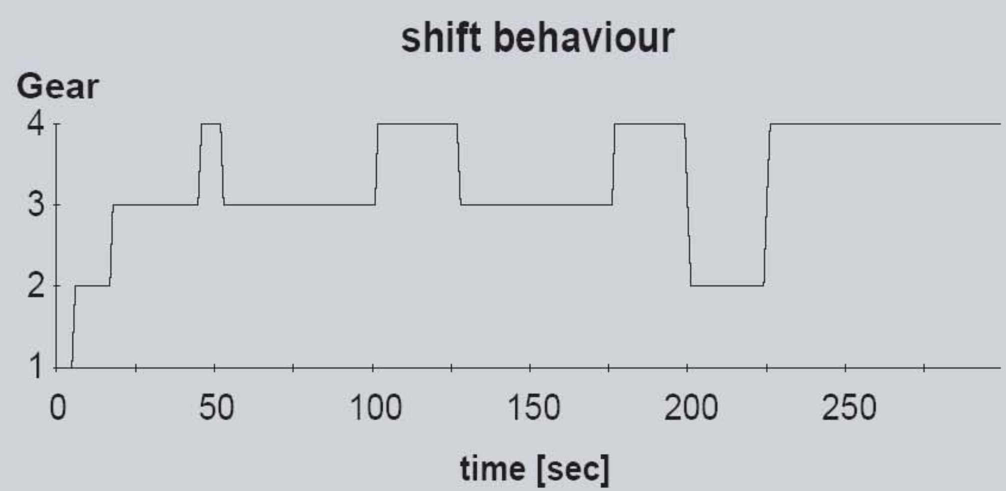
Disadvantages: - late shifting back
- no shifting back at downhill

Vehicle velocity and fuzzy shift pattern

Vehicle velocity:

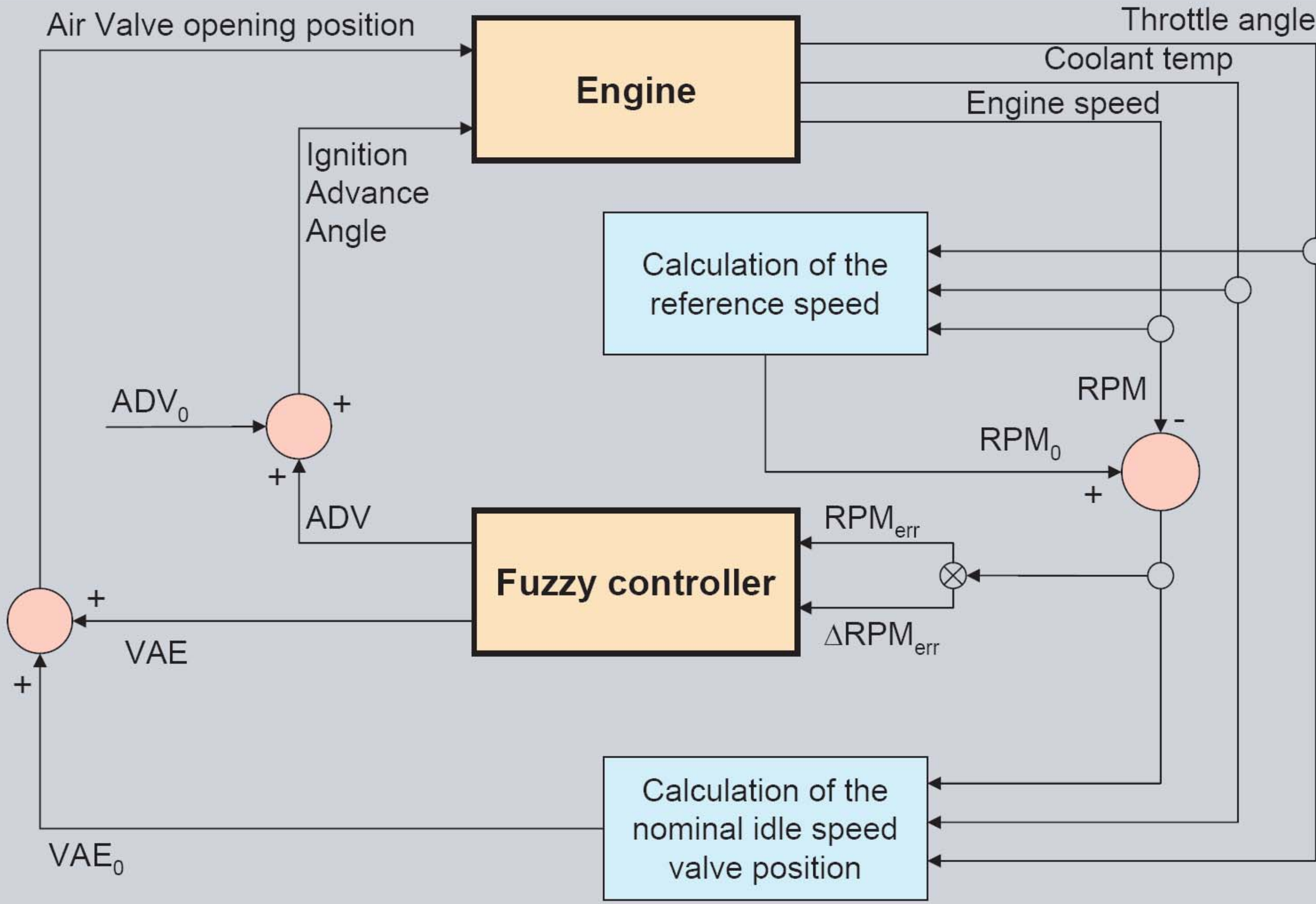


Fuzzy shift behaviour:

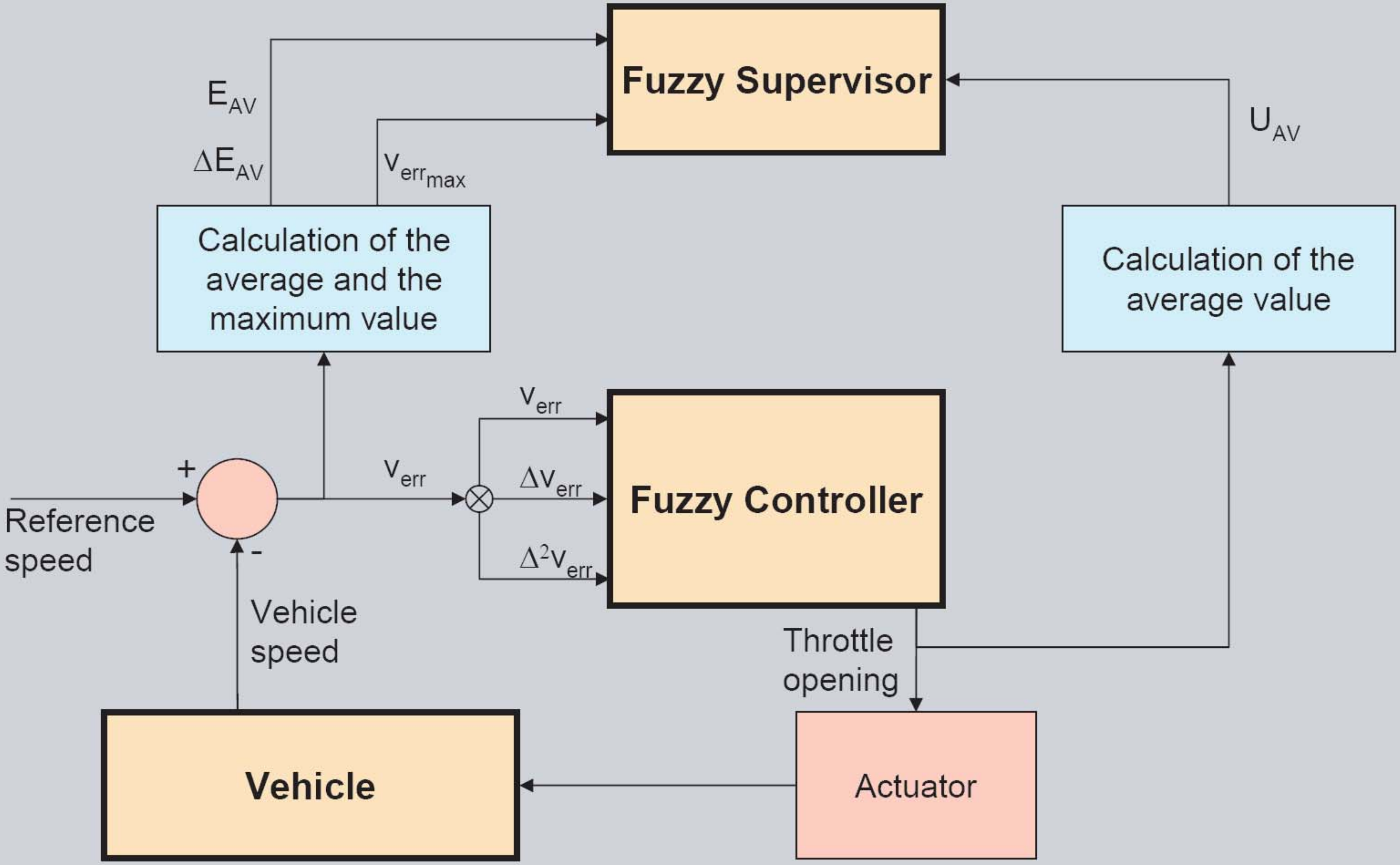


Advantages: - Delayed shifting up
- Early shifting back (mountain)
- Shifting back by down-hill

