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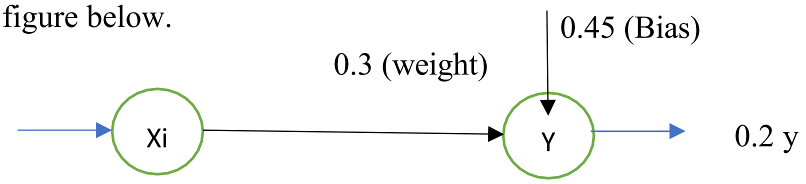
Practical No. 1

A. Design a simple linear neural network model.
B. Calculate the output of neural net using both binary and bipolar sigmoidal function.

A. Design a simple linear neural network model.

Problem:

Create C++ program to calculate net input to the output neuron for the network shown in figure below.



Solution :

```
#include<iostream.h>
#include<conio.h> void
main()
{ clrscr();
x,b,w,net;
float out; x
cout<<"Enter value of X"; cin>>x;
cout<<"Enter value of bias"; cin>>b;
cout<<"Enter value of weight";
cin>>w; net=(w*x+b);
cout<<"******output*********";
cout<<"\nnet="<<net<<endl;
if(net<0) {out=0;}
else if((net>=0)&&(net<=1))
{out=net;}
else out=1;
cout<<"Output ="<<out;
getch();
}
```

O/p

```
Enter value of X 0.2
Enter value of bias 0.45
Enter value of weight 0.3
******output*********
net=0.51
Output =0.51_
```

B. Calculate the output of neural net using both binary and bipolar sigmoidal function. For the network shown in the figure, calculate the net input to output

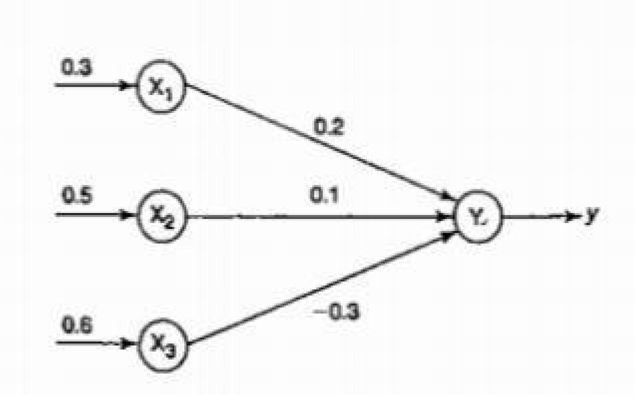


Figure 1 Neural net.

neuron.

Solution :The given neural net consist of three input neurons and one output neuron. The inputs and weight are

[x1, x2, x3] = [0.8, 0.6 0.4]

[w1, w2, w3] = [0.1, 0.3, -0.2]

The net input can be calculated as

Yin = x1w1+x2w2+x3w3

= 0.8*0.1+0.6*0.3+0.4*(-0.2)

= 0.53

Code :

```
#include<iostream.h>
#include<conio.h>
#include<math.h> void
main()
{ clrscr();
int i=0;
float x[10],b,w[10],net,n,sumxw=0,sigmo,e=2.71828;
float out; cout<<"Enter the number of input : ";
cin>>n;
for (i=0;i<n;i++)
{
cout<<"Enter value of X"<<i+1;
cin>>x[i];
cout<<"Enter value of weight w"<<i+1; cin>>w[i];
}
cout<<"Enter value of bias"; cin>>b;
for (i=0;i<n;i++)
{
	sumxw=sumxw+w[i]*x[i];
}
	net=(sumxw+b);
```

```
cout<<"******output*********"; cout<<"\nnet="<<net<<endl;
if(net<0) {out=0;}
else if((net>=0)&&(net<=1))
{out=net;}
else out=1;
cout<<"Output ="<<out;
cout<<"\n\n------------x------------- "; cout<<"\n\nBinary sigmodial actication
function : "<<(1/(1+(pow(e,-net)))); cout<<"\n\nBipolar sigmodial actication
function : "<<(2/(1+(pow(e,-net)))); getch();
}
```

Output :

```
Enter the number of input : 3
Enter value of X1 0.8
Enter value of weight w1 0.1
Enter value of X2 0.6
Enter value of weight w2 0.3
Enter value of X3 0.4
Enter value of weight w3 -0.2
Enter value of bias 0.35
******output*********
net=0.53
Output =0.53

------------x-------------

Binary sigmodial actication function : 0.629483

 Bipolar sigmodial actication function : 1.258966
```

[p

Practical No. 2

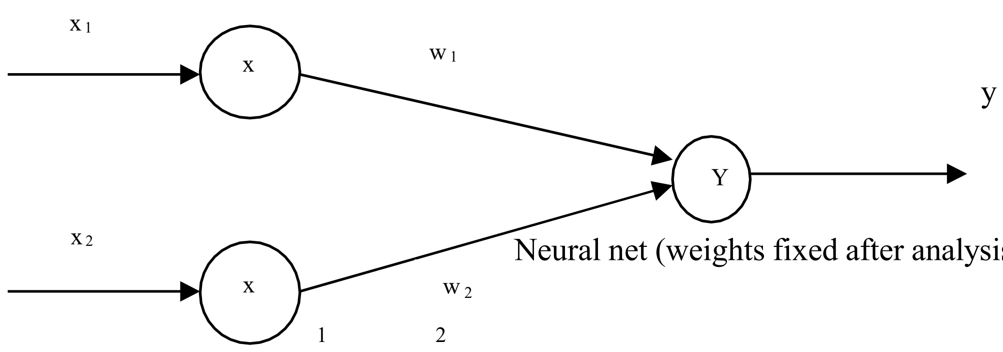
A. Generate AND/NOT function using McCulloch-Pitts neural net.
B. Generate XOR function using McCulloch-Pitts neural net.

A. Generate AND/NOT function using McCulloch-Pitts neural net.

Solution:
In the case of ANDNOT function, the response is true if the first input is true and the second input is false. For all the other variations , the response is false. The truth table for ANDNOT function is given in Table below. **Truth Table:**

x1	**x2**	**y**
0	0	0
0	1	0
1	0	1
1	1	0

The given function gives an output only when $x_1 = 1$ and $x_2 = 0$. The weights have to be decided only after the analysis. The net can be represent as shown in figure below:



Neural net (weights fixed after analysis).

Case 1: Assume that both weight W_1 and W_2 excitatory i.e.,

$$W_1 = W_2 = 1$$

Then for the inputs calculate the net using

$$y_{ij} = X_1W_1 + X_2W_2$$

For inputs
(1, 1), $y_{ij} = 1 \text{ x } 1 + 1 \text{ x } 1 = 2$
(1, 0), $y_{ij} = 1 \text{ x } 1 + 0 \text{ x } 1 = 1$
(0, 1), $y_{ij} = 0 \text{ x } 1 + 1 \text{ x } 1 = 1$
(0, 0), $y_{ij} = 0 \text{ x } 1 + 0 \text{ x } 1 = 0$
From the calculated net inputs, it is not possible to fire the neuron form input (1, 0) only. Hence, J-. weights are not suitable.

Assume one weight as excitatory and the other as inhibitory, i.e., $w1= 1$, $w2 = -1$
Now calculate the net input. For the inputs
(1,1), $y_{in} = 1 \times 1 + 1 \times -1 = 0$
(1,0), $y_{in} = 1 \times 1 + 0 \times -1 = 1$
(0,1), $y_{in} = 0 \times 1 + 1 \times -1 = -1$
(0, 0), $y_{in} = 0 \times 1 + 0 \times -1 = 0$
From the calculated net inputs, now it is possible to fire the neuron for input (1, 0) only by fixing a threshold of 1, i.e., $\theta \geq 1$ for Y unit. Thus, $w_1 = 1$, $w_2 = -1$; $\theta \geq 1$ Note: The value is calculated using the following:
$\theta \geq nw - p\,\theta$
$\geq 2 \times 1 - 1$
$\theta \geq 1$
Thus, the output of neuron Y can be written as

$$y = f(y_{in}) = \begin{cases} 0 \text{ if } y_{in} \geq 1 \\ 1 \text{ if } y_{in} < 1 \end{cases}$$

Code:

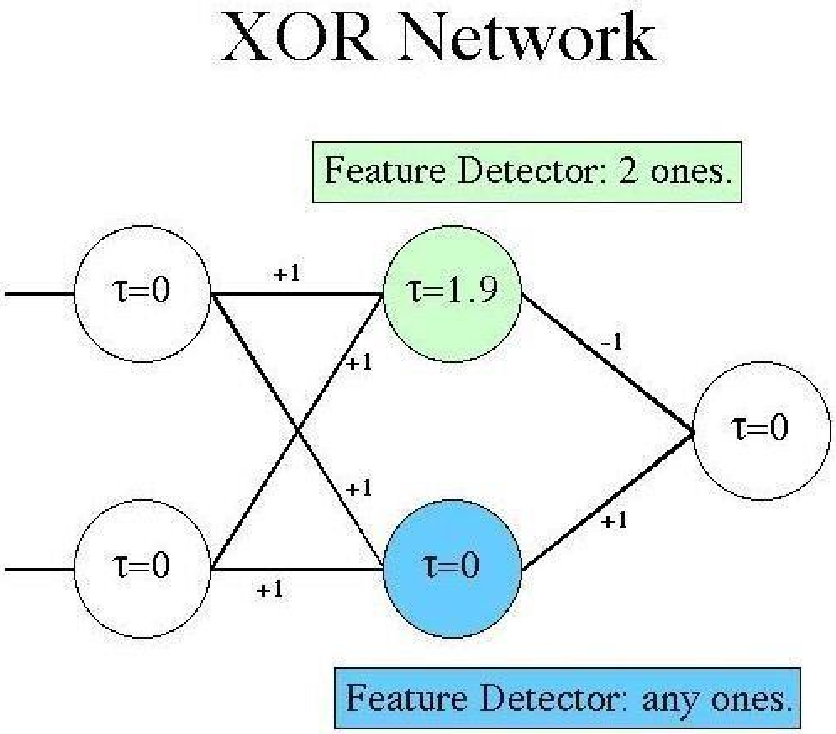
```
import numpy
num_ip=int(input("Enter the number of input: "))
w1 = 1 w2 = 1
print("For the",num_ip,"inpuets calculate the net inputs")
x1 = [] x2 = [] for j in range(0, num_ip):     ele1 =
int(input("x1 = "))     ele2 = int(input("x2 = "))
x1.append(ele1)     x2.append(ele2) print("x1 = ",x1)
print("x2 = ",x2) n = x1 * w1
m = x2 * w2

Yin = [] for i in range(0,
num_ip):     Yin.
append(n[i] + m[i])
print("Yin = ",Yin) Yin =
[] for i in range(0,
num_ip):     Yin.
append(n[i] - m[i])
print("After assuming one weight as excitatory & other")
Y = [] for i in range(0, num_ip):     if(Yin[i]>=1):
ele=1
     Y.append(ele)
if(Yin[i]<1):
     ele=0
     Y.append(ele)
print("Y = ",Y)
```

Output:

```
Enter the number of input: 4
For the 4 inpuets calculate the net inputs
x1 = 0
x2 = 0
x1 = 0
x2 = 1
x1 = 1
x2 = 0
x1 = 1
x2 = 1
x1 =  [0, 0, 1, 1]
x2 =  [0, 1, 0, 1]
Yin =  [0, 1, 1, 2]
After assuming one weight as excitatory & other
Y =  [0, 0, 1, 0]
```

B. Generate XOR function using McCulloch-Pitts neural net.



Code :

```
import math import
numpy import
random
# note that this only works for a single layer of depth
INPUT_NODES = 2
OUTPUT_NODES = 1
HIDDEN_NODES = 2
# 15000 iterations is a good point for playing with learning rate
MAX_ITERATIONS = 130000
# setting this too low makes everything change very slowly, but too high
# makes it jump at each and every example and oscillate. I found .5 to be good
LEARNING_RATE = .2
print ("Neural Network Program") class network:     def _init_(self,
input_nodes, hidden_nodes, output_nodes, learning_rate):
        self.input_nodes = input_nodes
self.hidden_nodes = hidden_nodes
self.output_nodes = output_nodes
        self.total_nodes = input_nodes + hidden_nodes + output_nodes
        self.learning_rate = learning_rate
        # set up the arrays
        self.values = numpy.zeros(self.total_nodes)
self.expectedValues = numpy.zeros(self.total_nodes)
self.thresholds = numpy.zeros(self.total_nodes)
        # the weight matrix is always square
        self.weights = numpy.zeros((self.total_nodes, self.total_nodes))
# set random seed! this is so we can experiment consistently
random.seed(10000)
```

[p


```
        # set initial random values for weights and thresholds
        # this is a strictly upper triangular matrix as there is no feedback
        # loop and there inputs do not affect other inputs          for i
in range(self.input_nodes, self.total_nodes):
self.thresholds[i] = random.random() / random.random()
for j in range(i + 1, self.total_nodes):
                self.weights[i][j] = random.random() * 2

    def process(self):
        # update the hidden nodes          for i in range(self.input_nodes,
self.input_nodes + self.hidden_nodes):
            # sum weighted input nodes for each hidden node, compare threshold, apply sigmoid
            W_i = 0.0              for j in
range(self.input_nodes):
                W_i += self.weights[j][i] * self.values[j]
W_i -= self.thresholds[i]
            self.values[i] = 1 / (1 + math.exp(-W_i))
        # update the output nodes          for i in range(self.input_nodes +
self.hidden_nodes, self.total_nodes):
            # sum weighted hidden nodes for each output node, compare threshold, apply sigmoid
            W_i = 0.0              for j in range(self.input_nodes, self.input_nodes +
self.hidden_nodes):
                W_i += self.weights[j][i] * self.values[j]
W_i -= self.thresholds[i]             self.values[i] = 1 /
(1 + math.exp(-W_i))     def processErrors(self):
        sumOfSquaredErrors = 0.0
        # we only look at the output nodes for error calculation      for i in
range(self.input_nodes + self.hidden_nodes, self.total_nodes):
error = self.expectedValues[i] - self.values[i]
            #print error
            sumOfSquaredErrors += math.pow(error, 2)
            outputErrorGradient = self.values[i] * (1 - self.values[i]) * error
            #print outputErrorGradient
            # now update the weights and thresholds             for j in
range(self.input_nodes, self.input_nodes + self.hidden_nodes):                #
first update for the hidden nodes to output nodes (1 layer)               delta =
self.learning_rate * self.values[j] * outputErrorGradient
                #print delta
                self.weights[j][i] += delta
                hiddenErrorGradient = self.values[j] * (1 - self.values[j]) * outputErrorGradient *
self.weights[j][i]
                # and then update for the input nodes to hidden nodes
for k in range(self.input_nodes):
                    delta = self.learning_rate * self.values[k] * hiddenErrorGradient
self.weights[k][j] += delta
                # update the thresholds for the hidden nodes
delta = self.learning_rate * -1 * hiddenErrorGradient
                #print delta
                self.thresholds[j] += delta
```

```
        # update the thresholds for the output node(s)
delta = self.learning_rate * -1 * outputErrorGradient
self.thresholds[i] += delta
    return sumOfSquaredErrors

class sampleMaker:
  def __init__(self, network):
self.counter = 0
self.network = network     def
setXor(self, x):        if x == 0:
        self.network.values[0] = 1
self.network.values[1] = 1
self.network.expectedValues[4] = 0        elif x
== 1:
        self.network.values[0] = 0
self.network.values[1] = 1
self.network.expectedValues[4] = 1        elif x
== 2:
        self.network.values[0] = 1
self.network.values[1] = 0
self.network.expectedValues[4] = 1        else:
        self.network.values[0] = 0
self.network.values[1] = 0
self.network.expectedValues[4] = 0     def
setNextTrainingData(self):
self.setXor(self.counter % 4)        self.counter
+= 1
# start of main program loop, initialize classes
net = network(INPUT_NODES, HIDDEN_NODES, OUTPUT_NODES, LEARNING_RATE)
samples = sampleMaker(net)

for i in range(MAX_ITERATIONS):
samples.setNextTrainingData()
net.process()     error =
net.processErrors()
  # prove that we got the right answers(ish)!
  if i > (MAX_ITERATIONS - 5):
    output = (net.values[0], net.values[1], net.values[4], net.expectedValues[4], error)
print (output)
# display final parameters print
(net.weights)
print (net.thresholds)
```

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Output :

```
Neural Network Program
(1.0, 1.0, 0.01492920800573836, 0.0, 0.00022288125167860235)
(0.0, 1.0, 0.9857295047367691, 1.0, 0.00020364703505789487)
(1.0, 0.0, 0.9856250336871464, 1.0, 0.00020663965649567642)
(0.0, 0.0, 0.016607849913409613, 0.0, 0.00027582067874633397)
[[ 0.          0.          5.75231929 -6.31595212  0.        ]
 [ 0.          0.         -5.97540997  6.18899346  0.        ]
 [ 0.          0.          0.          1.93019719  9.6814855 ]
 [ 0.          0.          0.          0.          9.57128428]
 [ 0.          0.          0.          0.          0.        ]]
[0.         0.         3.1933078  3.44466182 4.75885176]
```

Practical No. 3

A. Write a program to implement Hebb's rule.

Solution:

```
#include<iostream.h>
#include<conio.h> void
main()
{
float n,w,x=1,net,d,div,a,at=0.3,dw; clrscr();
cout<<"Consider a single neuron perceptron with a single i/p"; cin>>w;
cout<<"\nEnter the learining coefficient"; cin>>d;
for(int i=0; i<10;i++)
{ net=x+w;
if(w<0) a=0;
else a=1;
div=at+a+w;
w=w+div;
cout<<"\ni+1 in fraction are i "<<a<<"\tchange in weight "<<div<<"\nadjustment at "<<w<< "\tnet
value is "<<net;
} getch();
}
```

Output :

```
Consider a single neuron perceptron with a single i/p 1

Enter the learining coefficient 2

i+1 in fraction are i 1 change in weight 2.3
adjustment at 3.3       net value is 2
i+1 in fraction are i 1 change in weight 4.6
adjustment at 7.9       net value is 4.3
i+1 in fraction are i 1 change in weight 9.2
adjustment at 17.099998 net value is 8.9
i+1 in fraction are i 1 change in weight 18.399998
adjustment at 35.499996 net value is 18.099998
i+1 in fraction are i 1 change in weight 36.799995
adjustment at 72.299988 net value is 36.499996
i+1 in fraction are i 1 change in weight 73.599991
adjustment at 145.899979        net value is 73.299988
i+1 in fraction are i 1 change in weight 147.199982
adjustment at 293.099976        net value is 146.899979
i+1 in fraction are i 1 change in weight 294.399963
adjustment at 587.499939        net value is 294.099976
i+1 in fraction are i 1 change in weight 588.799927
adjustment at 1176.299805       net value is 588.499939
i+1 in fraction are i 1 change in weight 1177.599854
adjustment at 2353.899658       net value is 1177.299805
```

Python Code: #Learning Rules #

```
import math
def computeNet(input, weights):
        net = 0          for i in
range(len(input)):                  net = net +
input[i]*weights[i]          print ("NET:")
print (net)          return net #print
("NET:")
            #print net
            #return net

def computeFNetBinary(net):
        f_net = 0
if(net>0):
f_net = 1
if(net<0):
f_net = -1
        return f_net

def computeFNetCont(net):
        f_net = 0
        f_net = (2/(1+math.exp(-net)))-1
        return f_net

def hebb(f_net):
return f_net

def perceptron(desired, actual):
return (desired-actual)

def widrow(desired, actual):
return (desired-actual)

def adjustWeights(inputs, weights, last, binary, desired, rule):
c = 1          if(last):
                print ("COMPLETE")
                return
current_input = inputs[0]
inputs = inputs[1:]          if
desired :
                current_desired = desired[0]
desired = desired[1:]          if
len(inputs) == 0:                  last = True
        net = computeNet(current_input, weights)
if(binary):
                f_net = computeFNetBinary(net)
        else:
```

```
            f_net = computeFNetCont(net)
if rule == "hebb":         r = hebb(f_net)
elif rule == "perceptron":
            r = perceptron(current_desired, f_net)
elif rule == "widrow":                 r =
widrow(current_desired, net)         del_weights
= []         for i in range(len(current_input)):
x = (c*r)*current_input[i]
del_weights.append(x)                 weights[i] = x
      print("NEW WEIGHTS:")
print(weights)
      adjustWeights(inputs, weights, last, binary, desired, rule)

if __name__=="__main__":
      #total_inputs = (int)raw_input("Enter Total Number of Inputs)
#vector_length = (int)raw_input("Enter Length of vector)
total_inputs = 3         vector_length = 4
      #for i in range(vector_length):
      #weight.append(raw_input("Enter Initial Weight:")
weights = [1,-1,0,0.5]
      inputs = [[1,-2,1.5,0],[1,-0.5,-2,-1.5],[0,1,-1,1.5]]
desired = [1,2,1,-1]         print("BINARY HEBB!")
      adjustWeights(inputs, [1,-1,0,0.5], False, True, None, "hebb")
print("CONTINUOUS HEBB!")
      adjustWeights(inputs, [1,-1,0,0.5], False, False, None, "hebb")
print("PERCEPTRON!")
      adjustWeights(inputs, [1,-1,0,0.5], False, True, desired, "perceptron")
print("WIDROW HOFF!")
      adjustWeights(inputs, [1,-1,0,0.5], False, True, desired, "widrow")
```

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Output :

BINARY HEBB! NET:
3.0
NEW WEIGHTS:
[1, -2, 1.5, 0]
NET:
-1.0
NEW WEIGHTS:
[-1, 0.5, 2, 1.5]
NET: 0.75
NEW WEIGHTS:
[0, 1, -1, 1.5]
COMPLETE
CONTINUOUS HEBB! NET:
3.0
NEW WEIGHTS:
[0.9051482536448667, -
1.8102965072897335,
1.3577223804673002, 0.0] NET: -
0.905148253644867 NEW WEIGHTS:
[-0.42401264054072996, 0.21200632027036498, 0.8480252810814599, 0.6360189608110949] NET:
0.31800948040554744 NEW
WEIGHTS:
[0.0, 0.15767814164392502, -0.15767814164392502, 0.23651721246588753] COMPLETE
PERCEPTRON! NET:
3.0
NEW WEIGHTS:
[0, 0, 0.0, 0] NET:
0.0
NEW WEIGHTS:
[2, -1.0, -4, -3.0]
NET:
-1.5
NEW WEIGHTS:
[0, 2, -2, 3.0]
COMPLETE WIDROW
HOFF! NET:
3.0
NEW WEIGHTS:
[-2.0, 4.0, -3.0, -0.0] NET:
2.0
NEW WEIGHTS: [0.0,
-0.0, -0.0, -0.0] NET:
0.0
NEW WEIGHTS:
[0.0, 1.0, -1.0, 1.5]
COMPLETE
>>>

B. Write a program to implement of delta rule.

Solution :

```
#include<iostream.h
> #include<conio.h>
void main() { clrscr(
);
float input[3],d,del,a,val[10],w[10],weight[3],delta;
for(int i=0;i < 3 ; i++)
{
cout<<"\n initilize weight vector
"<<i<<"\t"; cin>>input[i]; }
cout<<"\n enter the desired output\t";
cin>>d; do { del=d-a;
if(del<0) for(i=0 ;i<3 ;i++)
w[i]=w[i]-input[i]; else
if(del>0) for(i=0;i<3;i++)
weight[i]=weight[i]+input[i]
; for(i=0;i<3;i++)
{ val[i]=del*input[i];
weight[+1]=weight[i]+val[i];
} cout<<"\n value of delta is "<<del;
cout<<"\n weight have been
adjusted";
}while(del==0); if(del==0)
cout<<"\n output is
correct"; getch(); }
```

Output:

```
initilize weight vector 0      1

initilize weight vector 1      2

initilize weight vector 2      1

enter the desired output       0

value of delta is -9.459045e-41
weight have been adjusted_
```

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Practical No. 4

A. Write a program for Back Propagation Algorithm.

Solution :

Python Code:

```
import math import
random
import sys

INPUT_NEURONS = 4
HIDDEN_NEURONS = 6
OUTPUT_NEURONS = 14

LEARN_RATE = 0.2 # Rho. NOISE_FACTOR
= 0.58
TRAINING_REPS = 10000
MAX_SAMPLES = 14

TRAINING_INPUTS = [[1, 1, 1, 0],
                [1, 1, 0, 0],
                [0, 1, 1, 0],
                [1, 0, 1, 0],
                [1, 0, 0, 0],
                [0, 1, 0, 0],
                [0, 0, 1, 0],
                [1, 1, 1, 1],
                [1, 1, 0, 1],
                [0, 1, 1, 1],
                [1, 0, 1, 1],
                [1, 0, 0, 1],
                [0, 1, 0, 1],
                [0, 0, 1, 1]]

TRAINING_OUTPUTS = [[1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0],
                [0, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0],
                [0, 0, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0],
                [0, 0, 0, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0],
                [0, 0, 0, 0, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0],
                [0, 0, 0, 0, 0, 1, 0, 0, 0, 0, 0, 0, 0, 0],
                [0, 0, 0, 0, 0, 0, 1, 0, 0, 0, 0, 0, 0, 0],
                [0, 0, 0, 0, 0, 0, 0, 1, 0, 0, 0, 0, 0, 0],
                [0, 0, 0, 0, 0, 0, 0, 0, 1, 0, 0, 0, 0, 0],
                [0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 0, 0, 0, 0],
                [0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 0, 0, 0],
                [0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 0, 0],
                [0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 0],
[0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1]]
```

```
class Example_4x6x16:
   def __init__(self, numInputs, numHidden, numOutput, learningRate, noise, epochs, numSamples,
inputArray, outputArray):
       self.mInputs = numInputs
       self.mHiddens = numHidden
self.mOutputs = numOutput
self.mLearningRate = learningRate
self.mNoiseFactor = noise
self.mEpochs = epochs        self.mSamples
= numSamples        self.mInputArray =
inputArray
       self.mOutputArray = outputArray

       self.wih = [] # Input to Hidden Weights
       self.who = [] # Hidden to Output Weights
inputs = []        hidden = []        target = []
actual = []        erro = []        errh = []
       return

   def initialize_arrays(self):
       for i in range(self.mInputs + 1): # The extra element represents bias node.
self.wih.append([0.0] * self.mHiddens)            for j in range(self.mHiddens):
            # Assign a random weight value between -0.5 and 0.5
self.wih[i][j] = random.random() - 0.5

       for i in range(self.mHiddens + 1): # The extra element represents bias node.
self.who.append([0.0] * self.mOutputs)            for j in range(self.mOutputs):
self.who[i][j] = random.random() - 0.5

       self.inputs = [0.0] * self.mInputs
self.hidden = [0.0] * self.mHiddens
self.target = [0.0] * self.mOutputs
self.actual = [0.0] * self.mOutputs        self.erro
= [0.0] * self.mOutputs
       self.errh = [0.0] * self.mHiddens

       return

   def get_maximum(self, vector):
       # This function returns an array index of the maximum.
       index = 0
maximum = vector[0]
       length = len(vector)

       for i in range(length):
if vector[i] > maximum:
maximum = vector[i]
            index = i
```

```
        return index

    def sigmoid(self, value):          return
1.0 / (1.0 + math.exp(-value))

    def sigmoid_derivative(self, value):
        return value * (1.0 - value)

    def feed_forward(self):
        total = 0.0

        # Calculate input to hidden layer.
for j in range(self.mHiddens):             total =
0.0            for i in range(self.mInputs):
total += self.inputs[i] * self.wih[i][j]

            # Add in bias.            total +=
self.wih[self.mInputs][j]
            self.hidden[j] = self.sigmoid(total)

        # Calculate the hidden to output layer.
for j in range(self.mOutputs):             total =
0.0            for i in range(self.mHiddens):
total += self.hidden[i] * self.who[i][j]

            # Add in bias.
            total += self.who[self.mHiddens][j]
self.actual[j] = self.sigmoid(total)

        return

    def back_propagate(self):
        # Calculate the output layer error (step 3 for output cell).
        for j in range(self.mOutputs):
            self.erro[j] = (self.target[j] - self.actual[j]) * self.sigmoid_derivative(self.actual[j])

        # Calculate the hidden layer error (step 3 for hidden cell).
for i in range(self.mHiddens):            self.errh[i] = 0.0
for j in range(self.mOutputs):                self.errh[i] +=
self.erro[j] * self.who[i][j]

            self.errh[i] *= self.sigmoid_derivative(self.hidden[i])

        # Update the weights for the output layer (step 4).         for j in
range(self.mOutputs):             for i in range(self.mHiddens):
self.who[i][j] += (self.mLearningRate * self.erro[j] * self.hidden[i])

            # Update the bias.
```

```
            self.who[self.mHiddens][j] += (self.mLearningRate * self.erro[j])

        # Update the weights for the hidden layer (step 4).         for j in
range(self.mHiddens):              for i in range(self.mInputs):
self.wih[i][j] += (self.mLearningRate * self.errh[j] * self.inputs[i])

            # Update the bias.
            self.wih[self.mInputs][j] += (self.mLearningRate * self.errh[j])

        return

    def print_training_stats(self):
sum = 0.0

        for i in range(self.mSamples):             for j
in range(self.mInputs):                 self.inputs[j]
= self.mInputArray[i][j]

            for j in range(self.mOutputs):
                self.target[j] = self.mOutputArray[i][j]

            self.feed_forward()

            if self.get_maximum(self.actual) == self.get_maximum(self.target):
                sum += 1
else:
                sys.stdout.write(str(self.inputs[0]) + "\t" + str(self.inputs[1]) + "\t" + str(self.inputs[2]) +
"\t" + str(self.inputs[3]) + "\n")
                sys.stdout.write(str(self.get_maximum(self.actual)) + "\t" +
str(self.get_maximum(self.target)) + "\n")

        sys.stdout.write("Network is " + str((float(sum) / float(MAX_SAMPLES)) * 100.0) + "%
correct.\n")

        return

    def train_network(self):
        sample = 0

        for i in range(self.mEpochs):
            sample += 1             if
sample == self.mSamples:
                sample = 0

            for j in range(self.mInputs):
                self.inputs[j] = self.mInputArray[sample][j]

            for j in range(self.mOutputs):
self.target[j] = self.mOutputArray[sample][j]
```

```
            self.feed_forward()

            self.back_propagate()

return

    def test_network(self):         for i in
range(self.mSamples):             for j in
range(self.mInputs):               self.inputs[j] =
self.mInputArray[i][j]

            self.feed_forward()

            for j in range(self.mInputs):
sys.stdout.write(str(self.inputs[j]) + "\t")

            sys.stdout.write("Output: " + str(self.get_maximum(self.actual)) + "\n")

return

    def test_network_with_noise(self):
        # This function adds a random fractional value to all the training inputs greater than zero.
        for i in range(self.mSamples):
for j in range(self.mInputs):
                self.inputs[j] = self.mInputArray[i][j] + (random.random() * NOISE_FACTOR)

            self.feed_forward()

            for j in range(self.mInputs):
sys.stdout.write("{:03.3f}".format(((self.inputs[j] * 1000.0) / 1000.0)) + "\t")

            sys.stdout.write("Output: " + str(self.get_maximum(self.actual)) + "\n")

        return

if __name___== '__main__':
    ex = Example_4x6x16(INPUT_NEURONS, HIDDEN_NEURONS, OUTPUT_NEURONS,
LEARN_RATE, NOISE_FACTOR, TRAINING_REPS, MAX_SAMPLES, TRAINING_INPUTS,
TRAINING_OUTPUTS)
ex.initialize_arrays()      ex.train_network()
ex.print_training_stats()
    sys.stdout.write("\nTest network against original input:\n")
ex.test_network()
    sys.stdout.write("\nTest network against noisy input:\n")
ex.test_network_with_noise()
```

Output:

```
Network is 100.0% correct.

Test network against original input:
1	1	1	0	Output: 0
1	1	0	0	Output: 1
0	1	1	0	Output: 2
1	0	1	0	Output: 3
1	0	0	0	Output: 4
0	1	0	0	Output: 5
0	0	1	0	Output: 6
1	1	1	1	Output: 7
1	1	0	1	Output: 8
0	1	1	1	Output: 9
1	0	1	1	Output: 10
1	0	0	1	Output: 11
0	1	0	1	Output: 12
0	0	1	1	Output: 13

Test network against noisy input:
1.129 1.530 1.184 0.132 Output: 0
1.487 1.044 0.468 0.464 Output: 1
0.168 1.555 1.184 0.032 Output: 2
1.316 0.013 1.108 0.453 Output: 10
1.063 0.174 0.049 0.095 Output: 4
0.109 1.064 0.079 0.264 Output: 5
0.477 0.528 1.560 0.083 Output: 0
1.386 1.438 1.554 1.109 Output: 7
1.074 1.234 0.171 1.313 Output: 8
0.236 1.134 1.497 1.336 Output: 9
1.375 0.037 1.374 1.384 Output: 10
1.017 0.463 0.448 1.389 Output: 11
0.252 1.202 0.343 1.447 Output: 7
0.533 0.388 1.252 1.342 Output: 13
>>>
```

C. Write a program for error Backpropagation algorithm.

Solution :

```
#include<conio.h>
#include<iostream.h> #include<math.h>
void main()
{  clrscr();
float l,c,s1,n1,n2,w10,b10,w20,b20,w11,b11,w21,b21,p,t,a0=-1,a1,a2,e,s2;
cout<<"enter the input weights/base of second n/w= "; cin>>w10>>b10;
cout<<"enter the input weights/base of second n/w= ";
cin>>w20>>b20;
cout<<"enter the learning coefficient of n/w c= "; cin>>c;
/* Step1:Propagation of signal through n/w */
 n1=w10*p+b10;
a1=tanh(n1); n2=w20*a1+b20;
a2=tanh(n2);
e=(t-a2); /* Back Propagation of Sensitivities */
s2=-2*(1-a2*a2)*e; s1=(1-a1*a1)*w20*s2;
/* Updation of weights and bases */
w21=w20-(c*s2*a1); w11=w10-
(c*s1*a0); b21=b20-(c*s2);
b11=b10-(c*s1);
cout<<"The uploaded weight of first n/w w11= "<<w11;
cout<<"\n"<<"The uploaded weight of second n/w w21= "<<w21;
cout<<"\n"<<"The uploaded base of second n/w b11= "<<b11;
cout<<"\n"<<"The uploaded base of second n/w b21= "<<b21; getch();
}
```

Output:

```
enter the input weights/base of first n/w= 0.23 -0.2
enter the input weights/base of second n/w= 0.45 0.3
enter the learning coefficient of n/w c= 0.45
The uploaded weight of second n/w w11= 0.307488
The uploaded weight of second n/w w21= 0.485365
The uploaded base of second n/w b11= -0.277488
The uploaded base of second n/w b21= 0.120823_
```

Python Code :

```
import math import
random
import sys

NUM_INPUTS = 3 # Input nodes, plus the bias input.
NUM_PATTERNS = 4 # Input patterns for XOR experiment.
NUM_HIDDEN = 4
NUM_EPOCHS = 200
LR_IH = 0.7 # Learning rate, input to hidden weights.
LR_HO = 0.07 # Learning rate, hidden to output weights.

# The data here is the XOR data which has been rescaled to the range -1 to 1.
# An extra input value of 1 is also added to act as the bias.
# e.g: [Value 1][Value 2][Bias]
TRAINING_INPUT = [[1, -1, 1], [-1, 1, 1], [1, 1, 1], [-1, -1, 1]]

# The output must lie in the range -1 to 1.
TRAINING_OUTPUT = [1, 1, -1, -1]


class Backpropagation1:     def __init__(self, numInputs, numPatterns, numHidden,
numEpochs, i2hLearningRate, h2oLearningRate, inputValues, outputValues):
self.mNumInputs = numInputs         self.mNumPatterns = numPatterns
self.mNumHidden = numHidden         self.mNumEpochs = numEpochs
self.mI2HLearningRate = i2hLearningRate         self.mH2OLearningRate =
h2oLearningRate         self.hiddenVal = [] # Hidden node outputs.         self.weightsIH =
[] # Input to Hidden weights.         self.weightsHO = [] # Hidden to Output weights.
        self.trainInputs = inputValues         self.trainOutput =
outputValues # "Actual" output values.
        self.errThisPat = 0.0         self.outPred = 0.0 #
"Expected" output values.         self.RMSerror = 0.0 #
Root Mean Squared error.         return

    def initialize_arrays(self):
        # Initialize weights to random values.
for j in range(self.mNumInputs):
newRow = []             for i in
range(self.mNumHidden):
                self.weightsHO.append((random.random() - 0.5) / 2.0)
weightValue = (random.random() - 0.5) / 5.0
newRow.append(weightValue)
                sys.stdout.write("Weight = " + str(weightValue) + "\n")
self.weightsIH.append(newRow)

        self.hiddenVal = [0.0] * self.mNumHidden
```

[p


```
return

    def calc_net(self, patNum):
        # Calculates values for Hidden and Output nodes.
for i in range(self.mNumHidden):
            self.hiddenVal[i] = 0.0             for j in range(self.mNumInputs):
self.hiddenVal[i] += (self.trainInputs[patNum][j] * self.weightsIH[j][i])

            self.hiddenVal[i] = math.tanh(self.hiddenVal[i])

        self.outPred = 0.0

        for i in range(self.mNumHidden):             self.outPred
+= self.hiddenVal[i] * self.weightsHO[i]

        self.errThisPat = self.outPred - self.trainOutput[patNum] # Error = "Expected" - "Actual"
return

    def adjust_hidden_to_output_weights(self):          for i in range(self.mNumHidden):
weightChange = self.mH2OLearningRate * self.errThisPat * self.hiddenVal[i]
self.weightsHO[i] -= weightChange

            # Regularization of the output weights.
if self.weightsHO[i] < -5.0:
self.weightsHO[i] = -5.0             elif
self.weightsHO[i] > 5.0:
self.weightsHO[i] = 5.0

return

    def adjust_input_to_hidden_weights(self, patNum):
        for i in range(self.mNumHidden):
for j in range(self.mNumInputs):
                x = 1 - math.pow(self.hiddenVal[i], 2)
                x = x * self.weightsHO[i] * self.errThisPat * self.mI2HLearningRate
x = x * self.trainInputs[patNum][j]

                weightChange = x
                self.weightsIH[j][i] -= weightChange

return

    def calculate_overall_error(self):
errorValue = 0.0

        for i in range(self.mNumPatterns):
            self.calc_net(i)
            errorValue += math.pow(self.errThisPat, 2)
```

```
        errorValue /= self.mNumPatterns

        return math.sqrt(errorValue)

    def train_network(self):
patNum = 0

        for j in range(self.mNumEpochs):
for i in range(self.mNumPatterns):
                # Select a pattern at random.
                patNum = random.randrange(0, 4)

                # Calculate the output and error for this pattern.
self.calc_net(patNum)

                # Adjust network weights.
self.adjust_hidden_to_output_weights()
self.adjust_input_to_hidden_weights(patNum)

            self.RMSerror = self.calculate_overall_error()

            sys.stdout.write("epoch = " + str(j) + " RMS Error = " + str(self.RMSerror) + "\n")

return

    def display_results(self):         for i in
range(self.mNumPatterns):
self.calc_net(i)
            sys.stdout.write("pat = " + str(i + 1) + " actual = " + str(self.trainOutput[i]) + " neural model
= " + str(self.outPred) + "\n")
        return

if __name__ == '__main__':
    bp1 = Backpropagation1(NUM_INPUTS, NUM_PATTERNS, NUM_HIDDEN, NUM_EPOCHS,
LR_IH, LR_HO, TRAINING_INPUT, TRAINING_OUTPUT)
bp1.initialize_arrays()      bp1.train_network()
    bp1.display_results()
```

Output :

Weight = -0.076830377741923
Weight = 0.05545767965063293
Weight = 0.04681339243357252
Weight = -0.09587746729203184

Weight = 0.04052189546257452
Weight = -0.07220251631291778
Weight = -0.007749552037827767
Weight = 0.0019251805560653646
Weight = 0.07080044114386415
Weight = -0.09274060371150909
Weight = 0.06861531194281656 Weight = -0.050378434324804135 epoch = 0 RMS Error = 1.0009512196803645 epoch = 1 RMS Error = 1.0007742300312352 epoch = 2 RMS Error = 0.9999697046881315 epoch = 3 RMS Error = 1.000262809842168 epoch = 4 RMS Error = 1.0003385668587828 epoch = 5 RMS Error = 1.0003689607981894 epoch = 6 RMS Error = 1.0000417221070503 epoch = 7 RMS Error = 1.000677139732449 epoch = 8 RMS Error = 1.0007592165353387 epoch = 9 RMS Error = 1.0008703183629073 epoch = 10 RMS Error = 1.0008861430891467 epoch = 11 RMS Error = 1.0033119707170162 epoch = 12 RMS Error = 1.0002096196793477 epoch = 13 RMS Error = 1.0024201859681148 epoch = 14 RMS Error = 1.0246045183898609 epoch = 15 RMS Error = 1.0866139947291669 epoch = 16 RMS Error = 1.1180846338077137 epoch = 17 RMS Error = 1.0945116890437883 epoch = 18 RMS Error = 1.049671043392105 epoch = 19 RMS Error = 1.0152914017108694 epoch = 20 RMS Error = 1.0145557750670153 epoch = 21 RMS Error = 0.9932716005906015 epoch = 22 RMS Error = 0.9888288662456067 epoch = 23 RMS Error = 0.9653028002781683 epoch = 24 RMS Error = 0.9462033680943689 epoch = 25 RMS Error = 0.9635046766036908 epoch = 26 RMS Error = 0.9269561335697628 epoch = 27 RMS Error = 0.8899991117968605 epoch = 28 RMS Error = 0.8494727403855441 epoch = 29 RMS Error = 0.8501197677217179 epoch = 30 RMS Error = 0.8762543447244755 epoch = 31 RMS Error = 0.692734715088619 epoch = 32 RMS Error = 0.6544776768372573 epoch = 33 RMS Error = 0.6560015814555122 epoch = 34 RMS Error = 0.5847946010413321 epoch = 35 RMS Error =

0.5914082563666686 epoch = 36 RMS Error = 0.4790604826735862 epoch = 37 RMS Error = 0.4397556713159569 epoch = 38 RMS Error = 0.41377584615296625 epoch = 39 RMS Error = 0.4092770588919743 epoch = 40 RMS Error = 0.35296071912275606 epoch = 41 RMS Error = 0.3365550034266497 epoch = 42 RMS Error = 0.3280232258315713 epoch = 43 RMS Error = 0.3414255796938536 epoch = 44 RMS Error = 0.3533005009273525 epoch = 45 RMS Error = 0.28281089343673405 epoch = 46 RMS Error = 0.2904741808739498 epoch = 47 RMS Error = 0.2454063473896513 epoch = 48 RMS Error = 0.25409458767312154 epoch = 49 RMS Error = 0.20305645683840176 epoch = 50 RMS Error = 0.18393541468120506 epoch = 51 RMS Error = 0.17846776577735193 epoch = 52 RMS Error = 0.18334390019732144 epoch = 53 RMS Error = 0.15508220138915574 epoch = 54 RMS Error = 0.139229488350614 epoch = 55 RMS Error = 0.11974475852816462 epoch = 56 RMS Error = 0.11421376611765871 epoch = 57 RMS Error = 0.10268100281075816 epoch = 58 RMS Error = 0.10482234090600366 epoch = 59 RMS Error = 0.0999742036362297 epoch = 60 RMS Error = 0.09458874373044308 epoch = 61 RMS Error = 0.08254877094465272 epoch = 62 RMS Error = 0.08088721000198916 epoch = 63 RMS Error = 0.08307283801412396 epoch = 64 RMS Error = 0.06969713131699112 epoch = 65 RMS Error = 0.06463747572427869 epoch = 66 RMS Error = 0.05673540946521857 epoch = 67 RMS Error = 0.05222188742710054 epoch = 68 RMS Error = 0.04788054379879637 epoch = 69 RMS Error = 0.04230121876786113 epoch = 70 RMS Error = 0.03763746732085769 epoch = 71 RMS Error = 0.03345238653179893 epoch = 72 RMS Error = 0.03368828484699634 epoch = 73 RMS Error = 0.029034612333551403 epoch = 74

RMS Error = 0.025997629514787002 epoch = 75 RMS Error = 0.023283968034267345 epoch = 76 RMS Error = 0.02275553127586748 epoch = 77 RMS Error = 0.022660941883036966 epoch = 78 RMS Error = 0.02376199011376938 epoch = 79 RMS Error = 0.024441464034659403 epoch = 80 RMS Error = 0.025075352824191304 epoch = 81 RMS Error = 0.02617665075137898 epoch = 82 RMS Error = 0.01992863074760936 epoch = 83 RMS Error = 0.014545322962480053 epoch = 84 RMS Error = 0.013045591218816883 epoch = 85 RMS Error = 0.011229028517607825 epoch = 86 RMS Error = 0.01025903711675883 epoch = 87 RMS Error = 0.01002411657073447 epoch = 88 RMS Error = 0.010305972985037241 epoch = 89 RMS Error = 0.008650306018804928 epoch = 90 RMS Error = 0.009152497894035112 epoch = 91 RMS Error = 0.009301414031326888 epoch = 92 RMS Error = 0.007604408287698745 epoch = 93 RMS Error = 0.007785189814859717 epoch = 94 RMS Error = 0.008036562022304714 epoch = 95 RMS Error = 0.006513592874088161 6 epoch = 96 RMS Error = 0.007015538276941596 epoch = 97 RMS Error = 0.007387497614085007 epoch = 98 RMS Error = 0.005077565383913 3265 epoch = 99 RMS Error = 0.005027281384600543 epoch = 100 RMS Error = 0.003859324377077451 epoch = 101 RMS Error = 0.003511204283321 2735 epoch = 102 RMS Error = 0.003499799697388121 3 epoch = 103 RMS Error = 0.002895225439976769 4 epoch = 104 RMS Error = 0.002568423552607127 epoch = 105 RMS Error = 0.002361451160813095 epoch = 106 RMS Error = 0.002155280061188411 4 epoch = 107 RMS Error = 0.001921842146137992 3 epoch = 108 RMS Error = 0.001731515387392159 epoch = 109 RMS Error = 0.001598632273724133 6 epoch =

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110 RMS Error = 0.0015128292602829211 epoch = 111 RMS Error = 0.0015088366258953208 epoch = 112 RMS Error = 0.0012987112428903436 epoch = 113 RMS Error = 0.0011018629306539375 epoch = 114 RMS Error = 0.0011065577292172176 epoch = 115 RMS Error = 0.0011089771459426357 epoch = 116 RMS Error = 0.0010047112460113657 epoch = 117 RMS Error = 0.0010148585595403199 epoch = 118 RMS Error = 0.0009908442377691941 epoch = 119 RMS Error = 0.0008304460522332652 epoch = 120 RMS Error = 0.0007747089415223214 epoch = 121 RMS Error = 0.0007599820231754118 epoch = 122 RMS Error = 0.0006306923848544624 epoch = 123 RMS Error = 0.0005663541153403198 epoch = 124 RMS Error = 0.0005487201564723689 epoch = 125 RMS Error = 0.0005229773607802055 epoch = 126 RMS Error = 0.0004657976207044722 epoch = 127 RMS Error = 0.0004080705106233442 epoch = 128 RMS Error = 0.0003699814798901 7216 epoch = 129 RMS Error = 0.0003550916524108227 epoch = 130 RMS Error = 0.0003022346617517 4473 epoch = 131 RMS Error = 0.0003357167368151245 epoch = 132 RMS Error = 0.0002568827392197539 epoch = 133 RMS Error = 0.0002304640331961993 epoch = 134 RMS Error = 0.0002162849815334 2633 epoch = 135 RMS Error = 0.0001949380413586 1293 epoch = 136 RMS Error = 0.0001980329552842 0247 epoch = 137 RMS Error = 0.0002090790559642 4757 epoch = 138 RMS Error = 0.0001533526278711 1439 epoch = 139 RMS Error = 0.0001460796585259 6715 epoch = 140 RMS Error = 0.0001308706660612 2427 epoch = 141 RMS Error = 0.0001310701669725 9374 epoch = 142 RMS Error = 0.0001150756799162 0269 epoch = 143 RMS Error = 0.0001028498205085 3022 epoch = 144 RMS

Error = 9.292485378643208e-05 epoch = 145
RMS Error = 8.343447649285541e-05 epoch =
146 RMS Error = 8.793306207224718e-05
epoch = 147 RMS Error =
8.707046038560856e-05 epoch = 148 RMS
Error = 7.38365399544037e-05 epoch = 149
RMS Error = 7.382182262986522e-05 epoch =
150 RMS Error = 7.761966487666859e-05
epoch = 151 RMS Error =
6.135295946788964e-05 epoch = 152 RMS
Error = 5.360015054234105e-05 epoch = 153
RMS Error = 5.077960248256503e-05 epoch =
154 RMS Error = 4.4228858203910684e-05
epoch = 155 RMS Error =
4.458895304383517e-05 epoch = 156 RMS
Error = 4.581503455710884e-05 epoch = 157
RMS Error = 3.5506424755293975e-05 epoch
= 158 RMS Error = 3.496237540404982e-05
epoch = 159 RMS Error =
3.287644381675574e-05 epoch = 160 RMS
Error = 2.8091049147891424e-05 epoch = 161
RMS Error = 2.5880939208598246e-05 epoch
= 162 RMS Error = 2.2919817738225087e-05
epoch = 163 RMS Error =
2.1142834970792857e-05 epoch = 164 RMS
Error = 1.9503917936346664e-05 epoch = 165
RMS Error = 1.8695389461958275e-05 epoch
= 166 RMS Error = 1.6660212708568678e-05
epoch = 167 RMS Error =
1.582339600722714e-05 epoch = 168 RMS
Error = 1.6218553296525844e-05 epoch = 169
RMS Error = 1.2446790077869108e-05 epoch
= 170 RMS Error = 1.1364488841747833e-05
epoch = 171 RMS Error =
1.1492799291221317e-05 epoch = 172 RMS
Error = 1.1935239845489047e-05 epoch = 173
RMS Error = 9.8945275937417e-06 epoch =
174 RMS Error = 1.034526737443712e-05
epoch = 175 RMS Error =
1.0941352084405505e-05 epoch = 176 RMS
Error = 8.64019424588387e-06 epoch = 177
RMS Error = 6.948345561870279e-06 epoch =
178 RMS Error = 6.841000724835082e-06

epoch = 179 RMS Error = 7.498689427415963e-06 epoch = 180 RMS Error = 7.537188714500655e-06 epoch = 181 RMS Error = 5.24014087532078e-06 epoch = 182 RMS Error = 4.5932620447212635e-06 epoch = 183 RMS Error = 4.247745851030866e-06 epoch = 184 RMS Error = 4.1552714340205e-06 epoch = 185 RMS Error = 4.222795805050674e-06 epoch = 186 RMS Error = 4.3907358630242534e-06 epoch = 187 RMS Error = 3.3014402308858223e-06 epoch = 188 RMS Error = 3.307976669902875e-06 epoch = 189 RMS Error = 3.487729575969274e-06 epoch = 190 RMS Error = 3.521219273796291e-06 epoch = 191 RMS Error = 3.6528551948410966e-06 epoch = 192 RMS Error = 3.765133447115511e-06 epoch = 193 RMS Error = 3.8074467357187595e-06 epoch = 194 RMS Error = 2.908648600092539e-06 epoch = 195 RMS Error = 2.4799267073853265e-06 epoch = 196 RMS Error = 2.5555389700947974e-06 epoch = 197 RMS Error = 2.3252854109401005e-06 epoch = 198 RMS Error = 2.2771751916395466e-06 epoch = 199 RMS Error = 2.105442499550845e-06 pat = 1 actual = 1 neural model = 0.9999970001299875 pat = 2 actual = 1 neural model = 0.9999996793968098 pat = 3 actual = -1 neural model = -0.9999996101382688 pat = 4 actual = -1 neural model = -0.9999970883760874
>>>

Practical No. 5

A. Write a program for Hopfield Network.

Given Pattern

[1,0,1,0] AND [0,1,0,1]

Given weighted vector

wt1 {0,-3,3,-3} wt2{-
3,0,-3,3} wt3 {3,-3,0,-
3} wt4 {-3,3,-3,0}

Solution :

Save HOP.H file in INCLUDE folder in C:\TurboC3\Include

HOP.H

```
#include <stdio.h>
#include
<iostream.h>
#include <math.h>
class neuron
{ protected:
    int activation;
friend class network;
public:     int
weightv[4];
neuron() {};
neuron(int *j) ;     int
act(int, int*);
}; class
network
{ public:     neuron  nrn[4];
int output[4];     int
threshld(int) ;     void
activation(int j[4]);
network(int*,int*,int*,int*);
};
```

________________________header file HOP.H ends here________________

Main program (hopnet.cpp)

```
#include "hop.h" #include<conio.h>
neuron::neuron(int *j)
{
int i;
for(i=0;i<4;i++)
    {
    weightv[i]= *(j+i);
```

```
int neuron::act(int m, int *x)
{
int i; int
a=0;
for(i=0;i<m;i++)
    {
    a += x[i]*weightv[i];
    }
return a; }
int network::threshld(int k)
{
if(k>=0)
    return (1);
else
return (0); }
network::network(int a[4],int b[4],int c[4],int d[4])
{ nrn[0] =
neuron(a) ; nrn[1] =
neuron(b) ; nrn[2] =
neuron(c) ; nrn[3] =
neuron(d) ;
}

void network::activation(int *patrn)
{
int i,j;
for(i=0;i<4;i++)
    {
    for(j=0;j<4;j++)
        {
        cout<<"\n nrn["<<i<<"].weightv["<<j<<"] is "
            <<nrn[i].weightv[j];
        }
    nrn[i].activation = nrn[i].act(4,patrn);
cout<<"\nactivation is "<<nrn[i].activation;
output[i]=threshld(nrn[i].activation);
    cout<<"\noutput value is  "<<output[i]<<"\n";
    } } void main () { int
patrn1[]= {1,0,1,0},i; int
wt1[]= {0,-3,3,-3}; int
wt2[]= {-3,0,-3,3}; int
```

```
wt3[]= {3,-3,0,-3}; int
wt4[]= {-3,3,-3,0};
cout<<"\nTHIS PROGRAM IS FOR A HOPFIELD NETWORK WITH A SINGLE LAYER
OF";
cout<<"\n4 FULLY INTERCONNECTED NEURONS. THE NETWORK SHOULD
RECALL THE"; cout<<"\nPATTERNS 1010 AND 0101
CORRECTLY.\n";
//create the network by calling its constructor.
// the constructor calls neuron constructor as many times as the number of //
neurons in the network.
network h1(wt1,wt2,wt3,wt4);
//present a pattern to the network and get the activations of the neurons
h1.activation(patrn1);
//check if the pattern given is correctly recalled and give message
for(i=0;i<4;i++)
    {
    if (h1.output[i] == patrn1[i])
        cout<<"\n pattern= "<<patrn1[i]<<
        "  output = "<<h1.output[i]<<"  component matches";
else
        cout<<"\n pattern= "<<patrn1[i]<<
        "  output = "<<h1.output[i]<<
        "  discrepancy occurred";
    }
cout<<"\n\n"; int
patrn2[]= {0,1,0,1};
h1.activation(patrn2);
for(i=0;i<4;i++)
    {
    if (h1.output[i] == patrn2[i])
        cout<<"\n pattern= "<<patrn2[i]<<
        "  output = "<<h1.output[i]<<"  component matches";
else
        cout<<"\n pattern= "<<patrn2[i]<<
        "  output = "<<h1.output[i]<<
        "  discrepancy occurred";
     }
getch();
}
```

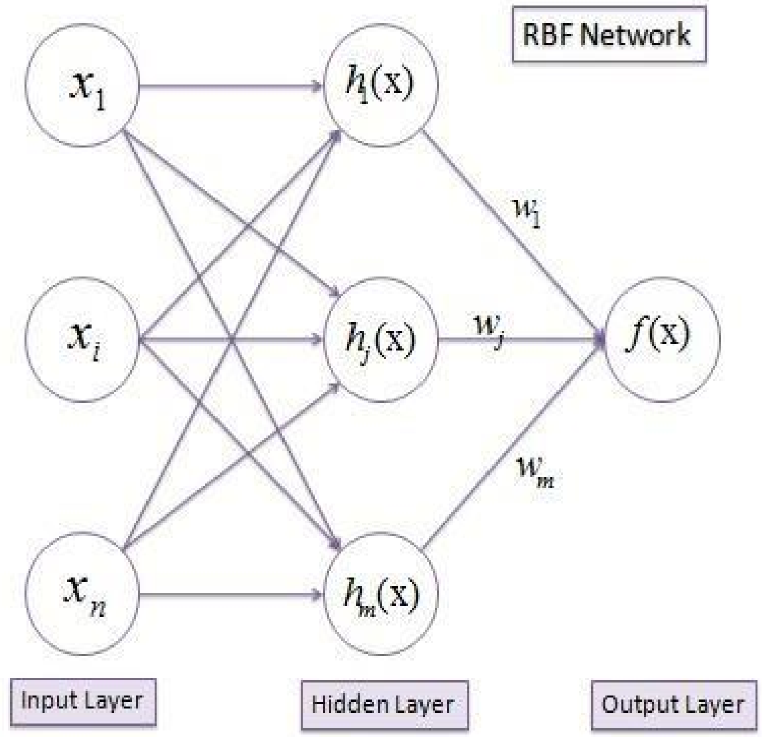
Output:

```
 nrn[1].weightv[0] is -3
 nrn[1].weightv[1] is 0
 nrn[1].weightv[2] is -3
 nrn[1].weightv[3] is 3
activation is 3
output value is  1

 nrn[2].weightv[0] is 3
 nrn[2].weightv[1] is -3
 nrn[2].weightv[2] is 0
 nrn[2].weightv[3] is -3
activation is -6
output value is  0
 nrn[3].weightv[0] is -3
 nrn[3].weightv[1] is 3
 nrn[3].weightv[2] is -3
 nrn[3].weightv[3] is 0
activation is 3
output value is  1

 pattern= 0  output = 0  component matches
 pattern= 1  output = 1  component matches
 pattern= 0  output = 0  component matches
 pattern= 1  output = 1  component matches
```

B. Write a program for Radial Basis function

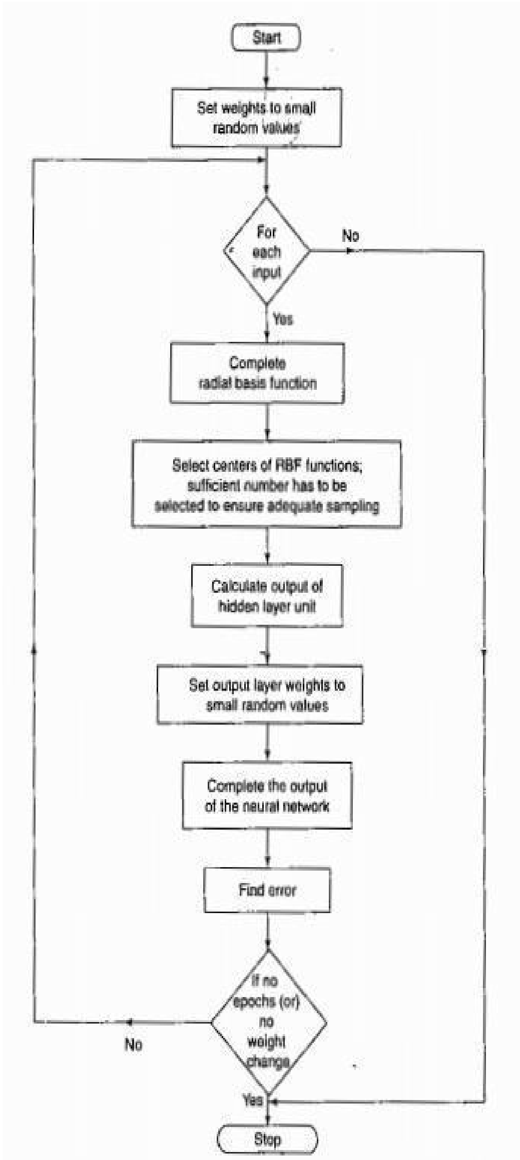


$$f(\mathrm{x}) = \sum_{j=1}^{m} w_j h_j(\mathrm{x})$$

$$h(x) = \exp\left(-\frac{(x-c)^2}{r^2} \right)$$

h(x) is the Gaussian activation function with the parameters r (the radius or standard deviation) and c (the center or average taken from the input space) defined separately at each RBF unit. The learning process is based on adjusting the parameters of the network to reproduce a set of input-output patterns. There are three types of parameters; the weight w between the hidden nodes and the output nodes, the center c of each neuron of the hidden layer and the unit width r.

Algorithm



One-dimensional dataset as an illustration of the gaussian influence:

```
rbf.gauss <- function(gamma=1.0) {

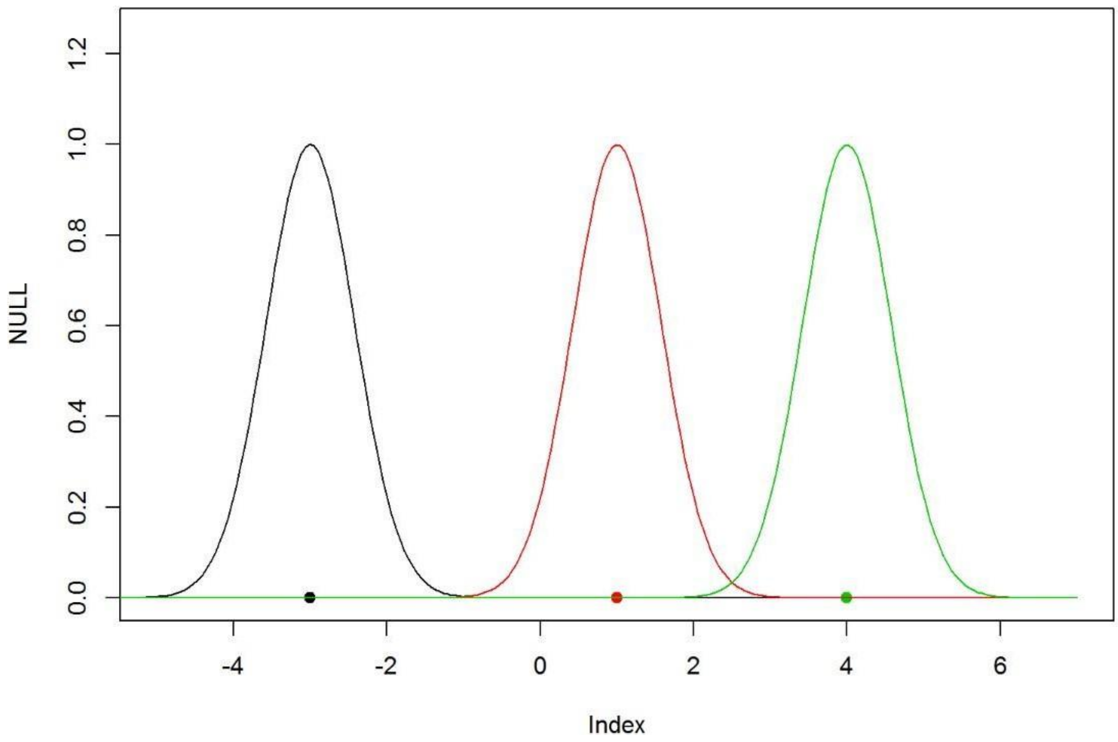
  function(x) {
    exp(-gamma * norm(as.matrix(x),"F")^2 )
  }
}

D <- matrix(c(-3,1,4), ncol=1) # 3 datapoints
N <- length(D[,1])

xlim  <- c(-5,7)
```

```
plot(NULL,xlim=xlim,ylim=c(0,1.25),type="n")
points(D,rep(0,length(D)),col=1:N,pch=19) x.coord
= seq(-7,7,length=250)
gamma <- 1.5
for (i in 1:N) {
  points(x.coord, lapply(x.coord - D[i,], rbf.gauss(gamma)), type="l", col=i)
}
```

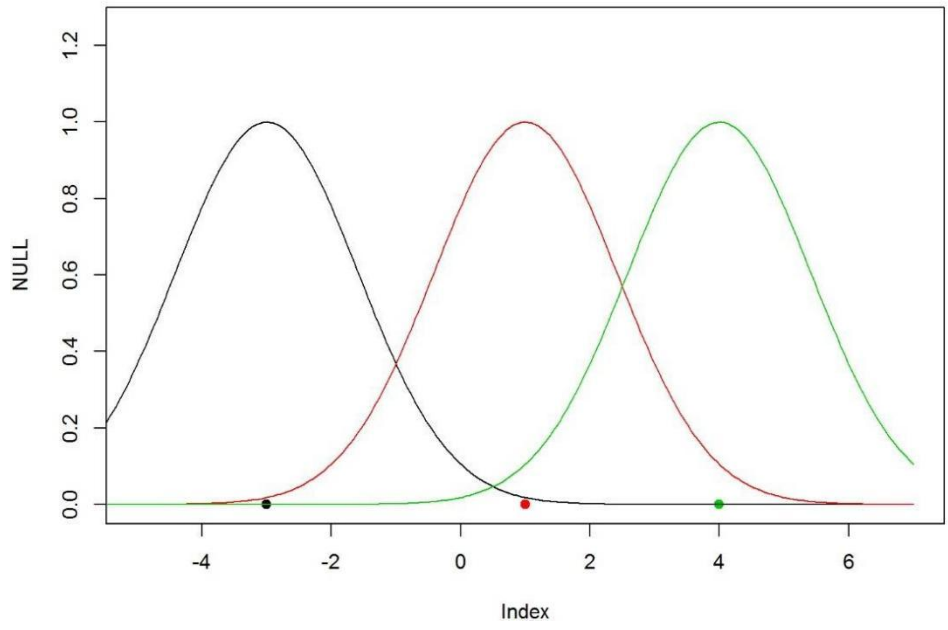
Output



The value of gamma controls how far or how little the influnce of each datapoint is felt:

```
plot(NULL,xlim=xlim,ylim=c(0,1.25),type="n")
points(D,rep(0,length(D)),col=1:N,pch=19)
x.coord = seq(-7,7,length=250)
gamma <- 0.25 for
(i in 1:N) {
  points(x.coord, lapply(x.coord - D[i,], rbf.gauss(gamma)), type="l", col=i) }
```

Output



Practical 6

A. Implementation of Kohonen Self Organising Map

A self-organizing map (SOM) is a bit hard to describe. Briefly, a SOM is a data structure that allows you to investigate the structure of a set of data. If you have data without class labels, a SOM can indicate how many classes there are in the data. If you have data with class labels, a SOM can be used for dimensionality reduction so the data can be graphed, where the resulting graph indicates how similar different classes are.

The example begins by creating a 30 x 30 SOM for the well-known Fisher's Iris dataset. The SOM is a data structure in memory. The demo uses the SOM to create what's called a U-Matrix, shown in Figure 1. In a U-Matrix, black cells indicate data items that are similar to each other and white cells indicate borders between groups of similar items. If you squint at the figure you can see that there appears to be three different areas of similar items, suggesting the data has three classes (which it does). An SOM can be used to reduce the number of dimensions in a dataset down to two, so the data can be graphed. The image in Figure 2 suggests that the items of class 0 (brown) are most different from items of class 2 (blue), and that items of class 1 (green) are somewhat similar to items of class 0 and class 2.

Execution of Program:

Step 1 : Save Data file and code file in same folder.

Step 2 : Execute code file **som_iris.py** in IDE python

Step 3 : Data will be start loading in to main memory

Step 4 : It will start building 30 X 30 U-matrix for given data set.

Step 5 : SOM can be used to reduce dimensionality so the data can be displayed as a two-dimensional graph in Figure 1.

Step 6 : Close Figure 1 then it will upload Figure 2.

Python Code som_iris.py :

```
import numpy as np
import matplotlib.pyplot as plt
# note: if this fails, try >pip uninstall matplotlib
# and then >pip install matplotlib

def closest_node(data, t, map, m_rows, m_cols):
# (row,col) of map node closest to data[t]
result = (0,0)   small_dist = 1.0e20   for i in
range(m_rows):     for j in range(m_cols):       ed
= euc_dist(map[i][j], data[t])       if ed <
small_dist:         small_dist = ed         result = (i,
j)
  return result

def euc_dist(v1, v2):   return
np.linalg.norm(v1 - v2)  def
manhattan_dist(r1, c1, r2, c2):
return np.abs(r1-r2) +
np.abs(c1-c2)

def most_common(lst, n):
```

```
 # lst is a list of values 0 . . n   if len(lst)
== 0: return -1   counts =
np.zeros(shape=n, dtype=np.int)   for i in
range(len(lst)):      counts[lst[i]] += 1
return np.argmax(counts)

# ==================================================================

def main():   # 0.
get started
np.random.seed(1)
Dim = 4
  Rows = 30; Cols = 30
  RangeMax = Rows + Cols
  LearnMax = 0.5
  StepsMax = 5000

  # 1. load data
  print("\nLoading Iris data into memory \n")
  data_file = ".\\iris_data_012.txt"
  data_x = np.loadtxt(data_file, delimiter=",", usecols=range(0,4),
dtype=np.float64)
  data_y = np.loadtxt(data_file, delimiter=",", usecols=[4],
dtype=np.int)
  # option: normalize data

  # 2. construct the SOM   print("Constructing a 30x30
SOM from the iris data")   map =
np.random.random_sample(size=(Rows,Cols,Dim))   for s
in range(StepsMax):
    if s % (StepsMax/10) == 0: print("step = ", str(s))
pct_left = 1.0 - ((s * 1.0) / StepsMax)      curr_range
= (int)(pct_left * RangeMax)      curr_rate = pct_left
* LearnMax

    t = np.random.randint(len(data_x))
    (bmu_row, bmu_col) = closest_node(data_x, t, map, Rows, Cols)
for i in range(Rows):        for j in range(Cols):
        if manhattan_dist(bmu_row, bmu_col, i, j) < curr_range:
          map[i][j] = map[i][j] + curr_rate * \
(data_x[t] - map[i][j])
  print("SOM construction complete \n")

  # 3. construct U-Matrix
  print("Constructing U-Matrix from SOM")  u_matrix =
np.zeros(shape=(Rows,Cols), dtype=np.float64)   for i in
range(Rows):     for j in range(Cols):
      v = map[i][j]  # a vector
      sum_dists = 0.0; ct = 0
```

```
    if i-1 >= 0:    # above
      sum_dists += euc_dist(v, map[i-1][j]); ct += 1
if i+1 <= Rows-1:  # below
      sum_dists += euc_dist(v, map[i+1][j]); ct += 1
if j-1 >= 0:  # left
      sum_dists += euc_dist(v, map[i][j-1]); ct += 1
if j+1 <= Cols-1:  # right
      sum_dists += euc_dist(v, map[i][j+1]); ct += 1

    u_matrix[i][j] = sum_dists / ct
  print("U-Matrix constructed \n")

  # display U-Matrix
  plt.imshow(u_matrix, cmap='gray')  # black = close = clusters
plt.show()

  # 4. because the data has labels, another possible visualization:
  # associate each data label with a map node
print("Associating each data label to one map node ")
mapping = np.empty(shape=(Rows,Cols), dtype=object)
for i in range(Rows):     for j in range(Cols):
mapping[i][j] = []

  for t in range(len(data_x)):
    (m_row, m_col) = closest_node(data_x, t, map, Rows, Cols)
mapping[m_row][m_col].append(data_y[t])

  label_map = np.zeros(shape=(Rows,Cols), dtype=np.int)
for i in range(Rows):     for j in range(Cols):
    label_map[i][j] = most_common(mapping[i][j], 3)

  plt.imshow(label_map, cmap=plt.cm.get_cmap('terrain_r', 4))
plt.colorbar()
  plt.show()

# ==================================================================

if _name_=="_main_":
main()
```

Output :

Loading Data set in to memory

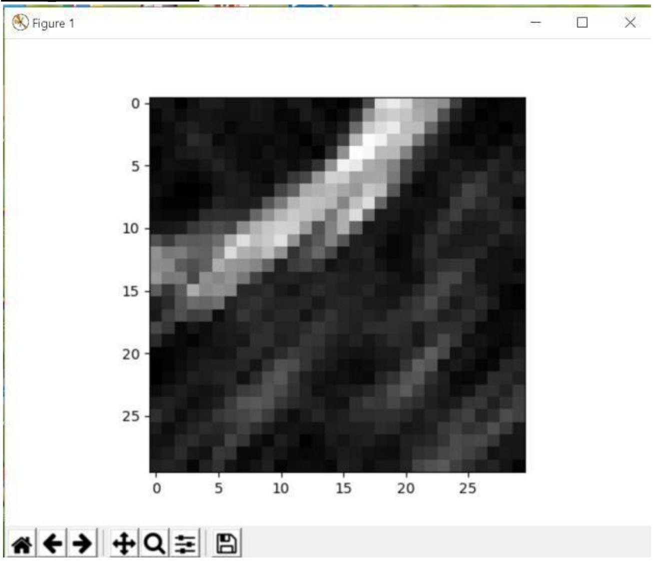
```
Loading Iris data into memory

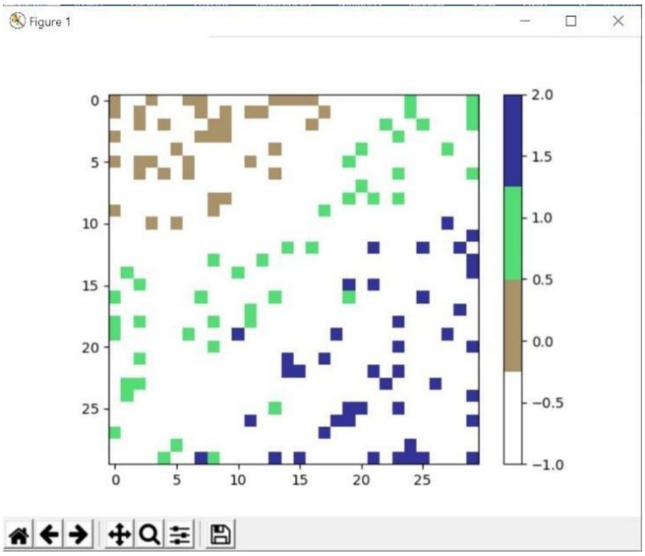
Constructing a 30x30 SOM from the iris data
step =  0
step =  500
step =  1000
step =  1500
step =  2000
step =  2500
step =  3000
step =  3500
step =  4000
step =  4500
SOM construction complete

Constructing U-Matrix from SOM
U-Matrix constructed

Associating each data label to one map node
```

Map Created :





B. Implementation of Adaptive resonance theory

```
from  __future__import  print_function

from  __future__import  division  import

numpy as np



class ART:

   ''' ART class

   Usage example:

   ---------

   # Create a ART network with input of size 5 and 20 internal units

   >>> network = ART(5,10,0.5)

   '''

   def __init__(self, n=5, m=10, rho=.5):

      '''

      Create network with specified shape

      Parameters:

      -------        n

: int            Size of

input        m : int

         Maximum number of internal units

      rho : float

         Vigilance parameter

      '''

      # Comparison layer        self.F1 =

np.ones(n)        # Recognition layer

self.F2 = np.ones(m)        # Feed-

forward weights        self.Wf =

np.random.random((m,n))        # Feed-

back weights        self.Wb =

np.random.random((n,m))
```

```
    # Vigilance
self.rho = rho
    # Number of active units in F2
    self.active = 0
def learn(self, X):
    ''' Learn X '''
    # Compute F2 output and sort them (I)
self.F2[...] = np.dot(self.Wf, X)
    I = np.argsort(self.F2[:self.active].ravel())[::-1]
    for i in I:
      # Check if nearest memory is above the vigilance level
d = (self.Wb[:,i]*X).sum()/X.sum()        if d >= self.rho:
# Learn data           self.Wb[:,i] *= X           self.Wf[i,:] =
self.Wb[:,i]/(0.5+self.Wb[:,i].sum())          return
self.Wb[:,i], i
    # No match found, increase the number of active units
# and make the newly active unit to learn data      if
self.active < self.F2.size:
      i = self.active        self.Wb[:,i] *= X
self.Wf[i,:] = self.Wb[:,i]/(0.5+self.Wb[:,i].sum())
self.active += 1        return self.Wb[:,i], i
    return None,None
# -------------------------------------------------------
if __name___== '__main__':
np.random.seed(1)
  # Example 1 : very simple data
  # -------------------------------------------------------
  network = ART( 5, 10, rho=0.5)
data = ["  O ",        "  O O",
      "   O",
      "  O O",
      "   O",
```

```
        "  O O",
        "    O",
        " OO O",
        " OO  ",
        " OO O",
        " OO  ",
        "OOO  ",
        "OO   ",
        "O    ",
        "OO   ",
        "OOO  ",
        "OOOO ",
        "OOOOO",
        "O    ",
        " O   ",
        "  O  ",
        "   O ",
        "    O",
        "  O O",
        " OO O",
        " OO  ",
        "OOO  ",
        "OO   ",
        "OOOO ",
        "OOOOO"]
  X = np.zeros(len(data[0]))     for i in
range(len(data)):         for j in
range(len(data[i])):             X[j] =
(data[i][j] == 'O')        Z, k =
network.learn(X)
print("|%s|"%data[i],"-> class", k)
  # Example 2 : