



# *Report Assignment I*

## *Neuro-Fuzzy Systems For Modelling Dynamic Processes*

**Departamento de Engenharia Informática**  
**Faculdade de Ciências e Tecnologia da Universidade de Coimbra**  
**Research Seminar on Adaptive Computing**  
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**Student: Afonso Bezerra Lima Neto - 2019130856**

# Agenda

- Calculating a discrete transfer function
- Using the transfer function in Simulink to generate the dataset
- Fuzzy Inference System based on FCM
- Fuzzy Inference System based on Subtractive
- Testing in Simulink

# Calculating a discrete transfer function

Considering the given function  $G(s): \frac{3(s+1)}{s^3 + 3s^2 + 4s + 2}$ , the followings code must be executed in Matlab:

```
num=[3 3]
den=[1 3 4 2]
[zz, pp, kk] = tf2zp(num, den) % to find zeros, poles and gains
maxPP = max(abs(real(pp)))
aux = (1/maxPP)*0.25
[numd, dend] = c2dm(num,den,aux,'zoh') % apply the discretization method
'zoh'
```

The results are:

pp =

```
-1.0000 + 1.0000i
-1.0000 - 1.0000i
-1.0000 + 0.0000i
```

maxPP = 1.0000

aux = 0.2500

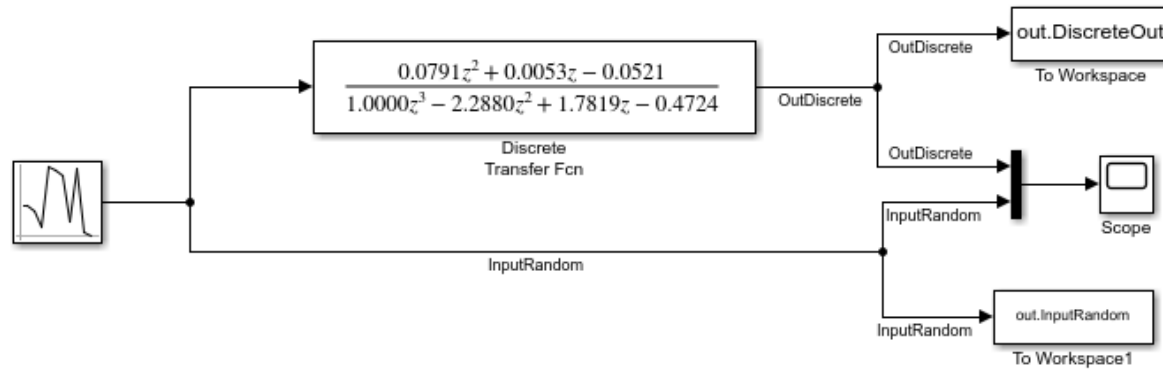
numd = [0 0.0791 0.0053 -0.0521] % The discrete numerator coefficients

dend = [1.0000 -2.2880 1.7819 -0.4724] % The discrete denominator coefficients

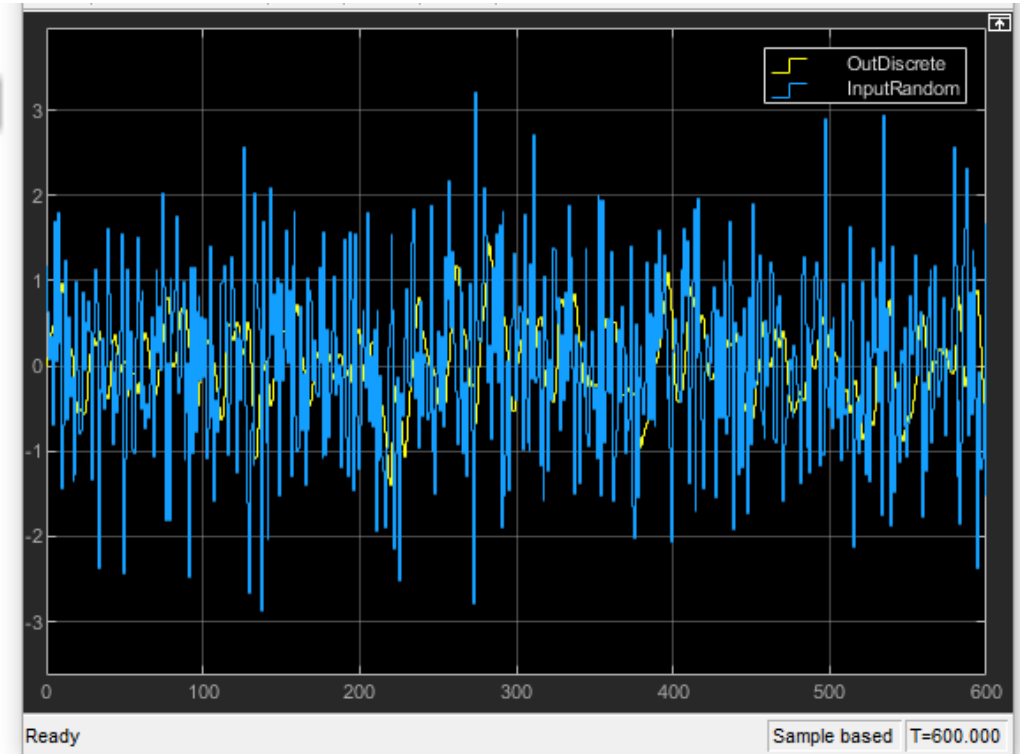
Thus, the following transfer function is obtained:

$$\frac{0.0791z^2 + 0.0053z - 0.0521}{1.0000z^3 - 2.2880z^2 + 1.7819z - 0.4724}$$

# Using the transfer function in Simulink to generate the dataset



dataMatrix							
499x7 double							
	1	2	3	4	5	6	7
1	0.2666	0.0921	0	0.0751	0.6268	1.1650	0.3943
2	0.3943	0.2666	0.0921	0.3516	0.0751	0.6268	0.4663
3	0.4663	0.3943	0.2666	-0.6965	0.3516	0.0751	0.4330
4	0.4330	0.4663	0.3943	1.6961	-0.6965	0.3516	0.4582
5	0.4582	0.4330	0.4663	0.0591	1.6961	-0.6965	0.5471
6	0.5471	0.4582	0.4330	1.7971	0.0591	1.6961	0.6939
7	0.6939	0.5471	0.4582	0.2641	1.7971	0.0591	0.8566
8	0.8566	0.6939	0.5471	0.8717	0.2641	1.7971	0.9586
9	0.9586	0.8566	0.6939	-1.4462	0.8717	0.2641	0.8711
10	0.8711	0.9586	0.8566	-0.7012	-1.4462	0.8717	0.5811
11	0.5811	0.8711	0.9586	1.2460	-0.7012	-1.4462	0.4004
12	0.4004	0.5811	0.8711	-0.6390	1.2460	-0.7012	0.2848
13	0.2848	0.4004	0.5811	0.5774	-0.6390	1.2460	0.1899
14	0.1899	0.2848	0.4004	-0.3600	0.5774	-0.6390	0.1241



# Fuzzy Inference System based on FCM

```
inputData = dataMatrix(:,1:6);
outputData = dataMatrix(:,7);

optFCM = genfisOptions('FCMClustering','FISType','sugeno');
optFCM.NumClusters = 5;
optFCM.Verbose = 0;

myFisFCM = genfis(inputData,outputData,optFCM);
showrule(myFisFCM)

% run fuzzyLogicDesigner to save in a .fis file
fuzzyLogicDesigner(myFisFCM)
```

```
[System]
Name='FISFCM'
Type='sugeno'
Version=2.0
NumInputs=6
NumOutputs=1
NumRules=5
AndMethod='prod'
OrMethod='probor'
ImpMethod='prod'
AggMethod='sum'
DefuzzMethod='wtaver'
```

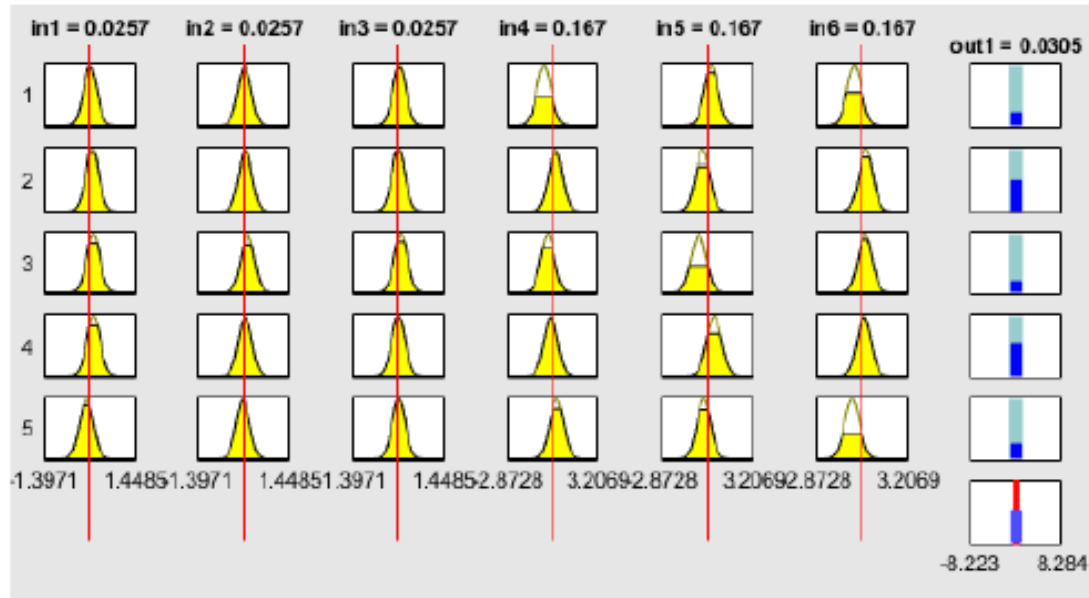
```
[Input1]
Name='in1'
Range=[-1.39709931547322 1.44848037009149]
NumMFs=5
MF1='in1cluster1':'gaussmf',[0.203928250346964 0.0426073314668295]
MF2='in1cluster2':'gaussmf',[0.204577801218229 0.107421564573074]
MF3='in1cluster3':'gaussmf',[0.204911145392131 0.138976288684256]
MF4='in1cluster4':'gaussmf',[0.20503666270888 0.148299460896762]
MF5='in1cluster5':'gaussmf',[0.211014818245536 -0.0694404763532825]
```

```
[Input2]
Name='in2'
Range=[-1.39709931547322 1.44848037009149]
NumMFs=5
MF1='in2cluster1':'gaussmf',[0.203719105007199 0.0556917793274846]
MF2='in2cluster2':'gaussmf',[0.204116578615613 0.0816358022642462]
MF3='in2cluster3':'gaussmf',[0.205265082851183 0.150582191054356]
MF4='in2cluster4':'gaussmf',[0.203519858501387 0.0746649276339012]
MF5='in2cluster5':'gaussmf',[0.204904018183953 0.00511965220042693]
```

```
[Output1]
Name='out1'
Range=[-1.39709931547322 1.44848037009149]
NumMFs=5
MF1='out1cluster1':'linear',[2.28799999999988 -1.78189999999982
0.47239999999993 0.0791 0.00530000000000932 -0.052099999999922 -
1.14761352364095e-16]
MF2='out1cluster2':'linear',[2.28799999999988 -1.78189999999982
0.47239999999993 0.0791 0.00530000000000932 -0.052099999999922 -
1.14761352364095e-16]
MF3='out1cluster3':'linear',[2.28799999999988 -1.78189999999982
0.47239999999993 0.0791 0.00530000000000932 -0.052099999999922 -
1.14761352364095e-16]
MF4='out1cluster4':'linear',[2.28799999999988 -1.78189999999982
0.47239999999993 0.0791 0.00530000000000932 -0.052099999999922 -
1.14761352364095e-16]
MF5='out1cluster5':'linear',[2.28799999999988 -1.78189999999982
0.47239999999993 0.0791 0.00530000000000932 -0.052099999999922 -
1.14761352364095e-16]
```

```
[Rules]
1 1 1 1 1, 1 (1) : 1
2 2 2 2 2, 2 (1) : 1
3 3 3 3 3, 3 (1) : 1
4 4 4 4 4, 4 (1) : 1
5 5 5 5 5, 5 (1) : 1
```

# Fuzzy Inference System based on FCM



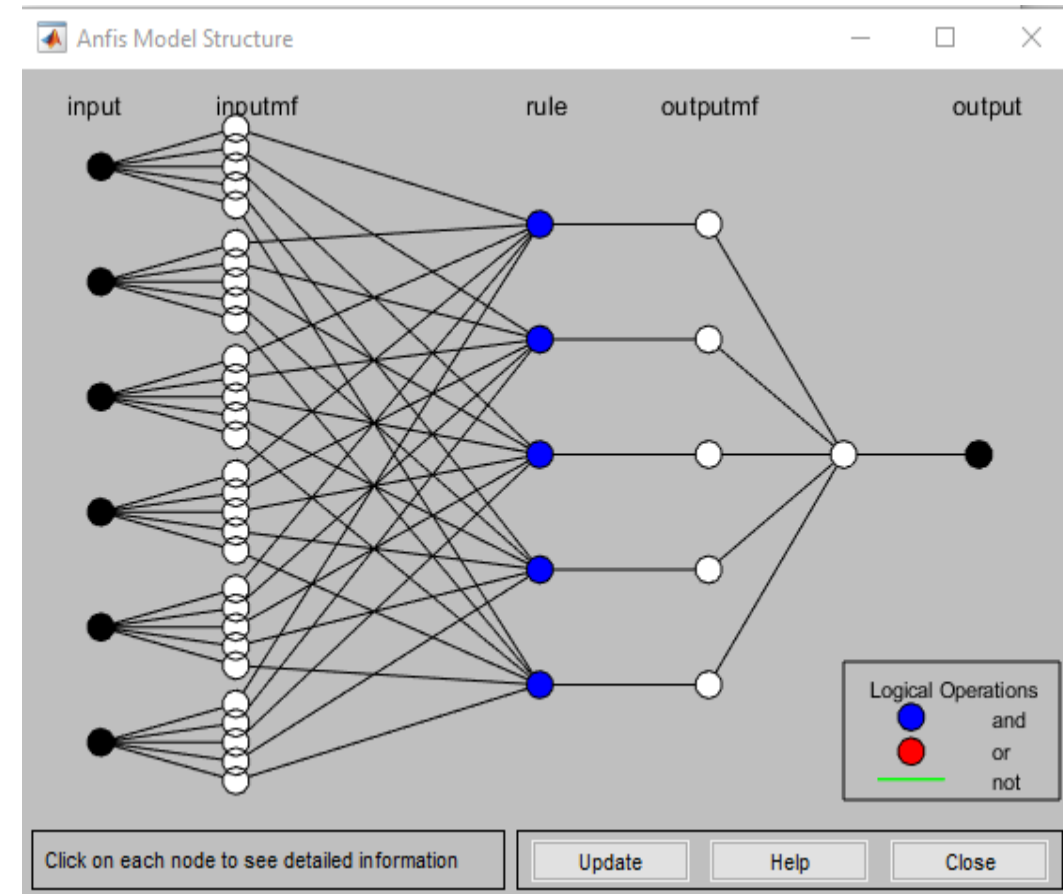
'1. If (in1 is in1cluster1) and (in2 is in2cluster1) and (in3 is in3cluster1) and (in4 is in4cluster1) and (in5 is in5cluster1) and (in6 is in6cluster1) then (out1 is out1cluster1) (1)'

'2. If (in1 is in1cluster2) and (in2 is in2cluster2) and (in3 is in3cluster2) and (in4 is in4cluster2) and (in5 is in5cluster2) and (in6 is in6cluster2) then (out1 is out1cluster2) (1)'

'3. If (in1 is in1cluster3) and (in2 is in2cluster3) and (in3 is in3cluster3) and (in4 is in4cluster3) and (in5 is in5cluster3) and (in6 is in6cluster3) then (out1 is out1cluster3) (1)'

'4. If (in1 is in1cluster4) and (in2 is in2cluster4) and (in3 is in3cluster4) and (in4 is in4cluster4) and (in5 is in5cluster4) and (in6 is in6cluster4) then (out1 is out1cluster4) (1)'

'5. If (in1 is in1cluster5) and (in2 is in2cluster5) and (in3 is in3cluster5) and (in4 is in4cluster5) and (in5 is in5cluster5) and (in6 is in6cluster5) then (out1 is out1cluster5) (1)'



# Fuzzy Inference System (optimized) based on FCM - Hybrid

```
[System]
Name='FISFCMHyb'
Type='sugeno'
Version=2.0
NumInputs=6
NumOutputs=1
NumRules=5
AndMethod='prod'
OrMethod='probor'
ImpMethod='prod'
AggMethod='sum'
DefuzzMethod='wtaver'

[Input1]
Name='in1'
Range=[-1.39709931547322 1.44848037009149]
NumMFs=5
MF1='in1cluster1':'gaussmf',[0.20319675173294 0.0412518558709949]
MF2='in1cluster2':'gaussmf',[0.211106194050416 0.108598936362734]
MF3='in1cluster3':'gaussmf',[0.197138953361984 0.139139065842394]
MF4='in1cluster4':'gaussmf',[0.20405667481472 0.148787241560201]
MF5='in1cluster5':'gaussmf',[0.211727167174901 -0.0699659850215811]

[Input2]
Name='in2'
Range=[-1.39709931547322 1.44848037009149]
NumMFs=5
MF1='in2cluster1':'gaussmf',[0.204366163740471 0.0541907820898719]
MF2='in2cluster2':'gaussmf',[0.210983966433717 0.0823334519308659]
MF3='in2cluster3':'gaussmf',[0.200668501229767 0.150254163415181]
MF4='in2cluster4':'gaussmf',[0.20010784365137 0.0757757322208385]
MF5='in2cluster5':'gaussmf',[0.205094869148318 0.00503954671646644]
```

```
[Output1]
Name='out1'
Range=[-1.39709931547322 1.44848037009149]
NumMFs=5
MF1='out1cluster1':'linear',[0.872888242114102 0.353588595294471 -0.385620005200573
0.0790964280037406 0.117233152674803 0.0425848533354474 1.37179750633667e-05]
MF2='out1cluster2':'linear',[0.862355774867929 0.369488226227544 -0.392002832014664
0.0790849201982997 0.118066617500216 0.0432974899468204 4.50904694503072e-05]
MF3='out1cluster3':'linear',[0.868755424372594 0.359803193957827 -0.388081431361103
0.079072862062165 0.117532218400336 0.0428689651690784 -5.69181083037712e-05]
MF4='out1cluster4':'linear',[0.863335918567111 0.368104728774326 -0.391525496959728
0.079067221388875 0.117993646288011 0.043199027136113 1.56473122400914e-05]
MF5='out1cluster5':'linear',[0.878044771457899 0.345839156247712 -0.382511317098839
0.0791104111111216 0.11682638982625 0.0422478464392243 4.47794931999734e-06]

[Rules]
1 1 1 1 1, 1 (1) : 1
2 2 2 2 2, 2 (1) : 1
3 3 3 3 3, 3 (1) : 1
4 4 4 4 4, 4 (1) : 1
5 5 5 5 5, 5 (1) : 1
```



# Fuzzy Inference System (optimized) based on FCM - Hybrid

```
[System]
Name='FISFCMHyb'
Type='sugeno'
Version=2.0
NumInputs=6
NumOutputs=1
NumRules=5
AndMethod='prod'
OrMethod='probor'
ImpMethod='prod'
AggMethod='sum'
DefuzzMethod='wtaver'
```

```
[Input1]
Name='in1'
Range=[-1.39709931547322 1.44848037009149]
NumMFs=5
MF1='in1cluster1':gaussmf',[0.20319675173294 0.0412518558709949]
MF2='in1cluster2':gaussmf',[0.211106194050416 0.108598936362734]
MF3='in1cluster3':gaussmf',[0.197138953361984 0.139139065842394]
MF4='in1cluster4':gaussmf',[0.20405667481472 0.148787241560201]
MF5='in1cluster5':gaussmf',[0.211727167174901 -0.0699659850215811]
```

```
[Input2]
Name='in2'
Range=[-1.39709931547322 1.44848037009149]
NumMFs=5
MF1='in2cluster1':gaussmf',[0.204366163740471 0.0541907820898719]
MF2='in2cluster2':gaussmf',[0.210983966433717 0.0823334519308659]
MF3='in2cluster3':gaussmf',[0.200668501229767 0.150254163415181]
MF4='in2cluster4':gaussmf',[0.20010784365137 0.0757757322208385]
MF5='in2cluster5':gaussmf',[0.205094869148318 0.00503954671646644]
```

```
[Output1]
Name='out1'
Range=[-1.39709931547322 1.44848037009149]
NumMFs=5
MF1='out1cluster1':linear',[0.872888242114102 0.353588595294471 -0.385620005200573
0.0790964280037406 0.117233152674803 0.0425848533354474 1.37179750633667e-05]
MF2='out1cluster2':linear',[0.862355774867929 0.369488226227544 -0.392002832014664
0.0790849201982997 0.118066617500216 0.0432974899468204 4.50904694503072e-05]
```

```
[Input1]
Name='in1'
Range=[-1.39709931547322 1.44848037009149]
NumMFs=5
MF1='in1cluster1':gaussmf',[0.203928250346964 0.0426073314668295]
MF2='in1cluster2':gaussmf',[0.204577801218229 0.107421564573074]
MF3='in1cluster3':gaussmf',[0.204911145392131 0.138976288684256]
MF4='in1cluster4':gaussmf',[0.20503666270888 0.148299460896762]
MF5='in1cluster5':gaussmf',[0.211014818245536 -0.0694404763532825]
```

```
[Input2]
Name='in2'
Range=[-1.39709931547322 1.44848037009149]
NumMFs=5
MF1='in2cluster1':gaussmf',[0.203719105007199 0.0556917793274846]
MF2='in2cluster2':gaussmf',[0.204116578615613 0.0816358022642462]
MF3='in2cluster3':gaussmf',[0.205265082851183 0.150582191054356]
MF4='in2cluster4':gaussmf',[0.203519858501387 0.0746649276339012]
MF5='in2cluster5':gaussmf',[0.204904018183953 0.00511965220042693]
```



Non-optimized



# Fuzzy Inference System (optimized) based on FCM - Backpropagation

```
[System]
Name='FISFCMBack'
Type='sugeno'
Version=2.0
NumInputs=6
NumOutputs=1
NumRules=5
AndMethod='prod'
OrMethod='probor'
ImpMethod='prod'
AggMethod='sum'
DefuzzMethod='wtaver'

[Input1]
Name='in1'
Range=[-1.39709931547322 1.44848037009149]
NumMFs=5
MF1='in1cluster1':'gaussmf',[0.204435872557712 0.0424329175370261]
MF2='in1cluster2':'gaussmf',[0.205219178244866 0.107378994199849]
MF3='in1cluster3':'gaussmf',[0.204703952538069 0.138862293811268]
MF4='in1cluster4':'gaussmf',[0.205456553060156 0.148289244686225]
MF5='in1cluster5':'gaussmf',[0.21000331403767 -0.0694142875282039]

[Input2]
Name='in2'
Range=[-1.39709931547322 1.44848037009149]
NumMFs=5
MF1='in2cluster1':'gaussmf',[0.204178908075546 0.0556142260446388]
MF2='in2cluster2':'gaussmf',[0.204842423566733 0.0816614964322076]
MF3='in2cluster3':'gaussmf',[0.205155245281537 0.150538381161005]
MF4='in2cluster4':'gaussmf',[0.204052192710663 0.0746611150835347]
MF5='in2cluster5':'gaussmf',[0.203358521820876 0.00510572595591061]
```

```
[Output1]
Name='out1'
Range=[-1.39709931547322 1.44848037009149]
NumMFs=5
MF1='out1cluster1':'linear',[2.28809250847018 -1.78177176758463 0.472559533674615
0.0779060281036141 0.00606360950964869 -0.0530668847064562 0.00120694580996838]
MF2='out1cluster2':'linear',[2.28815754043078 -1.78180883582886 0.47240052009133
0.0797960941369835 0.00500850172438012 -0.0514522841007416 0.000822717815848342]
MF3='out1cluster3':'linear',[2.2888258715405 -1.78100241743163 0.473159026268339
0.078386819535019 0.00351208108474546 -0.0510091584572587 0.0019702523879757]
MF4='out1cluster4':'linear',[2.28825790599364 -1.78179587533055 0.472400375006354
0.0791675662548462 0.0062561133395093 -0.0517210281042744 0.000768918539120406]
MF5='out1cluster5':'linear',[2.28698772858877 -1.78262391859207 0.471880209979654
0.0816586823767592 0.00478185106451871 -0.0549994857508084 0.00283930919757474]

[Rules]
1 1 1 1 1, 1 (1) : 1
2 2 2 2 2, 2 (1) : 1
3 3 3 3 3, 3 (1) : 1
4 4 4 4 4, 4 (1) : 1
5 5 5 5 5, 5 (1) : 1
```

# Fuzzy Inference System (optimized) based on FCM - Backpropagation

```
[System]
Name='FISFCMBack'
Type='sugeno'
Version=2.0
NumInputs=6
NumOutputs=1
NumRules=5
AndMethod='prod'
OrMethod='probor'
ImpMethod='prod'
AggMethod='sum'
DefuzzMethod='wtaver'
```

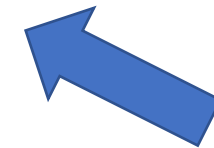
```
[Input1]
Name='in1'
Range=[-1.39709931547322 1.44848037009149]
NumMFs=5
MF1='in1cluster1':gaussmf,[0.204435872557712 0.0424329175370261]
MF2='in1cluster2':gaussmf,[0.205219178244866 0.107378994199849]
MF3='in1cluster3':gaussmf,[0.204703952538069 0.138862293811268]
MF4='in1cluster4':gaussmf,[0.205456553060156 0.148289244686225]
MF5='in1cluster5':gaussmf,[0.21000331403767 -0.0694142875282039]
```

```
[Input2]
Name='in2'
Range=[-1.39709931547322 1.44848037009149]
NumMFs=5
MF1='in2cluster1':gaussmf,[0.204178908075546 0.0556142260446388]
MF2='in2cluster2':gaussmf,[0.204842423566733 0.0816614964322076]
MF3='in2cluster3':gaussmf,[0.205155245281537 0.150538381161005]
MF4='in2cluster4':gaussmf,[0.204052192710663 0.0746611150835347]
MF5='in2cluster5':gaussmf,[0.203358521820876 0.00510572595591061]
```

```
[Output1]
Name='out1'
Range=[-1.39709931547322 1.44848037009149]
NumMFs=5
MF1='out1cluster1':linear,[2.28809250847018 -1.78177176758463 0.472559533674615
0.0779060281036141 0.00606360950964869 -0.0530668847064562 0.00120694580996838]
MF2='out1cluster2':linear,[2.28815754043078 -1.78180883582886 0.47240052009133
0.0797960941369835 0.00500850172438012 -0.0514522841007416 0.000822717815848342]
```

```
[Input1]
Name='in1'
Range=[-1.39709931547322 1.44848037009149]
NumMFs=5
MF1='in1cluster1':gaussmf,[0.203928250346964 0.0426073314668295]
MF2='in1cluster2':gaussmf,[0.204577801218229 0.107421564573074]
MF3='in1cluster3':gaussmf,[0.204911145392131 0.138976288684256]
MF4='in1cluster4':gaussmf,[0.20503666270888 0.148299460896762]
MF5='in1cluster5':gaussmf,[0.211014818245536 -0.0694404763532825]
405 -1.78100241743163 0.473159026268339
6 -0.0510091584572587 0.0019702523879757]
9364 -1.78179587533055 0.472400375006354
3 -0.0517210281042744 0.000768918539120406]
8877 -1.78262391859207 0.471880209979654
71 -0.0549994857508084 0.00283930919757474]
```

```
[Input2]
Name='in2'
Range=[-1.39709931547322 1.44848037009149]
NumMFs=5
MF1='in2cluster1':gaussmf,[0.203719105007199 0.0556917793274846]
MF2='in2cluster2':gaussmf,[0.204116578615613 0.0816358022642462]
MF3='in2cluster3':gaussmf,[0.205265082851183 0.150582191054356]
MF4='in2cluster4':gaussmf,[0.203519858501387 0.0746649276339012]
MF5='in2cluster5':gaussmf,[0.204904018183953 0.00511965220042693]
```



Non-optimized

# Fuzzy Inference System based on Subtractive

```
inputData = dataMatrix(:,1:6);
outputData = dataMatrix(:,7);

optSub = genfisOptions('SubtractiveClustering');
optSub.Verbose = 0;

myFisSUB = genfis(inputData,outputData,optSub);
showrule(myFisSUB)

% run fuzzyLogicDesigner to save the .fis file
fuzzyLogicDesigner(myFisSUB)
```

```
[System]
Name='FISSUB'
Type='sugeno'
Version=2.0
NumInputs=6
NumOutputs=1
NumRules=3
AndMethod='prod'
OrMethod='probor'
ImpMethod='prod'
AggMethod='sum'
DefuzzMethod='wtaver'
```

```
[Input1]
Name='in1'
Range=[-1.39709931547322 1.44848037009149]
NumMFs=3
MF1='in1cluster1':'gaussmf',[0.503032173017372 0.131160501197739]
MF2='in1cluster2':'gaussmf',[0.503032173017372 -0.338425657499384]
MF3='in1cluster3':'gaussmf',[0.503032173017372 0.495950695023009]
```

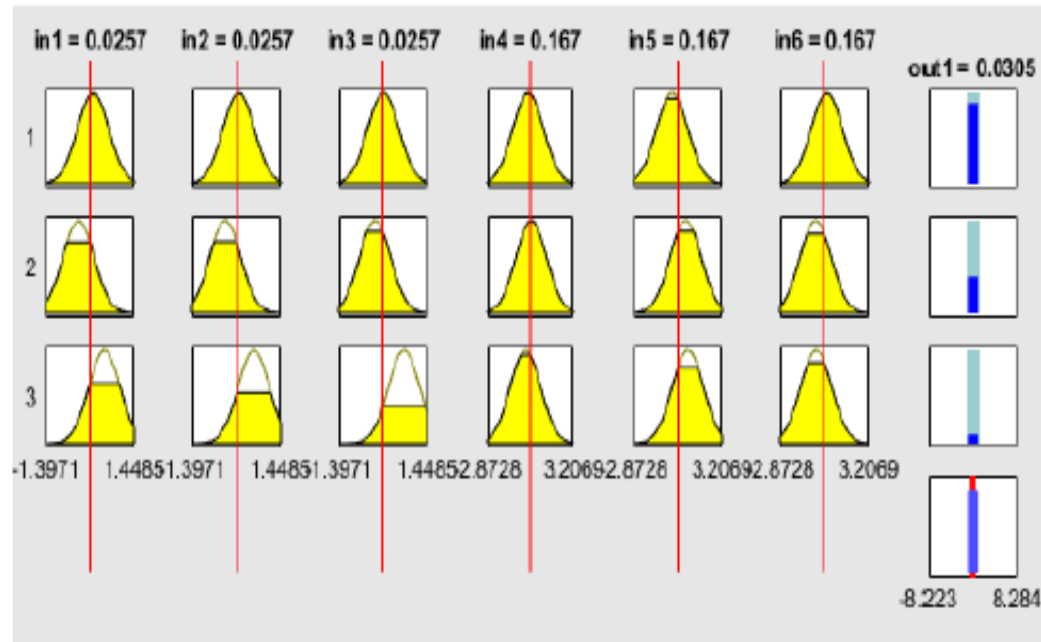
```
[Input2]
Name='in2'
Range=[-1.39709931547322 1.44848037009149]
NumMFs=3
MF1='in2cluster1':'gaussmf',[0.503032173017372 0.0984487706074979]
MF2='in2cluster2':'gaussmf',[0.503032173017372 -0.334730292805416]
MF3='in2cluster3':'gaussmf',[0.503032173017372 0.584690513313855]
```

```
[Input3]
Name='in3'
Range=[-1.39709931547322 1.44848037009149]
NumMFs=3
MF1='in3cluster1':'gaussmf',[0.503032173017372 0.0369478595404813]
MF2='in3cluster2':'gaussmf',[0.503032173017372 -0.230561547893462]
MF3='in3cluster3':'gaussmf',[0.503032173017372 0.706076348201561]
```

```
[Output1]
Name='out1'
Range=[-1.39709931547322 1.44848037009149]
NumMFs=3
MF1='out1cluster1':'linear',[2.28799999999767 -1.78189999999648
0.472399999998585 0.0791 0.00530000000018494 -0.052099999999844
4.8260557500795e-16]
MF2='out1cluster2':'linear',[2.2879999999996 -1.7818999999994 0.472399999999758
0.0791000000000001 0.00530000000003143 -0.0520999999999735 -
4.5186833771821e-16]
MF3='out1cluster3':'linear',[2.288000000000521 -1.781900000000786
0.4724000000003159 0.0791000000000002 0.00529999999958741 -
0.0521000000003483 1.17248158251235e-15]
```

```
[Rules]
1 1 1 1 1 1, 1 (1) : 1
2 2 2 2 2, 2 (1) : 1
3 3 3 3 3, 3 (1) : 1
```

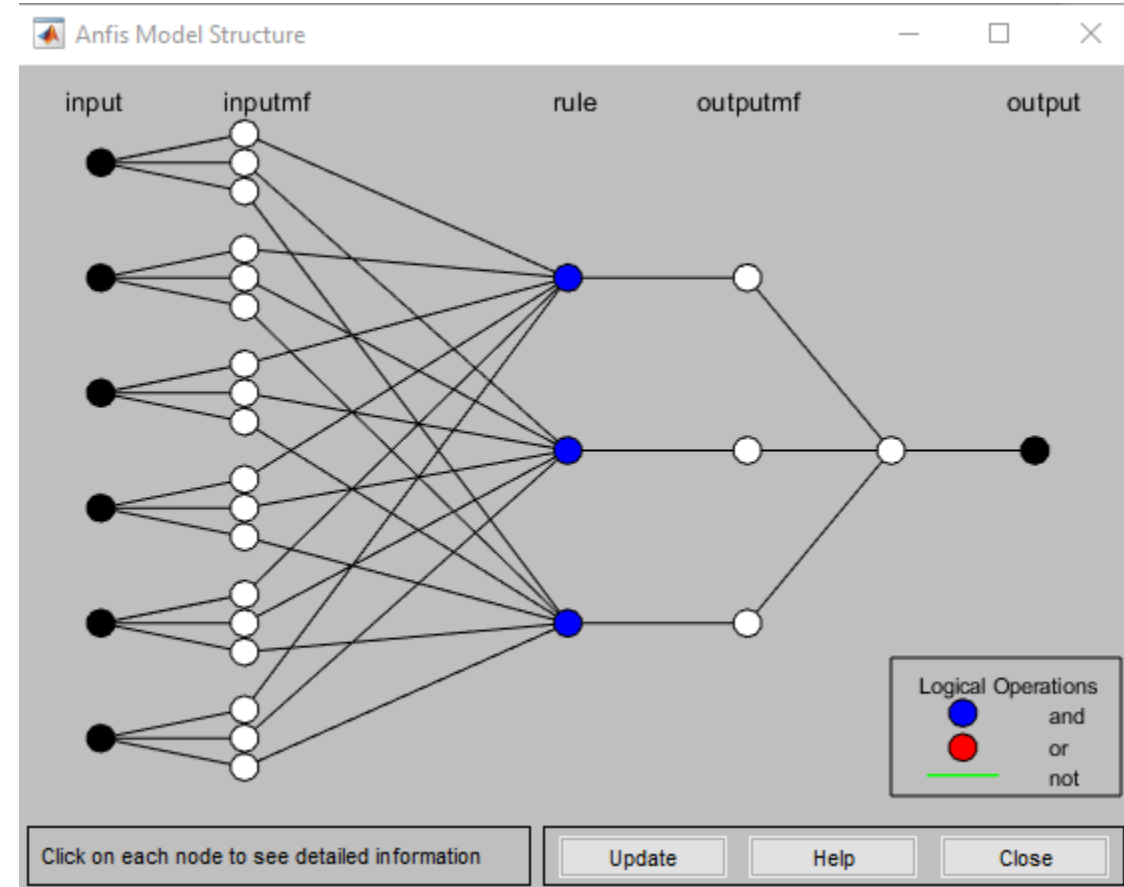
# Fuzzy Inference System based on Subtractive



'1. If (in1 is in1cluster1) and (in2 is in2cluster1) and (in3 is in3cluster1) and (in4 is in4cluster1) and (in5 is in5cluster1) and (in6 is in6cluster1) then (out1 is out1cluster1) (1)'

'2. If (in1 is in1cluster2) and (in2 is in2cluster2) and (in3 is in3cluster2) and (in4 is in4cluster2) and (in5 is in5cluster2) and (in6 is in6cluster2) then (out1 is out1cluster2) (1)'

'3. If (in1 is in1cluster3) and (in2 is in2cluster3) and (in3 is in3cluster3) and (in4 is in4cluster3) and (in5 is in5cluster3) and (in6 is in6cluster3) then (out1 is out1cluster3) (1)'



# Fuzzy Inference System (optimized) based on Subtractive - Hybrid

```
[System]
Name='FISSUBHyb'
Type='sugeno'
Version=2.0
NumInputs=6
NumOutputs=1
NumRules=3
AndMethod='prod'
OrMethod='probor'
ImpMethod='prod'
AggMethod='sum'
DefuzzMethod='wtaver'
```

```
[Input1]
Name='in1'
Range=[-1.39709931547322 1.44848037009149]
NumMFs=3
MF1='in1cluster1':gaussmf,[0.533105528703421 0.188951656176213]
MF2='in1cluster2':gaussmf,[0.47967651903559 -0.344769773630531]
MF3='in1cluster3':gaussmf,[0.502442126801145 0.479251496761449]
```

```
[Input2]
Name='in2'
Range=[-1.39709931547322 1.44848037009149]
NumMFs=3
MF1='in2cluster1':gaussmf,[0.540853045610932 0.159936853090036]
MF2='in2cluster2':gaussmf,[0.482919424215853 -0.343326666944355]
MF3='in2cluster3':gaussmf,[0.501354896208444 0.573148886041063]
```

```
[Output1]
Name='out1'
Range=[-1.39709931547322 1.44848037009149]
NumMFs=3
MF1='out1cluster1':linear,[0.897742149233273 0.316145864661859 -0.370573231848332
0.0790992824876198 0.115259933367491 0.0409255390072035 -6.3176995076392e-06]
MF2='out1cluster2':linear,[0.885774422235934 0.334228683698691 -0.377839880052881
0.0791021560287103 0.116214929230702 0.041739347344067 5.21113486602618e-05]
MF3='out1cluster3':linear,[0.870353092062564 0.357443632352897 -0.387158553353995
0.0790826381396501 0.117455075554637 0.0427463931624358 -3.5623671329401e-05]
```

```
[Rules]
1 1 1 1 1 1, 1 (1) : 1
2 2 2 2 2 2, 2 (1) : 1
3 3 3 3 3 3, 3 (1) : 1
```



# Fuzzy Inference System (optimized) based on Subtractive - Hybrid

```
[System]
Name='FISSUBHyb'
Type='sugeno'
Version=2.0
NumInputs=6
NumOutputs=1
NumRules=3
AndMethod='prod'
OrMethod='probor'
ImpMethod='prod'
AggMethod='sum'
DefuzzMethod='wtaver'
```

```
[Input1]
Name='in1'
Range=[-1.39709931547322 1.44848037009149]
NumMFs=3
MF1='in1cluster1':'gaussmf',[0.533105528703421 0.188951656176213]
MF2='in1cluster2':'gaussmf',[0.47967651903559 -0.344769773630531]
MF3='in1cluster3':'gaussmf',[0.502442126801145 0.479251496761449]
```

```
[Input2]
Name='in2'
Range=[-1.39709931547322 1.44848037009149]
NumMFs=3
MF1='in2cluster1':'gaussmf',[0.540853045610932 0.159936853090036]
MF2='in2cluster2':'gaussmf',[0.482919424215853 -0.343326666944355]
MF3='in2cluster3':'gaussmf',[0.501354896208444 0.573148886041063]
```

```
[Output1]
Name='out1'
Range=[-1.39709931547322 1.44848037009149]
NumMFs=3
MF1='out1cluster1':'linear',[0.897742149233273 0.316145864661859 -0.370573231848332
0.0790992824876198 0.115259933367491 0.0409255390072035 -6.3176995076392e-06]
MF2='out1cluster2':'linear',[0.885774422235934 0.334228683698691 -0.377839880052881
0.0781021550287102 0.115214829330702 0.041728247244057 5.21113486602618e-05]
MF3='out1cluster3':'linear',[0.897742149233273 0.316145864661859 -0.370573231848332
352897 -0.387158553353995
158 -3.5623671329401e-05]
```

```
[Input1]
Name='in1'
Range=[-1.39709931547322 1.44848037009149]
NumMFs=3
MF1='in1cluster1':'gaussmf',[0.503032173017372 0.131160501197739]
MF2='in1cluster2':'gaussmf',[0.503032173017372 -0.338425657499384]
MF3='in1cluster3':'gaussmf',[0.503032173017372 0.495950695023009]
```

```
[Input2]
Name='in2'
Range=[-1.39709931547322 1.44848037009149]
NumMFs=3
MF1='in2cluster1':'gaussmf',[0.503032173017372 0.0984487706074979]
MF2='in2cluster2':'gaussmf',[0.503032173017372 -0.334730292805416]
MF3='in2cluster3':'gaussmf',[0.503032173017372 0.584690513313855]
```



Non-optimized

# Fuzzy Inference System (optimized) based on Subtractive - Backpropagation

```
[System]
Name='FISSUBBack'
Type='sugeno'
Version=2.0
NumInputs=6
NumOutputs=1
NumRules=3
AndMethod='prod'
OrMethod='probor'
ImpMethod='prod'
AggMethod='sum'
DefuzzMethod='wtaver'
```

```
[Input1]
Name='in1'
Range=[-1.39709931547322 1.44848037009149]
NumMFs=3
MF1='in1cluster1':gaussmf,[0.502823985655774 0.131094990093116]
MF2='in1cluster2':gaussmf,[0.503160495446989 -0.338311267530688]
MF3='in1cluster3':gaussmf,[0.50307751216927 0.495945848181888]
```

```
[Input2]
Name='in2'
Range=[-1.39709931547322 1.44848037009149]
NumMFs=3
MF1='in2cluster1':gaussmf,[0.502814884447492 0.0983683792066203]
MF2='in2cluster2':gaussmf,[0.50313855065494 -0.334629995242577]
MF3='in2cluster3':gaussmf,[0.503074414444226 0.584658312345976]
```

```
[Output1]
Name='out1'
Range=[-1.39709931547322 1.44848037009149]
NumMFs=3
MF1='out1cluster1':linear,[2.28726108290726 -1.78257610044353 0.471949465714607
0.0783429736653273 0.00798255272259209 -0.0551483471251275 -0.00425454738544047]
MF2='out1cluster2':linear,[2.28854890226791 -1.78126688525381 0.473020640419253
0.0782764127895448 0.00496864463094985 -0.0521593717461456 -0.00173452575353558]
MF3='out1cluster3':linear,[2.28681337006798 -1.78309946062204 0.471274429691294
0.0791996994891441 0.00497429642033952 -0.0525967672733436 -0.00226728912854374]
```

```
[Rules]
1 1 1 1 1 1, 1 (1) : 1
2 2 2 2 2 2, 2 (1) : 1
3 3 3 3 3 3, 3 (1) : 1
```



# Fuzzy Inference System (optimized) based on Subtractive - Backpropagation

```
[System]
Name='FISSUBBack'
Type='sugeno'
Version=2.0
NumInputs=6
NumOutputs=1
NumRules=3
AndMethod='prod'
OrMethod='probor'
ImpMethod='prod'
AggMethod='sum'
DefuzzMethod='wtaver'
```

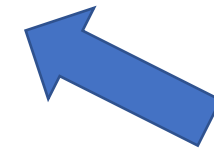
```
[Input1]
Name='in1'
Range=[-1.39709931547322 1.44848037009149]
NumMFs=3
MF1='in1cluster1':'gaussmf',[0.502823985655774 0.131094990093116]
MF2='in1cluster2':'gaussmf',[0.503160495446989 -0.338311267530688]
MF3='in1cluster3':'gaussmf',[0.50307751216927 0.495945848181888]
```

```
[Input2]
Name='in2'
Range=[-1.39709931547322 1.44848037009149]
NumMFs=3
MF1='in2cluster1':'gaussmf',[0.502814884447492 0.0983683792066203]
MF2='in2cluster2':'gaussmf',[0.50313855065494 -0.334629995242577]
MF3='in2cluster3':'gaussmf',[0.503074414444226 0.584658312345976]
```

```
[Output1]
Name='out1'
Range=[-1.39709931547322 1.44848037009149]
NumMFs=3
MF1='out1cluster1':'linear',[2.28726108290726 -1.78257610044353 0.471949465714607
0.0783429736653273 0.00798255272259209 -0.0551483471251275 -0.00425454738544047]
MF2='out1cluster2':'linear',[2.28854890226791 -1.78126688525381 0.473020640419253
0.0782764127895448 0.00406864463004085 -0.0521503717461456 -0.00173452575353558]
MF3='out1cluster3':'linear',[2.28854890226791 -1.78126688525381 0.473020640419253
0.0782764127895448 0.00406864463004085 -0.0521503717461456 -0.00173452575353558]
```

```
[Input1]
Name='in1'
Range=[-1.39709931547322 1.44848037009149]
NumMFs=3
MF1='in1cluster1':'gaussmf',[0.503032173017372 0.131160501197739]
MF2='in1cluster2':'gaussmf',[0.503032173017372 -0.338425657499384]
MF3='in1cluster3':'gaussmf',[0.503032173017372 0.495950695023009]
```

```
[Input2]
Name='in2'
Range=[-1.39709931547322 1.44848037009149]
NumMFs=3
MF1='in2cluster1':'gaussmf',[0.503032173017372 0.0984487706074979]
MF2='in2cluster2':'gaussmf',[0.503032173017372 -0.334730292805416]
MF3='in2cluster3':'gaussmf',[0.503032173017372 0.584690513313855]
```



Non-optimized

# Checking the Performance of all FIS

- a. First of all, I got a range of data that wasn't used neither in training nor in test.
- b. Then I called evalfis method in Matlab for each FIS file. Below are the commands:

```
evalfismyFisFCM = evalfis(FISFCMBack, inputChk)
evalfismyFisFCMBP = evalfis(FISFCMBack, inputChk)
evalfismyFisFCMHibrid = evalfis(FISFCMHyb, inputChk)
evalfismyFisSUB = evalfis(FISSUBBack, inputChk)
evalfismyFisSUBBP = evalfis(FISSUBBack, inputChk)
evalfismyFisSUBHibrid = evalfis(FISSUBHyb, inputChk)
```

- c. Next, I created a table concatenating the arrays:

```
ds = table(outputChk, evalfismyFisFCM, evalfismyFisFCMBP,
evalfismyFisFCMHibrid, evalfismyFisSUB, evalfismyFisSUBBP,
evalfismyFisSUBHibrid);
ds.Properties.VariableNames = {'Observed', 'FCM', 'FCM_BP', 'FCM_Hibr',
'Sub', 'Sub_BP', 'Sub_Hibr'}
```

- d. Next, I calculated the errors:

```
ds.Err_FCM = (ds.Observed - ds.FCM)
ds.Err_FCM_BP = (ds.Observed - ds.FCM_BP)
ds.Err_FCM_Hibr = (ds.Observed - ds.FCM_Hibr)
ds.Err_Sub = (ds.Observed - ds.Sub)
ds.Err_Sub_BP = (ds.Observed - ds.Sub_BP)
ds.Err_Sub_Hibr = (ds.Observed - ds.Sub_Hibr)
```

- e. Next, I calculated the Squared Errors:

```
ds.SqrErr_FCM = ds.Err_FCM.^2
ds.SqrErr_FCM_BP = ds.Err_FCM_BP.^2
ds.SqrErr_FCM_Hibr = ds.Err_FCM_Hibr.^2
ds.SqrErr_Sub = ds.Err_Sub.^2
ds.SqrErr_Sub_BP = ds.Err_Sub_BP.^2
ds.SqrErr_Sub_Hibr = ds.Err_Sub_Hibr.^2
```

- f. Finally, the Mean Squared Errors where calculated:

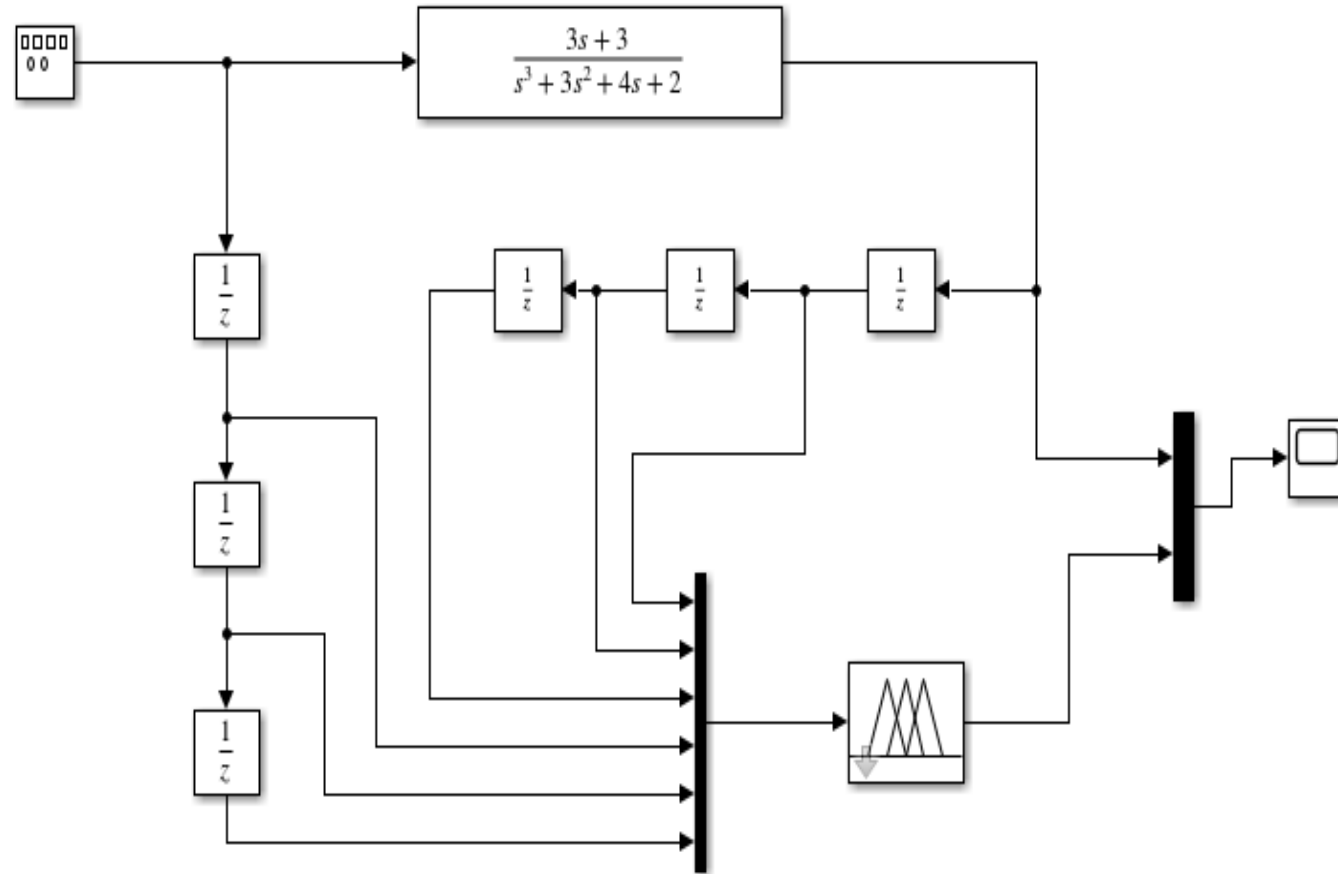
```
mseFCM = num2str(sum(ds.SqrErr_FCM)/height(ds), '%.10f')
mseFCM_BP = num2str(sum(ds.SqrErr_FCM_BP)/height(ds), '%.10f')
mseFCM_Hibr = num2str(sum(ds.SqrErr_FCM_Hibr)/height(ds), '%.10f')
mseSub = num2str(sum(ds.SqrErr_Sub)/height(ds), '%.10f')
mseSub_BP = num2str(sum(ds.SqrErr_Sub_BP)/height(ds), '%.10f')
mseSub_Hibr = num2str(sum(ds.SqrErr_Sub_Hibr)/height(ds), '%.10f')
```

The table below contains the results:

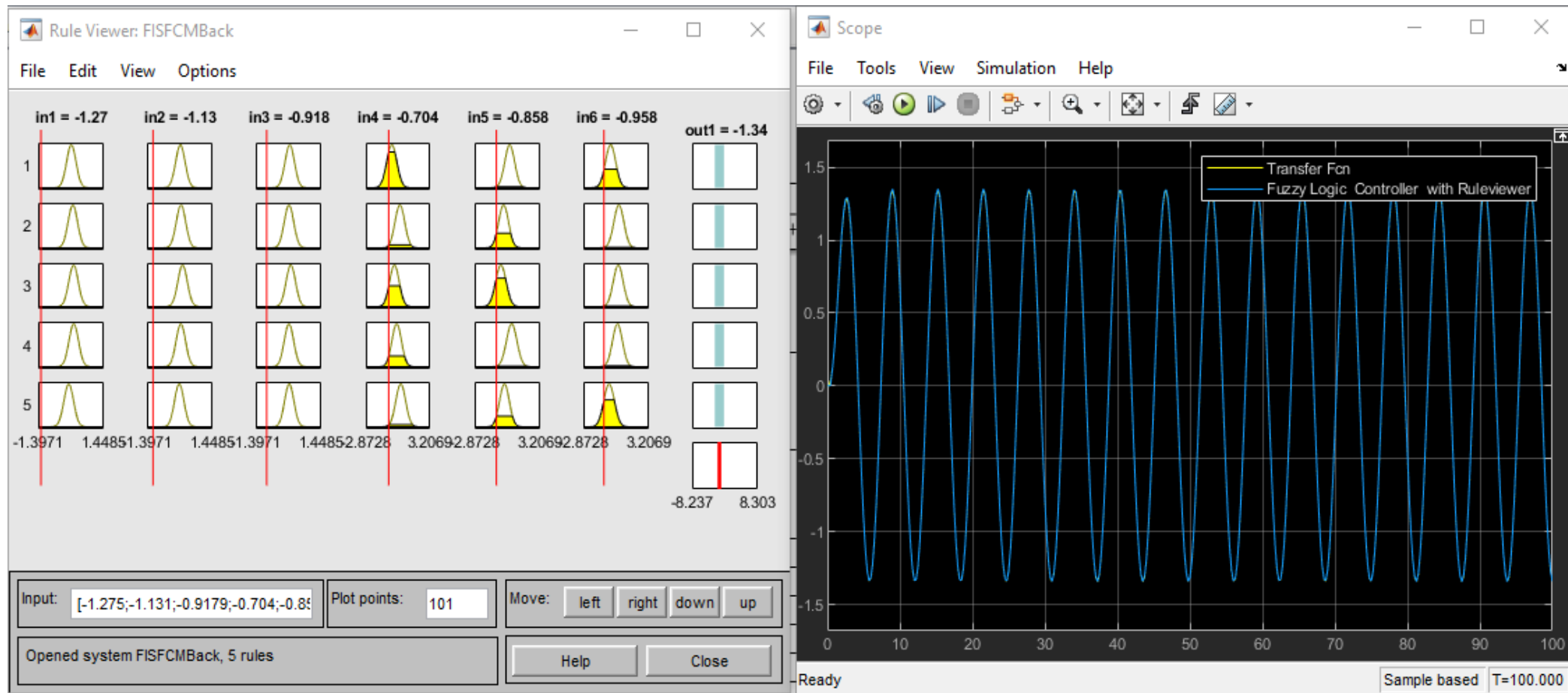
mseFCM	mseFCM_BP	mseFCM_Hibr	mseSub	mseSub_BP	mseSub_Hibr
0.0000270530	0.0000270530	0.0000000025	0.0000262986	0.0000262986	0.0000000023

Thus, considering the least MSE is the best, the Subtractive Clustering with Hybrid optimization was the best, followed by Fuzzy c-means Clustering with Hybrid optimization. Backpropagation wasn't so good.

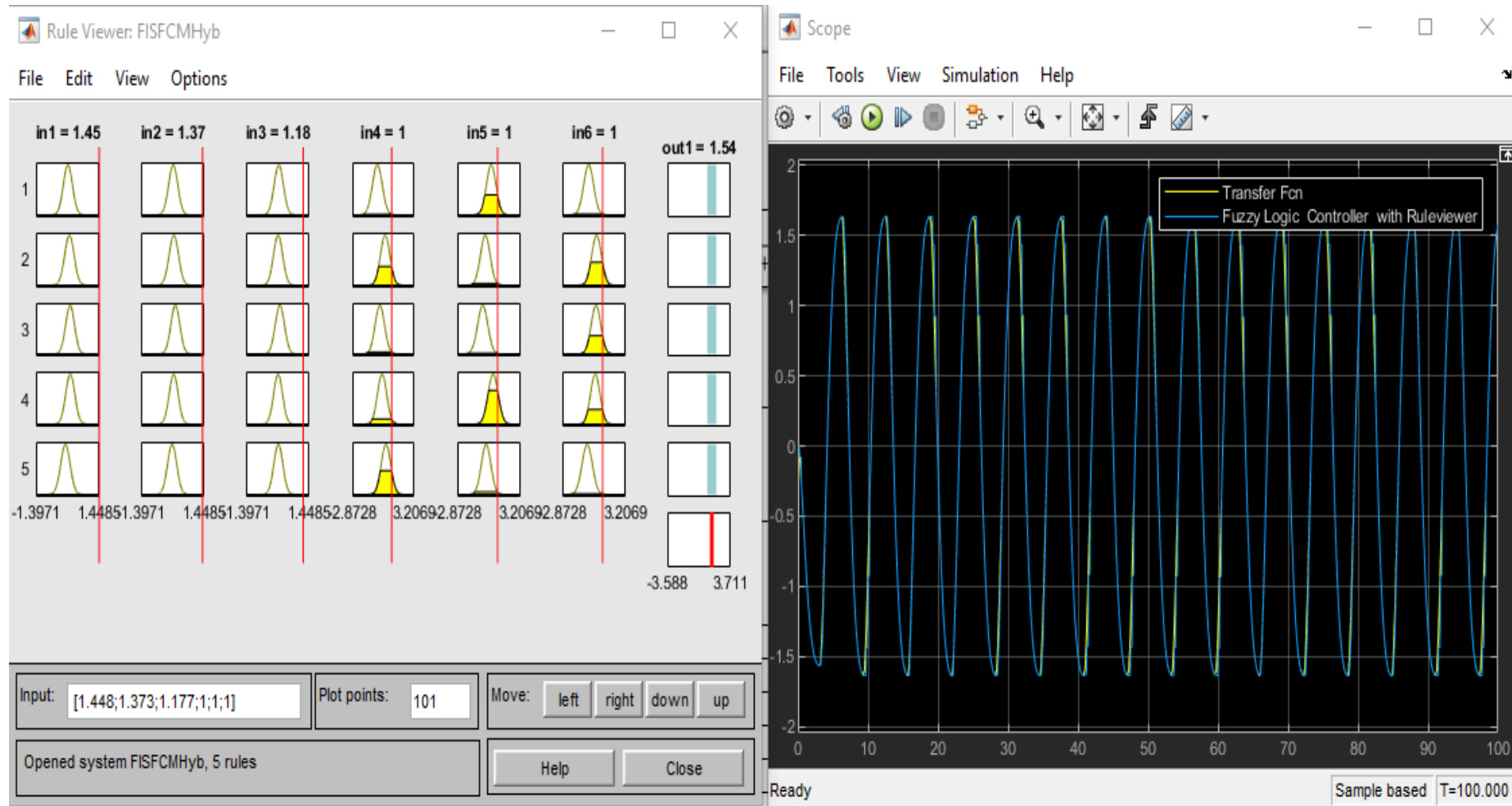
# Simulink



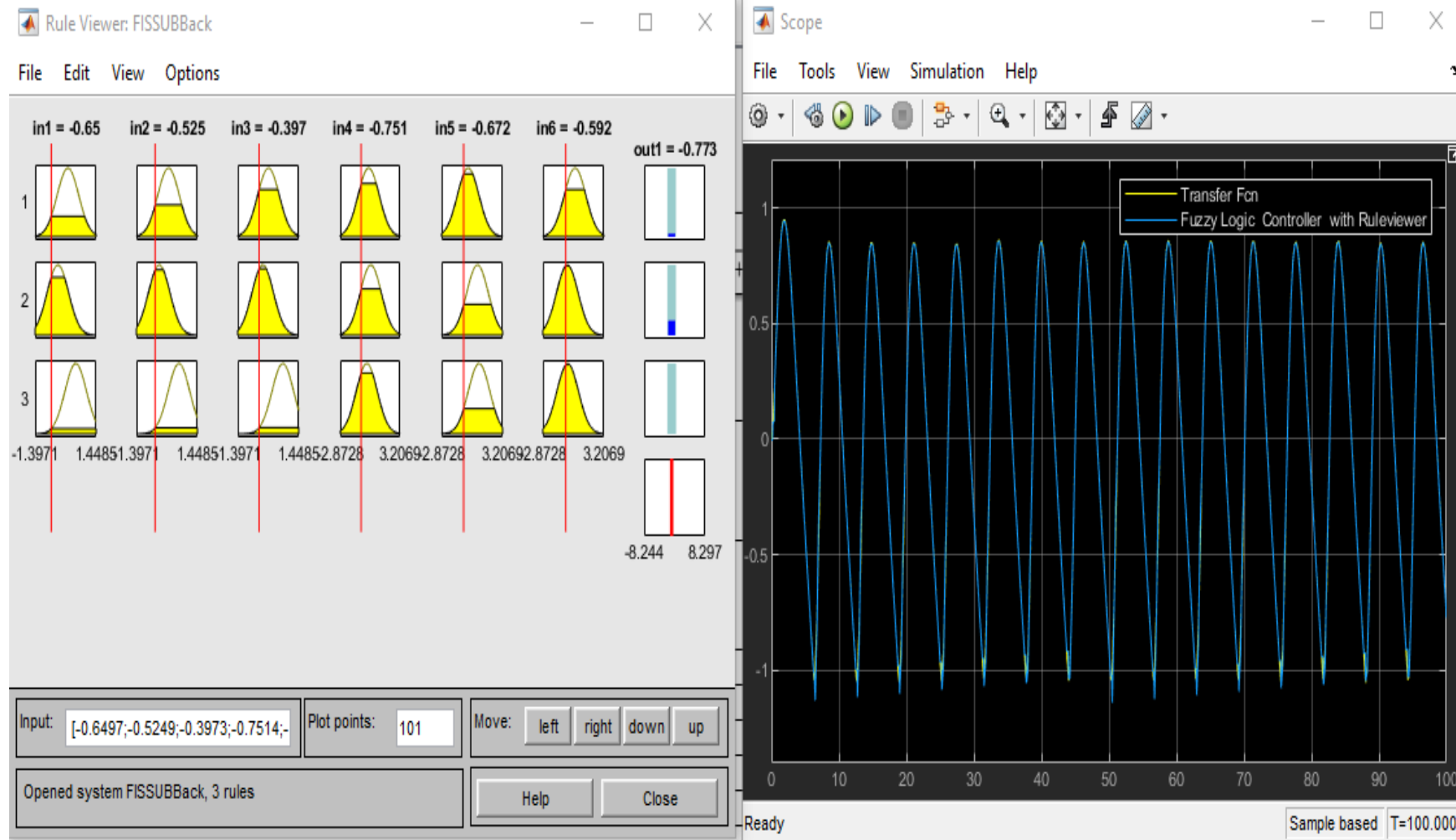
# Simulink - FCM with Backpropagation



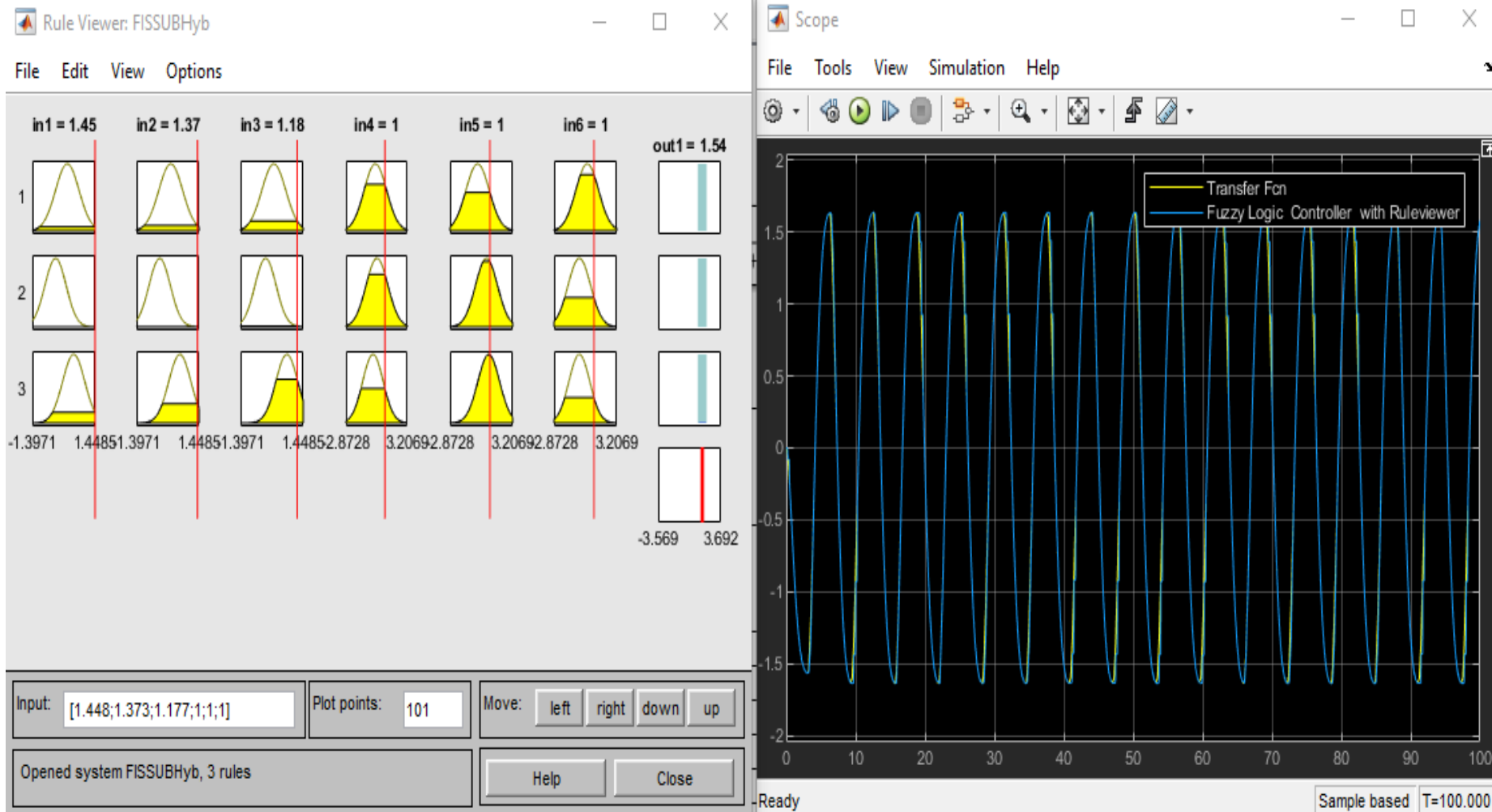
# Simulink - FCM with Hybrid



# Simulink - Subtractive with Backpropagation



# Simulink - Subtractive with Hybrid





Thank you!