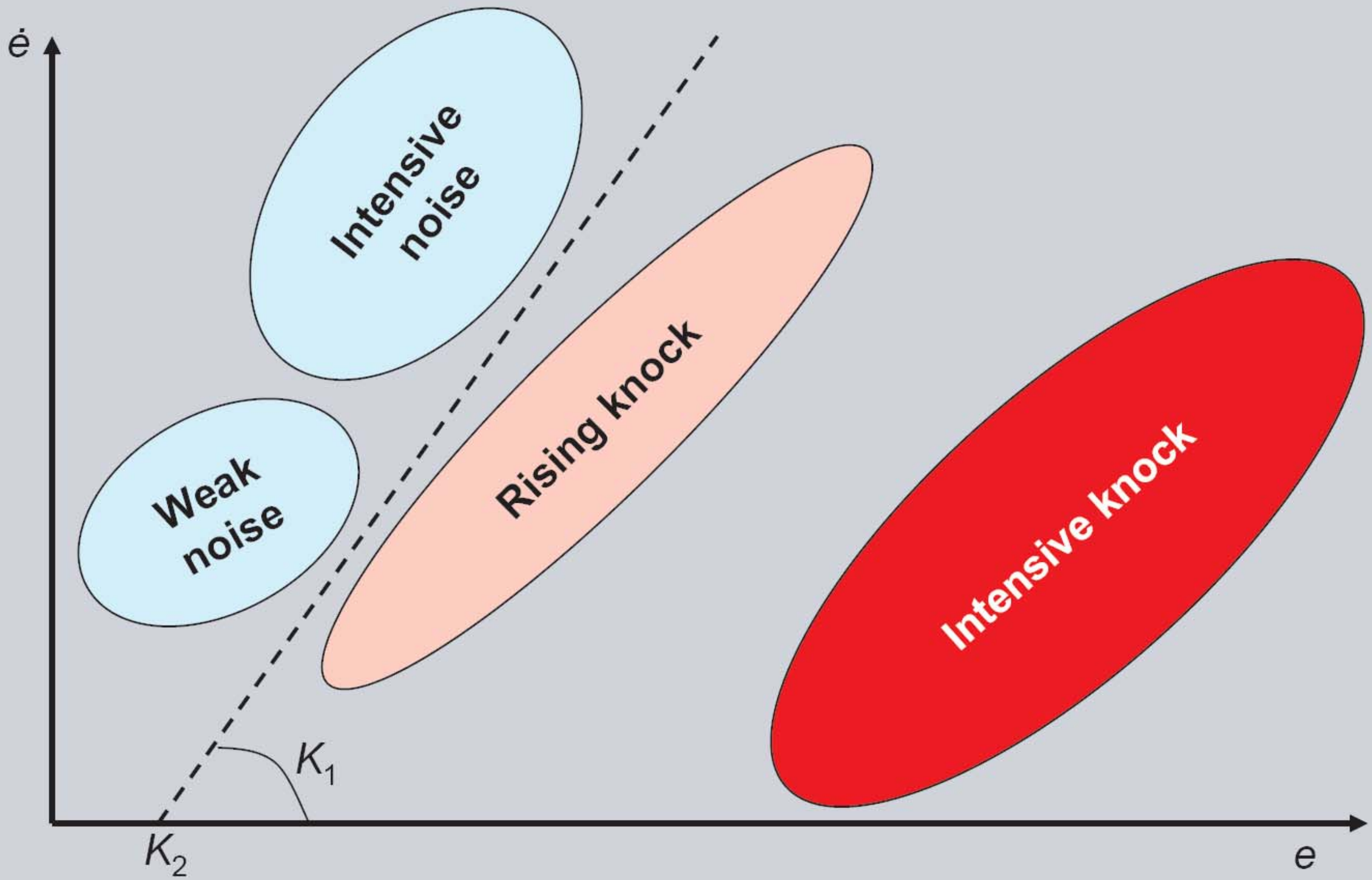
Idle speed fuzzy controller



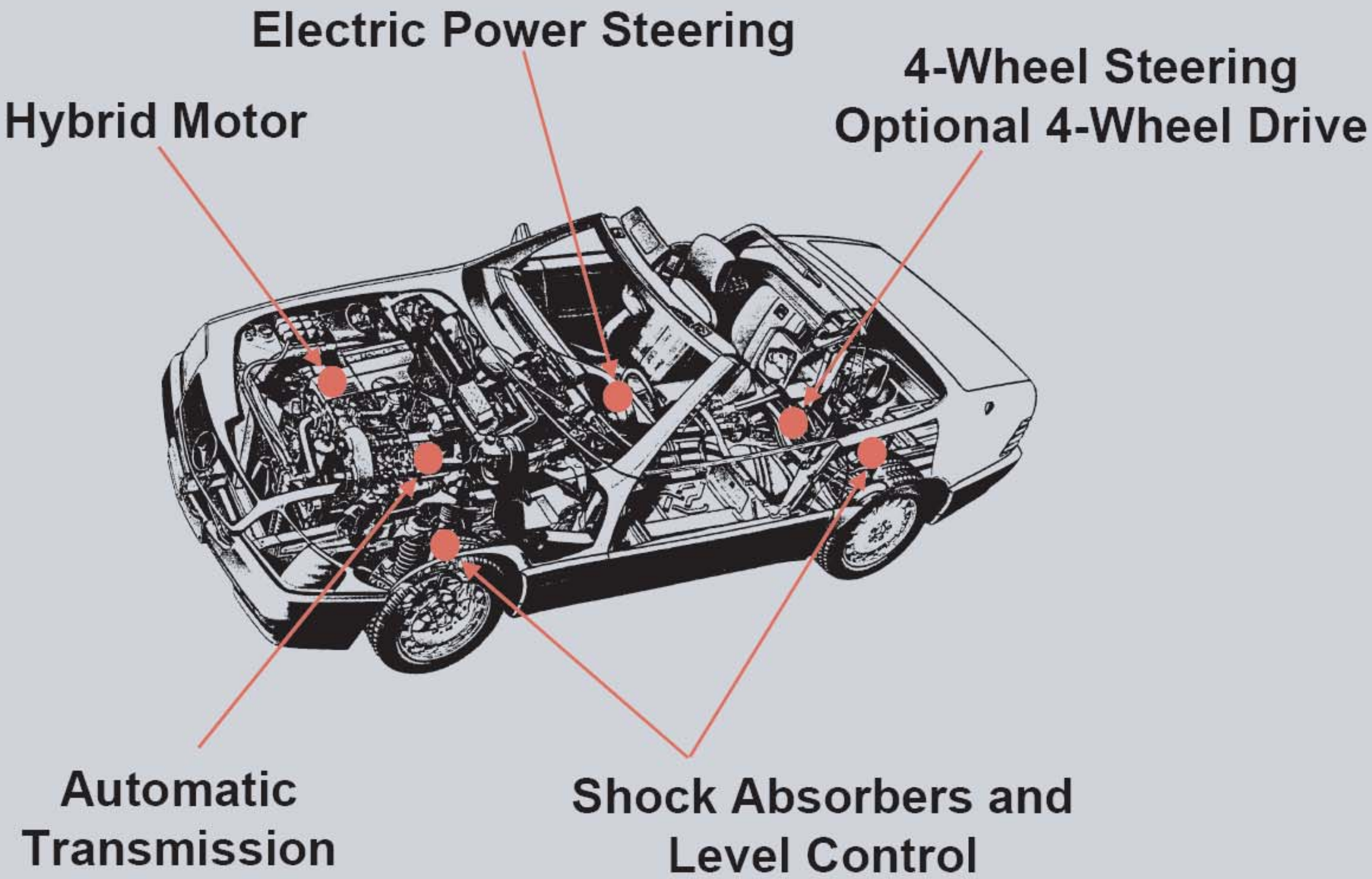
Cruise control

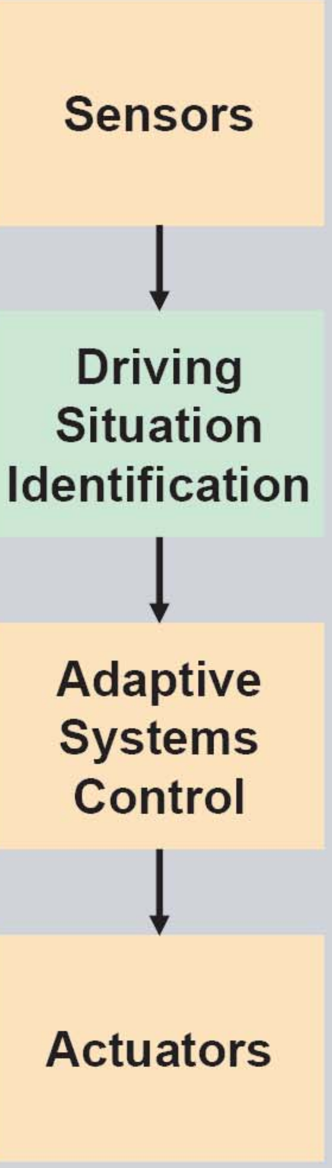


Anti knock control

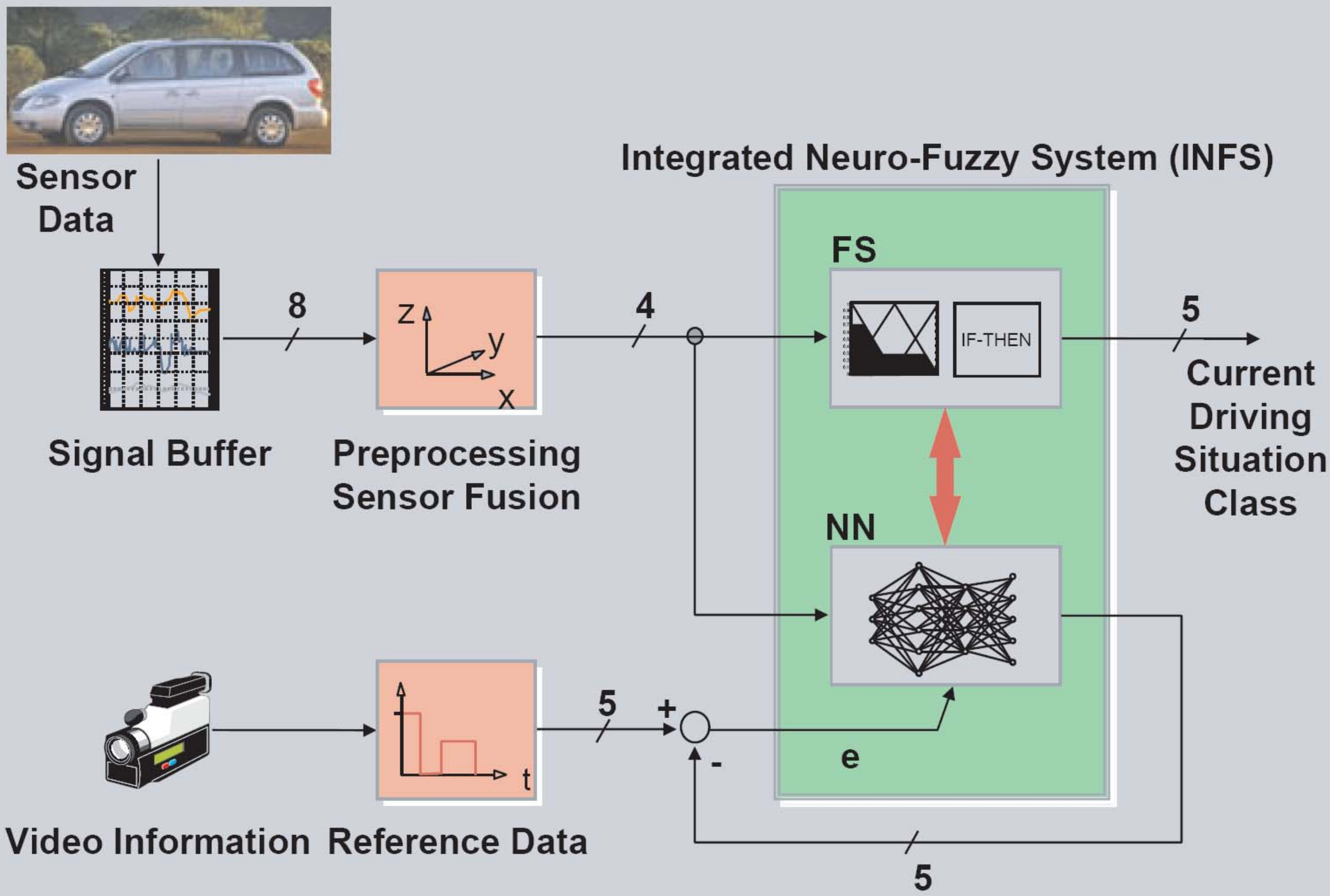


Car electronics





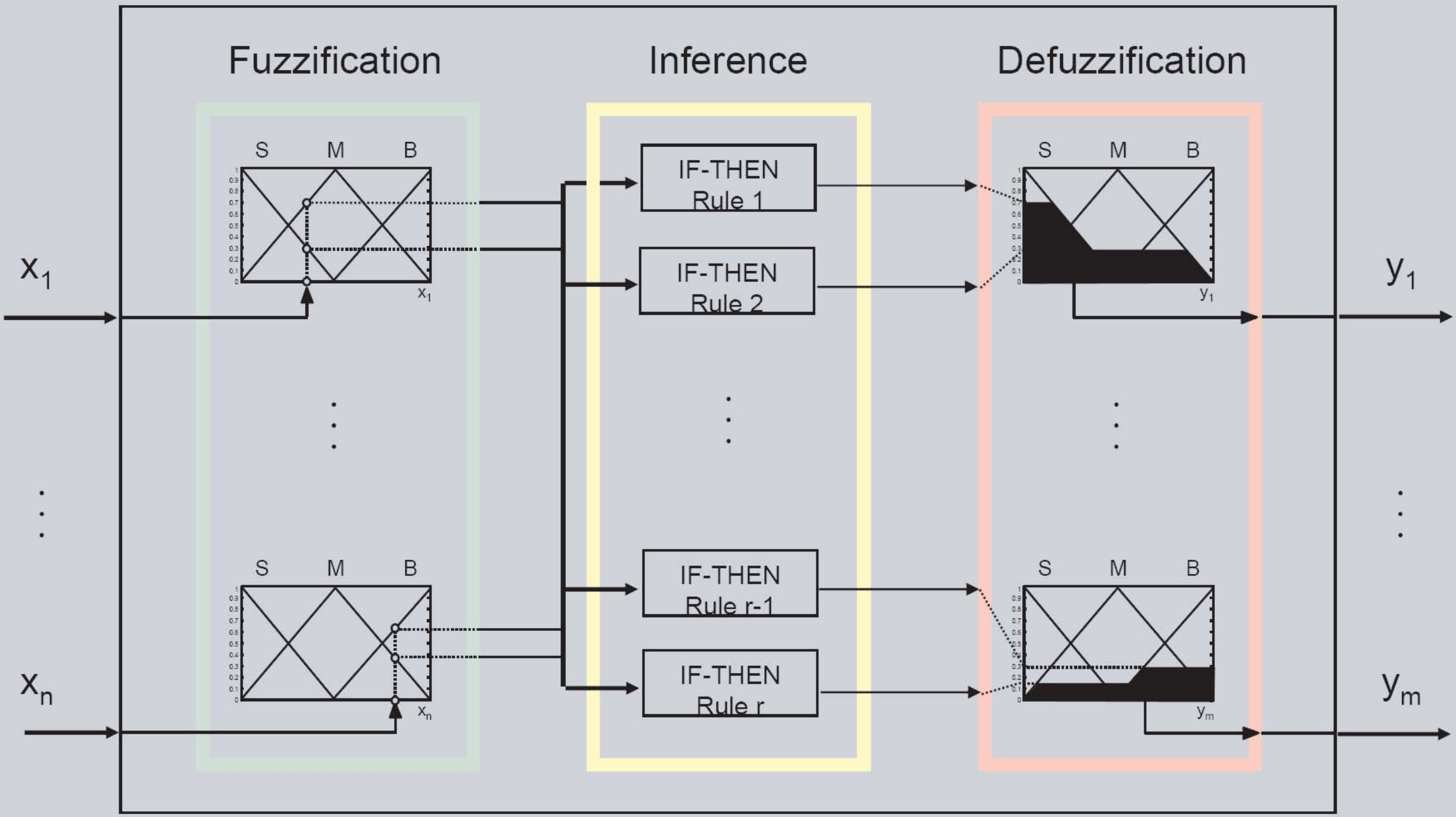
Driving Situation Identification



Driving Situation Classes

Class 1:	Very high speed, continuous driving situation, straight section, low lateral acceleration, no steep climbs nor descents (freeway)
Class 2:	High speed, continuous driving situation, straight section, low lateral accelerations, no steep climbs nor descents (highway, local road)
Class 3:	High/medium speed, continuous or discontinuous driving situation, possible high lateral accelerations and/or steep climbs or descents (curvy, hilly roads, transitions between class 1 and 2, etc.)
Class 4:	Low speed, often discontinuous driving situation, high traffic density, medium/no lateral accelerations, medium/low climbs or descents (downtown, Stop & Go, outer city area)
Class 5:	Very low speed or stop (Traffic Light, Intersection, Parking, etc.)

Fuzzy System Components



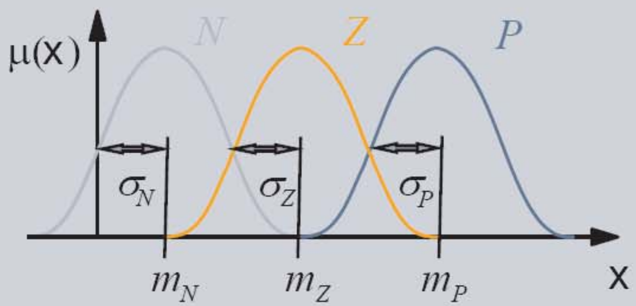
Fuzzification Layer

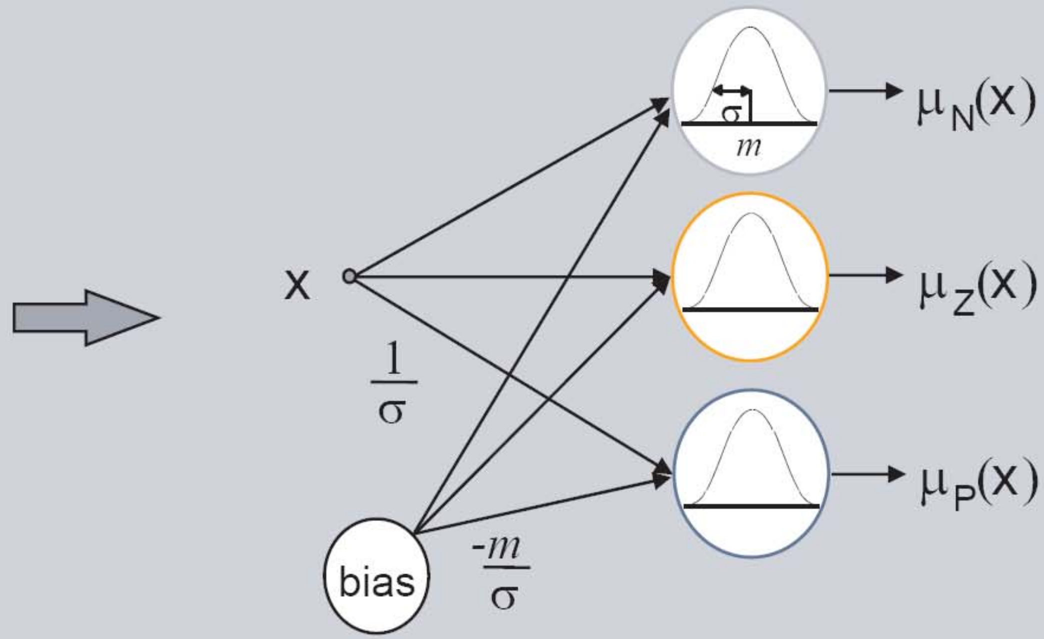
Gaussian Membership Functions

m_K :   Center of Input-MBF

σ_K :   Width of Input-MBF

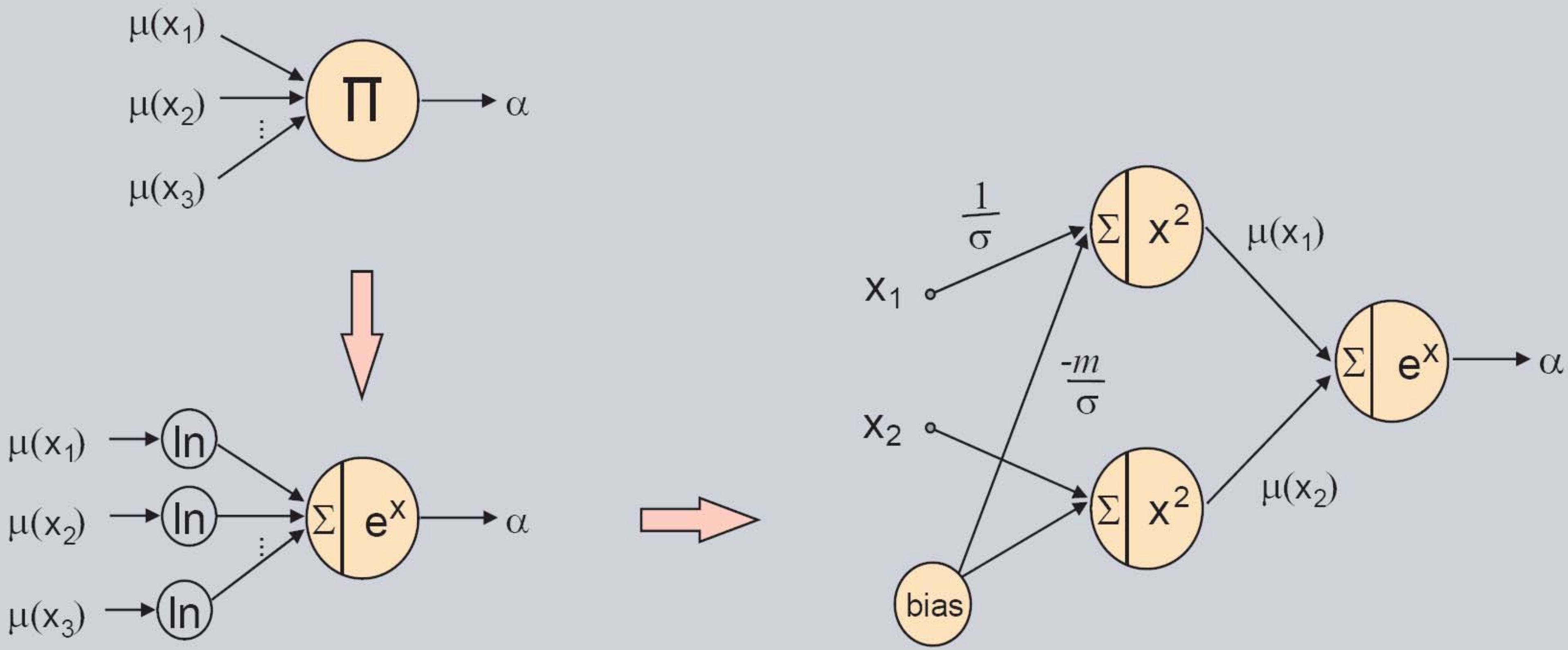
$$\mu(x) = \exp\left[-\left(\frac{x_i - m}{\sigma}\right)^2\right]$$





Evaluation of Premises

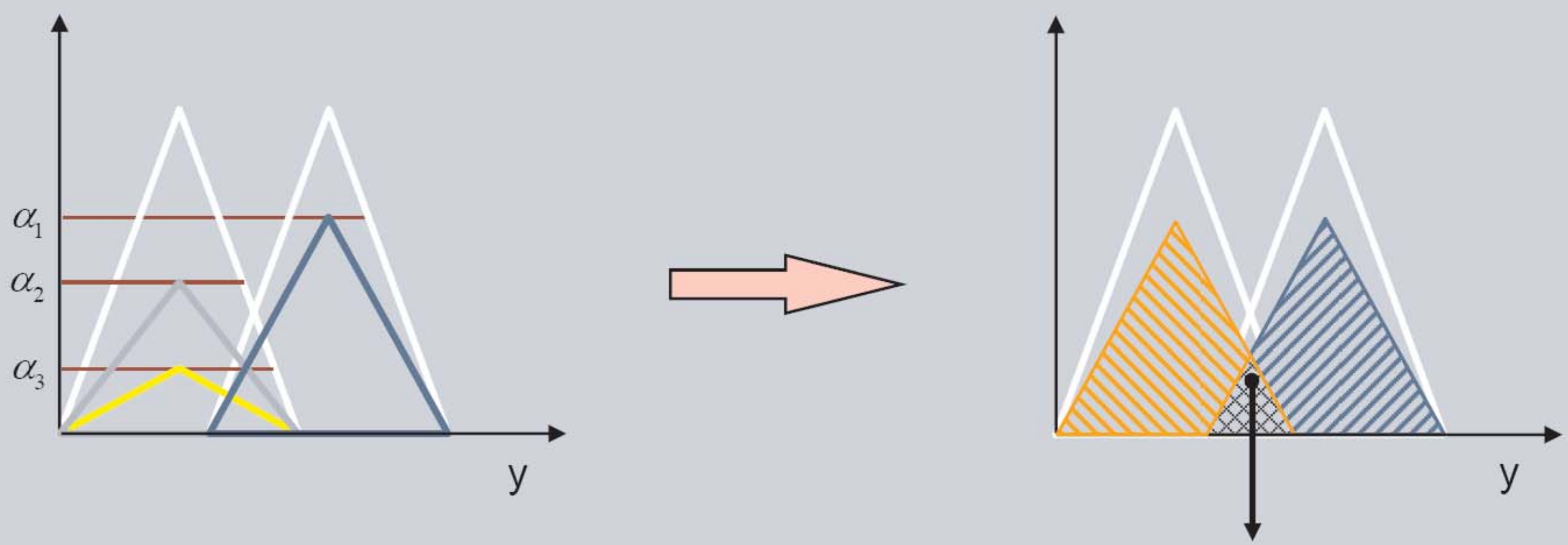
$$\alpha = \prod_{k=1}^{n_{mbf}} \mu_k(x) = \prod_{k=1}^{n_{mbf}} \exp\left[-\left(\frac{x-m_k}{\sigma_k}\right)^2\right] = \exp\left[\sum_{k=1}^{n_{mbf}}\left(\frac{x}{\sigma_k}-\frac{m_k}{\sigma_k}\right)^2\right]$$



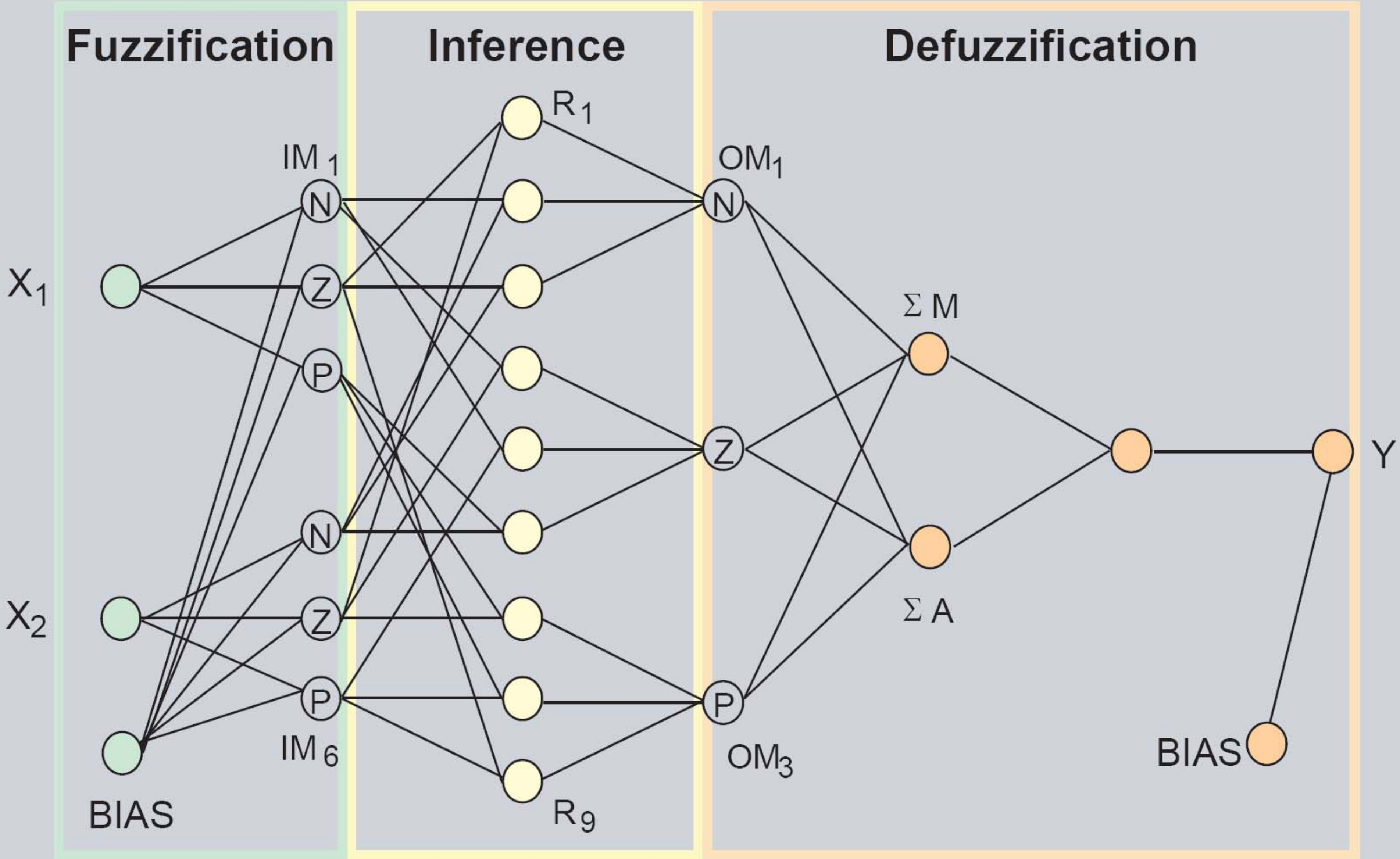
Inference and Defuzzification

- Max-Dot Inference
- "Center of Sums" Defuzzification

$$y = \frac{\sum_{k=1}^{n_{ombf}} M_k \cdot \sum_{j=1}^{n_r} \left(w_{kj} \cdot \alpha_j \right)}{\sum_{k=1}^{n_{ombf}} A_k \cdot \sum_{j=1}^{n_r} \left(w_{kj} \cdot \alpha_j \right)} \qquad \text{where} \begin{cases} w_{kj} = 1 & \text{if partial conclusion exists} \\ w_{kj} = 0 & \text{otherwise} \end{cases}$$

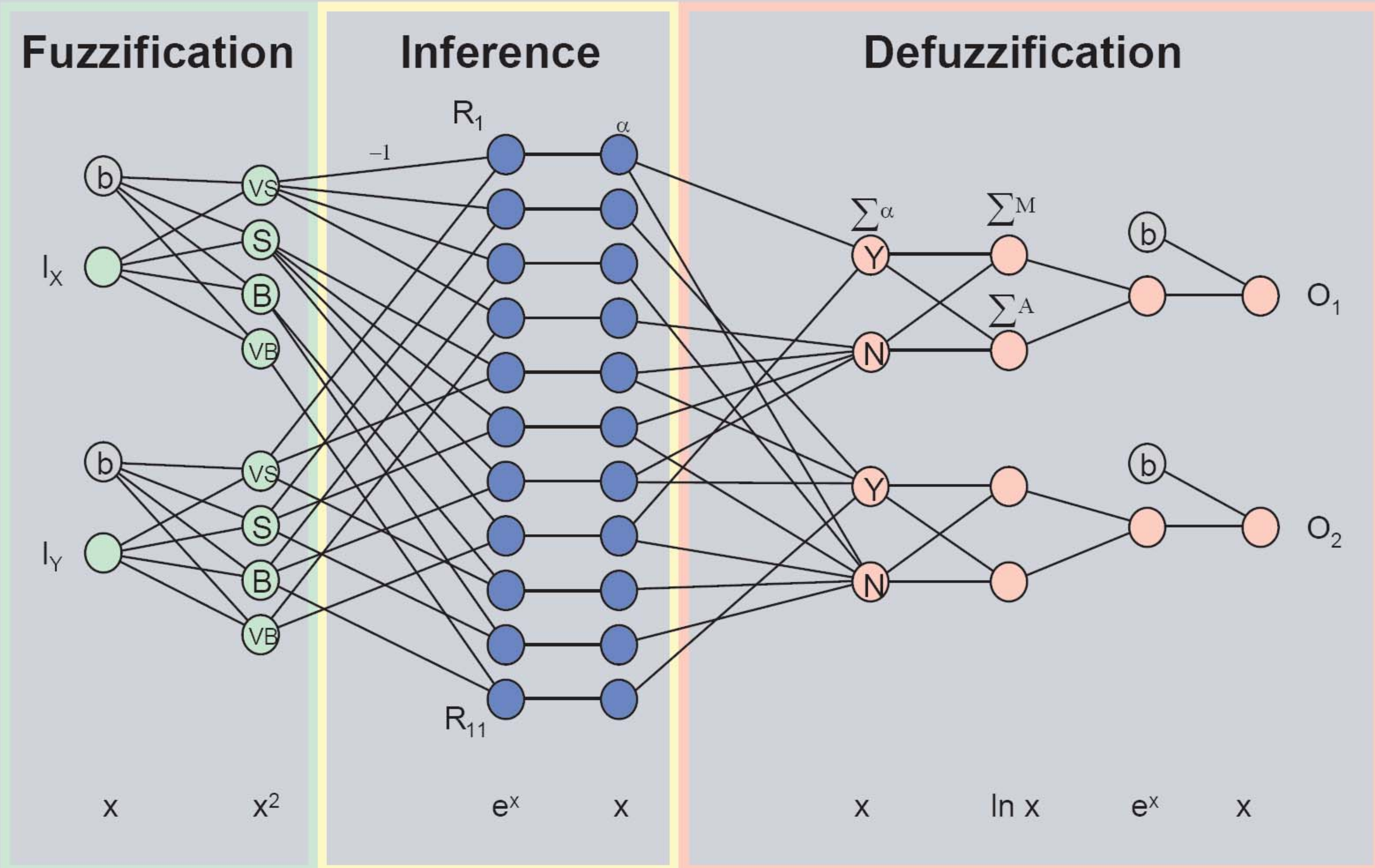


Network

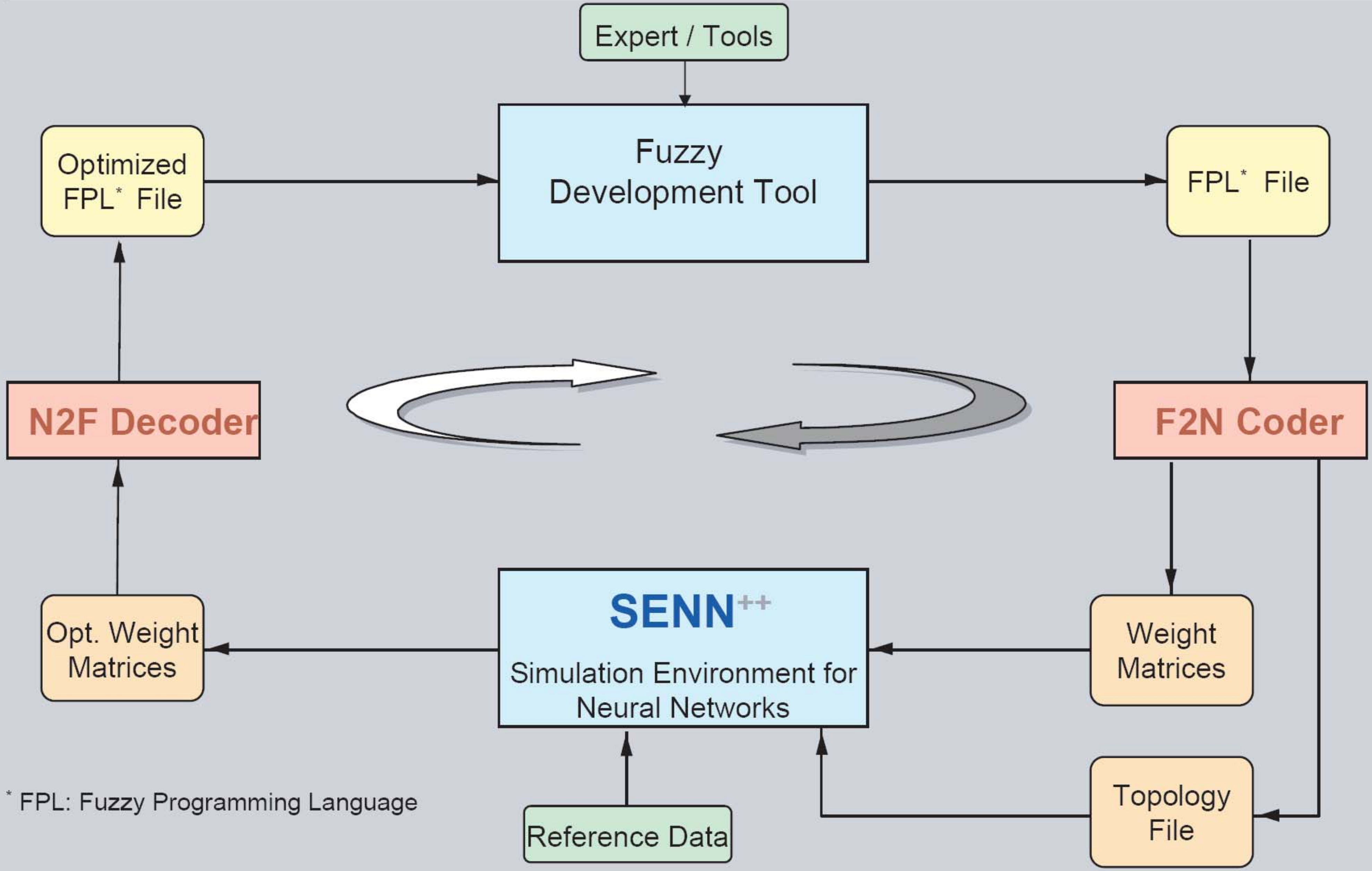


Fuzzification
Inference
Defuzzification
X1
X2
BIAS
IM 1
N
Z
P
N
Z
P
IM 6
R 1
R 9
OM1
N
Z
P
OM3
Σ M
Σ A
Y
BIAS

Neuro-Fuzzy topology

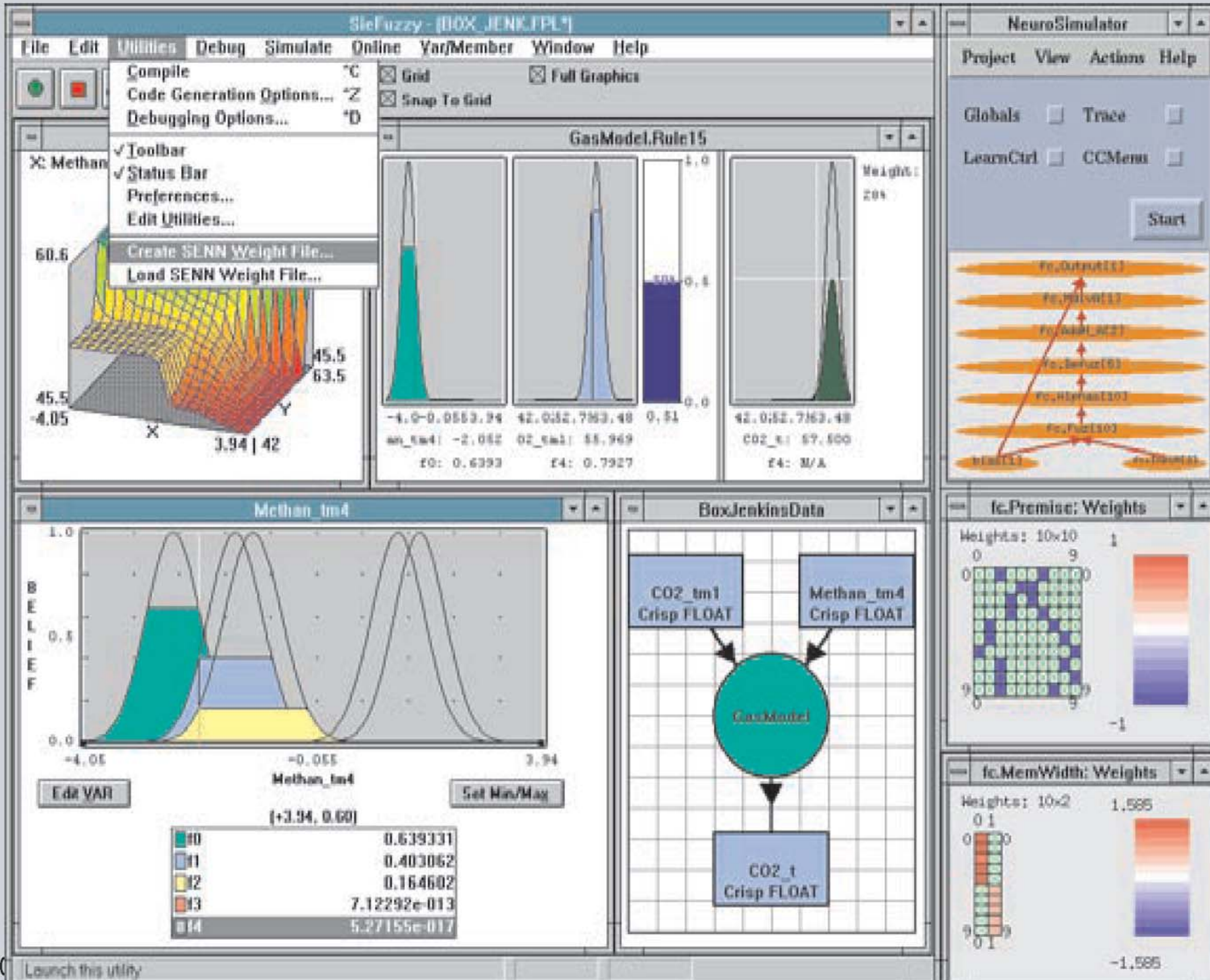


Integrated Neuro-Fuzzy system



* FPL: Fuzzy Programming Language

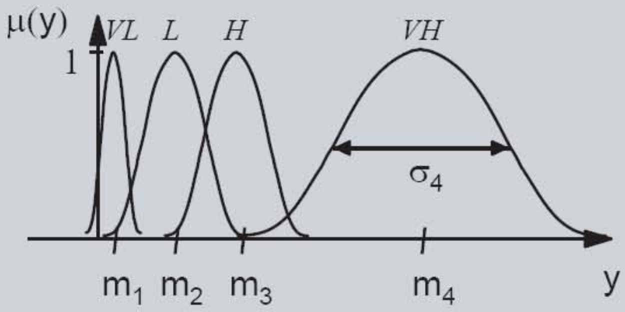
Fuzzy tool


SieFuzzy - [BOX_JENK.FPL*]
File Edit Utilities Debug Simulate Online Var/Member Window Help
Compile
Code Generation Options...
Debugging Options...
Toolbar
Status Bar
Preferences...
Edit Utilities...
Create SENN Weight File...
Load SENN Weight File...
Grid
Snap To Grid
Full Graphics
GasModel.Rule15
NeuroSimulator
Project View Actions Help
Globals
Trace
LearnCtrl
CCMem
Start
Methan_tm4
BoxJenkinsData
CO2_tm1
Crisp FLOAT
Methan_tm4
Crisp FLOAT
GasModel
CO2_t
Crisp FLOAT
fc.Premise: Weights
fc.MemWidth: Weights
Edit VAR
Set Min/Max
BELIEF
Launch this utility

Fuzzy System Structure

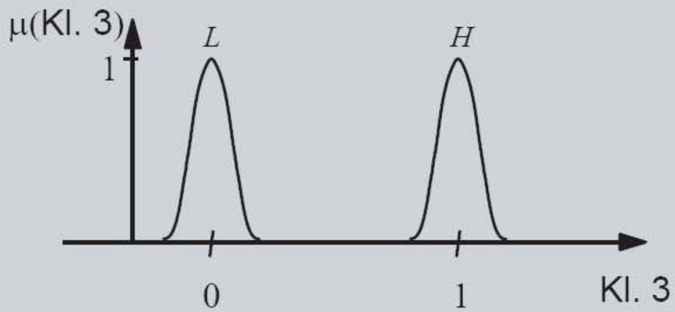
Inputs

- 4 Input Variables: x, y, z, w
- Membership Functions: VL, L, H, VH



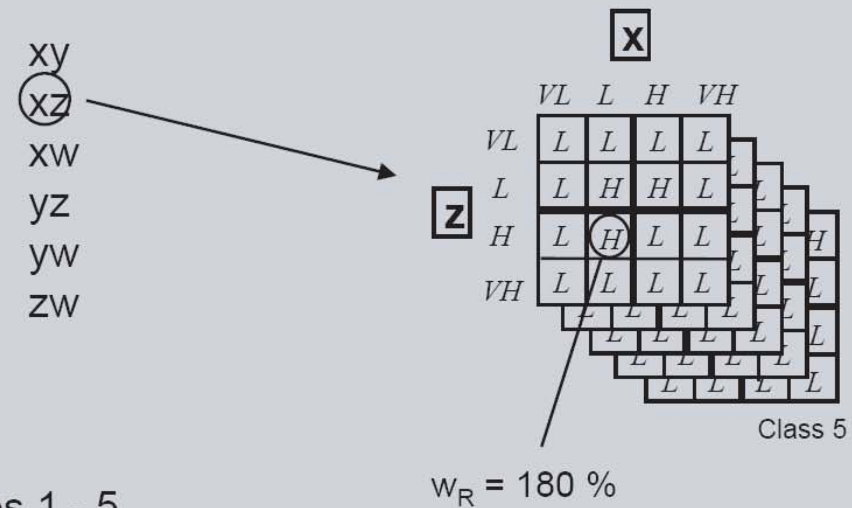
Outputs

- 5 Output Variables: Driving Situation Classes 1 - 5
- 2 Membership Functions L, H
- Defuzzification -> Belief for Each Class (0 ...1)



Rulebase

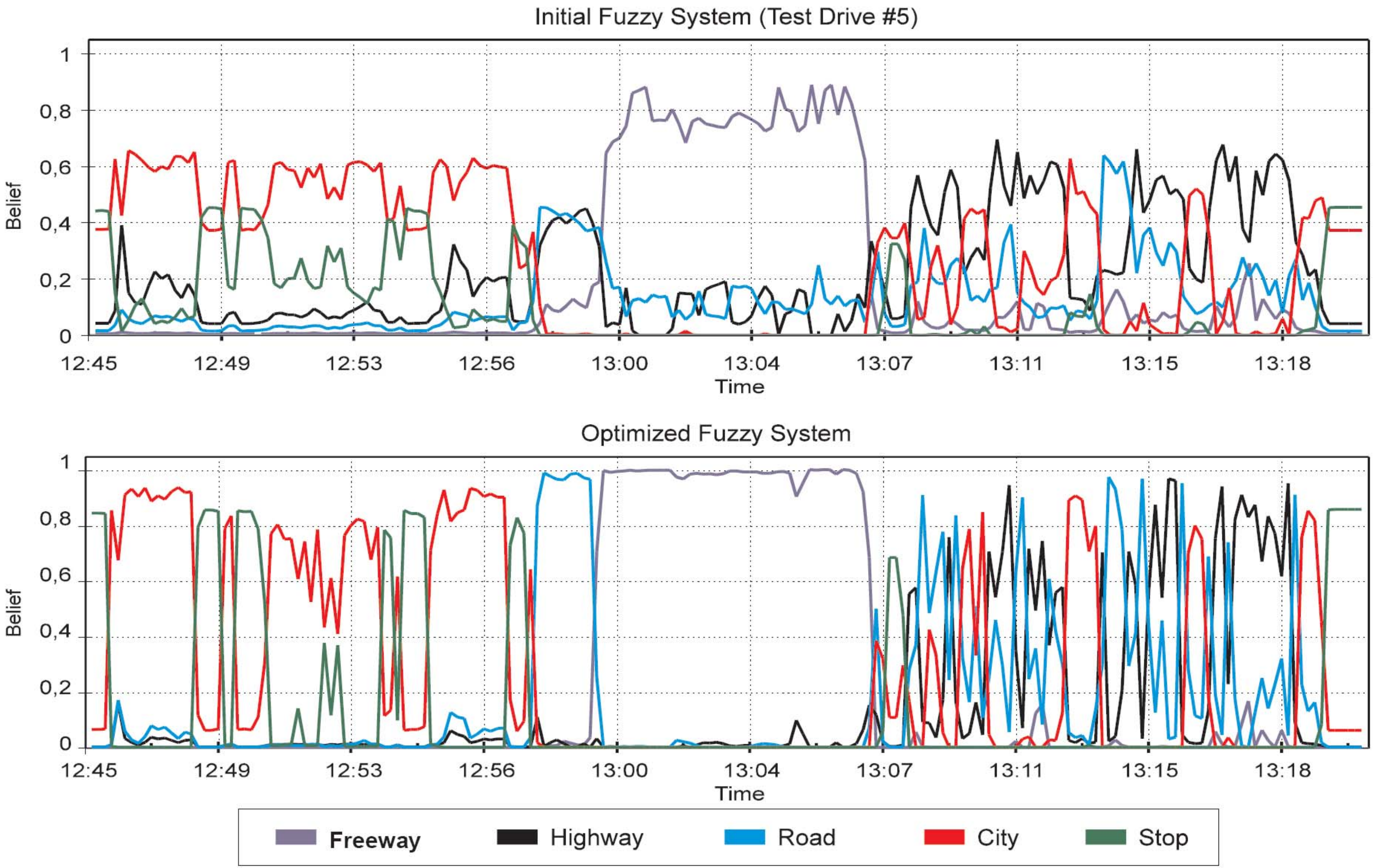
- Design of Initial Rulebase
- 6 x 4 x 4 = 96 Rules



Optimization Parameters

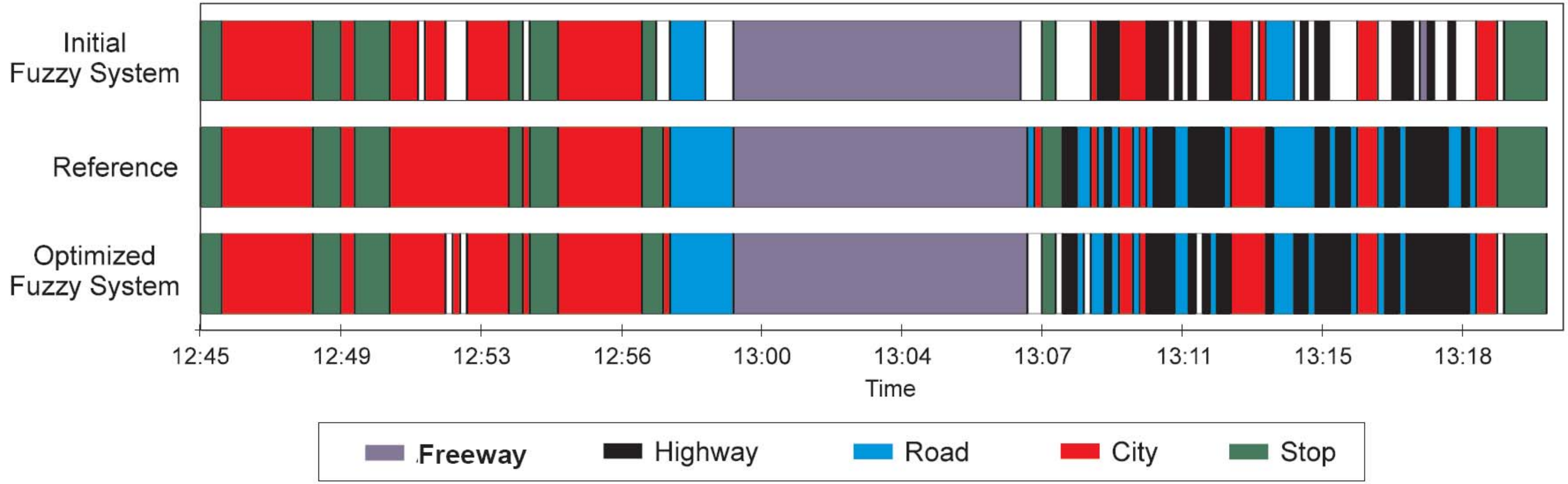
- In-Mbf: Centers m_i
- In-Mbf: Widths σ_i
- Rule Weights w_R
- Conclusions

Test drive

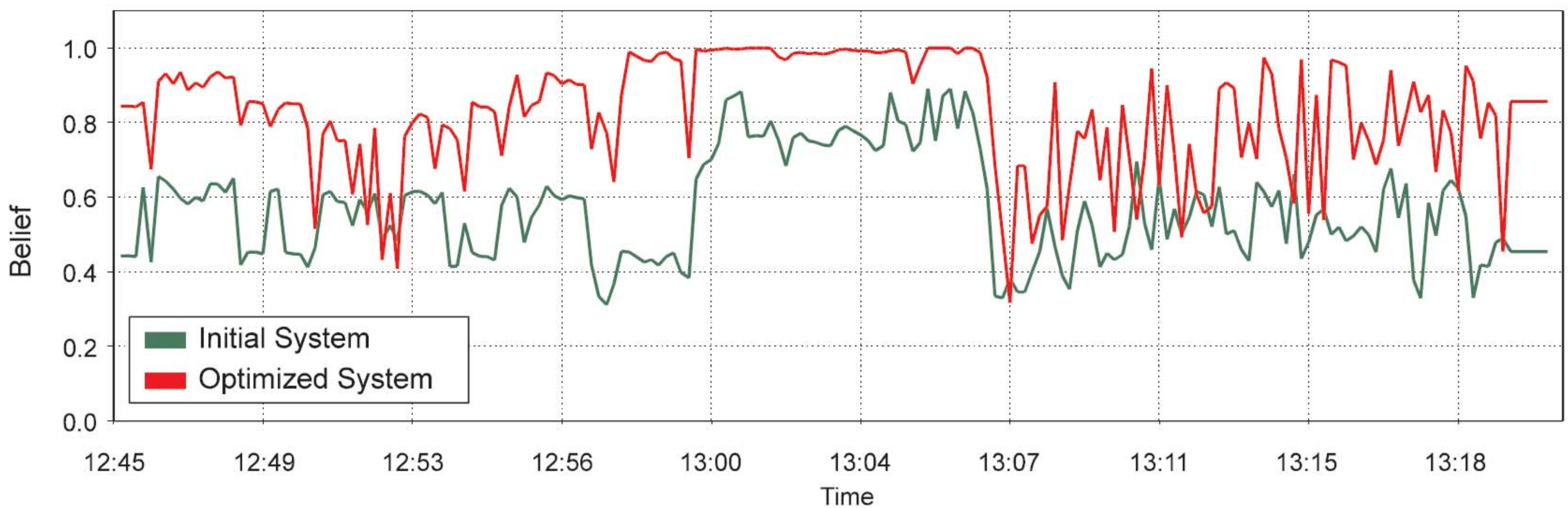


Initial Fuzzy System (Test Drive #5)
Belief
1
0,8
0,6
0,4
0,2
0
12:45
12:49
12:53
12:56
13:00
13:04
13:07
13:11
13:15
13:18
Time
Optimized Fuzzy System
Belief
1
0,8
0,6
0,4
0,2
0
12:45
12:49
12:53
12:56
13:00
13:04
13:07
13:11
13:15
13:18
Time
Freeway
Highway
Road
City
Stop

Test drive

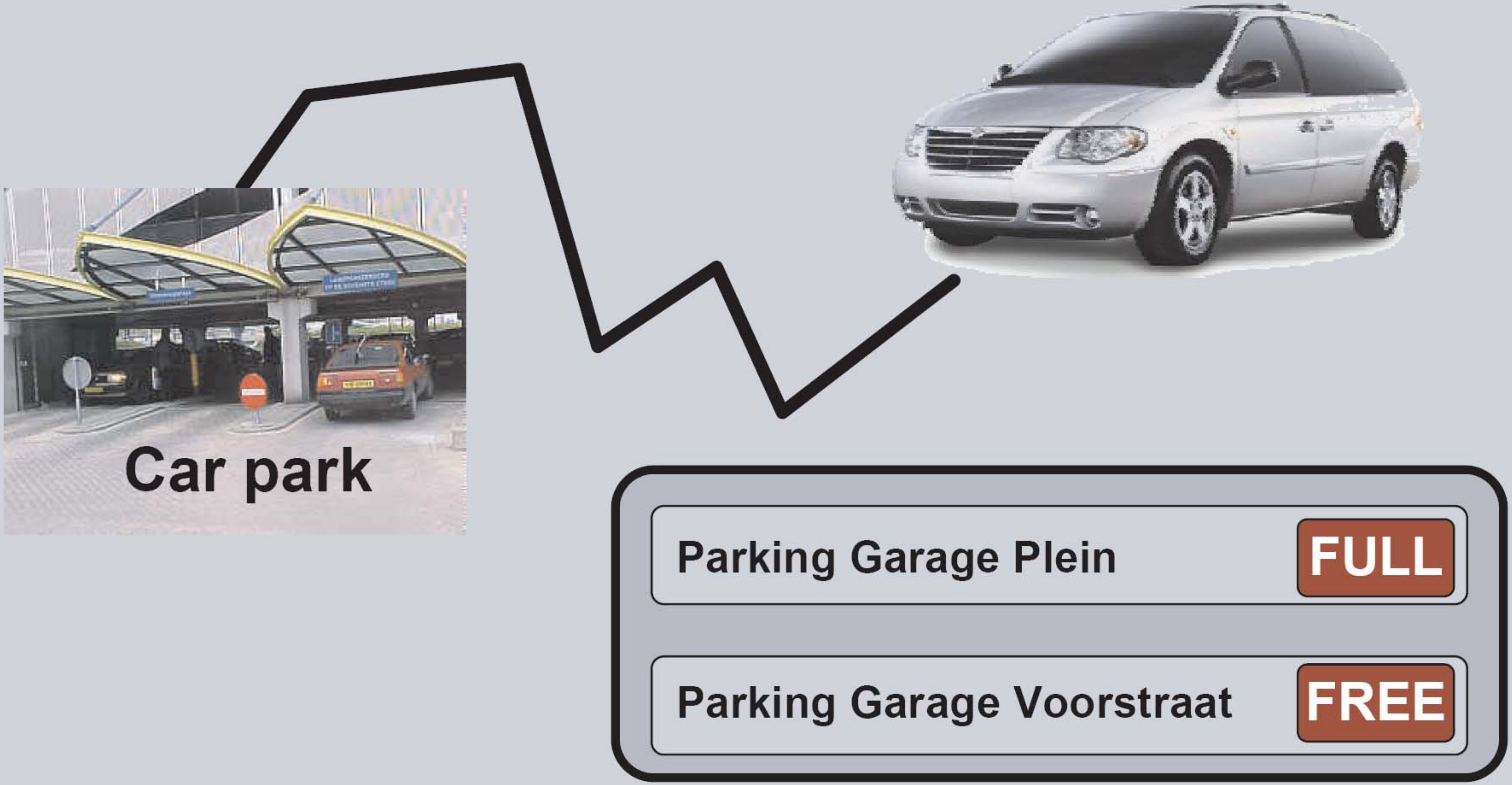


Initial Fuzzy System
Reference
Optimized Fuzzy System
12:45
12:49
12:53
12:56
13:00
13:04
13:07
13:11
13:15
13:18
Time
Freeway
Highway
Road
City
Stop



Belief
1.0
0.8
0.6
0.4
0.2
0.0
Initial System
Optimized System
12:45
12:49
12:53
12:56
13:00
13:04
13:07
13:11
13:15
13:18
Time

Fuzzy Parking Control



Traffic parameters

Number of cars driving in and out of the parking garage
- most important for short-time prognoses

Traffic density

Time
- time of the day (early afternoon, midnight)
- day of the week
- season (Christmas, Summer, sales)

Weather conditions
- cold, rainy weather: people tend to go to the large shopping centers
- very hot, sunny weather: many people go out of town

Special traffic situations
- e.g., roadworks, holidays, etc.

Special events
- pop concerts, parades, processions, . . .

Kind of parking garage

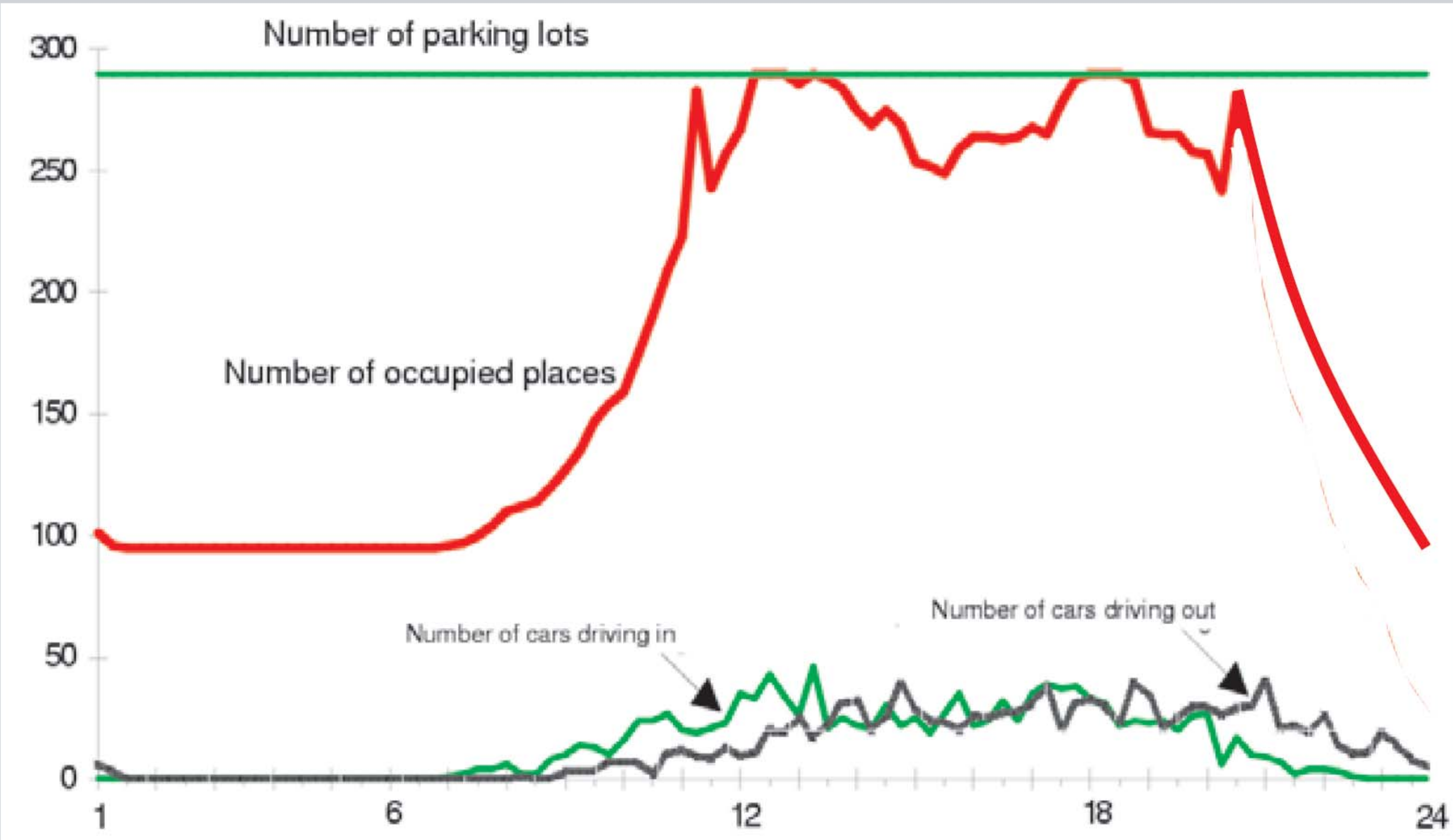
Situated downtown, near the shopping center, mainly used by people that go shopping

Short time parking during the day, low percentage of long-term parkers

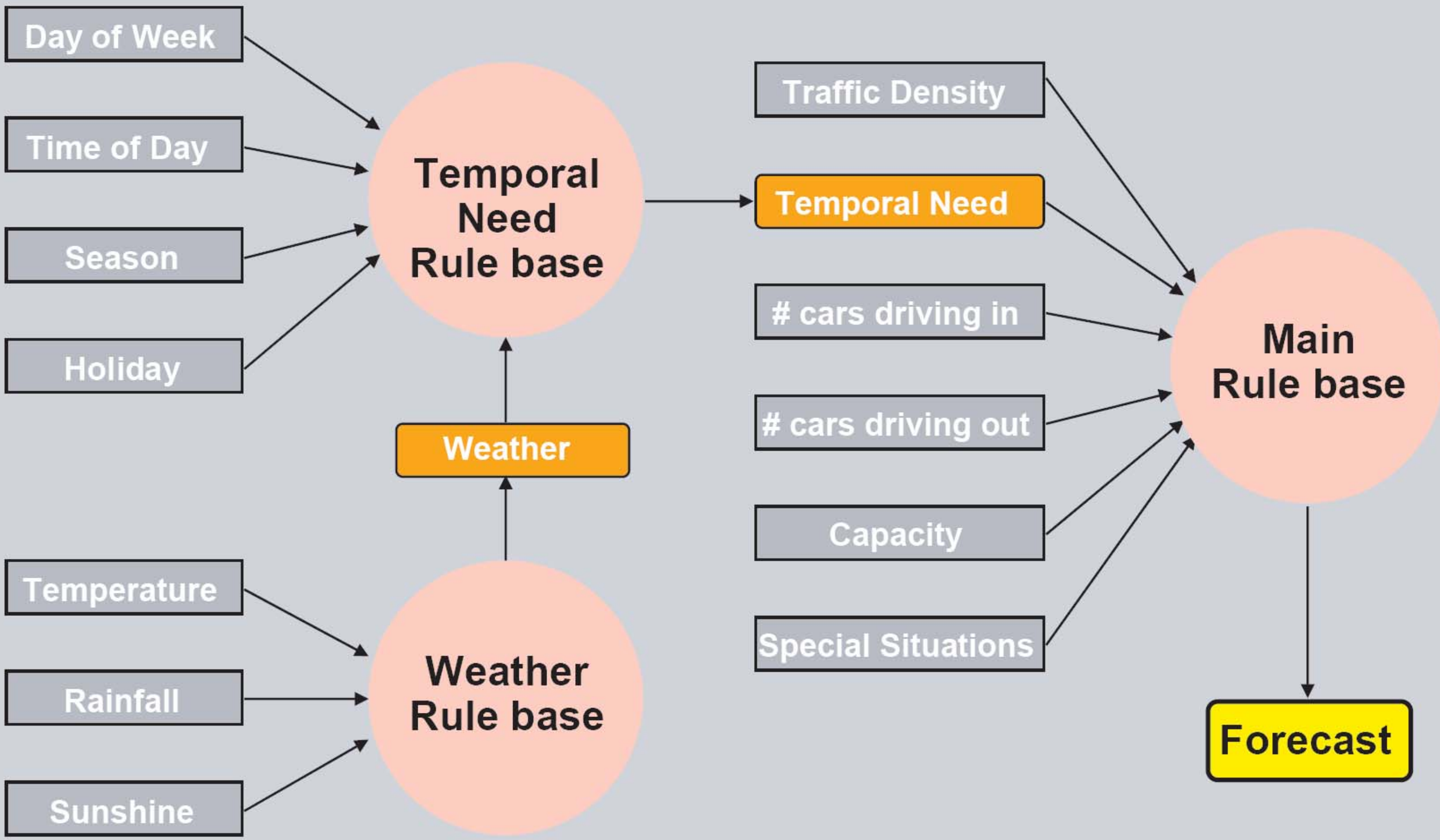
Cannot be filled within one hour, due to the structure of the garage

Data from ten parking garages in Düsseldorf, Germany. Weather data from the weather institute in Offenbach

Car park Karlsplatz, Thursday



The inputs and outputs



Examples of some rules

RULE SUB_Rule_I_good weather_1
IF (Temperature IS high)
AND (Rainfall IS dry)
AND (Sunshine IS sunny)
THEN (Weather IS small_traffic)

When it is nice weather (hot, not raining, sunny) it will be relatively quiet downtown in comparison to other weather conditions.

RULE SUB_Rule_II_Day_of_week_5
IF (Holiday IS false)
AND (Time_of_day IS evening)
AND (Day_of_Week IS **NOT** weekend)
AND (Day_of_Week IS **NOT** Thursday)
THEN (Temporal_need IS low)

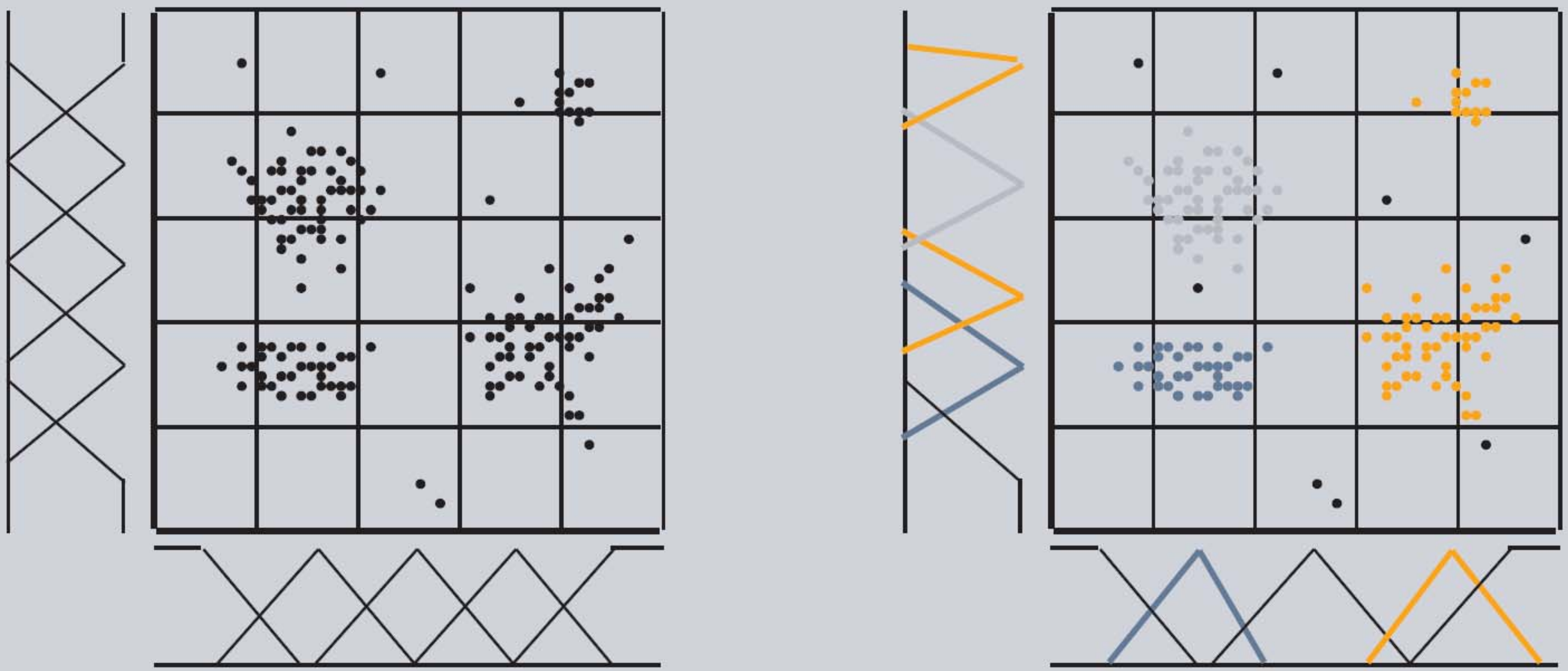
On a normal day (Thursday evening shops are opened, not a holiday, not during the weekend) it is relatively quiet during the evening. This is independent from the weather situation.

RULE Rule_II__8
IF (Capacity IS critical)
AND ((Temporal_need IS high)
OR (Temporal_need IS very_high))
THEN (Forecast IS parking_garage_full)

This rule expresses the prognosis for the time after one hour. So, if the parking garage is almost full and it is to be expected that many vehicles are driving towards the parking garage then the prognosis is that it will be full within one hour.

Clustering with NN

The neural network directly generates input for the fuzzy system



Results after learning with NN

Initial prediction quality: 78%

After tuning by hand:
(one system for all garages)

PG1 J	0.9548	PG1 A	0.9239
PG2 J	0.9147	PG2 A	0.9086
PG3 J	0.9298	PG3 A	0.9272
PG4 J	0.9415	PG4 A	0.9051
PG5 J	0.9147	PG5 A	0.8849
PG6 J	0.9415	PG6 A	0.9374

Average: 0.9237

After using the described method: 86% - 88%

After using the described method for each parking garage separately: 93%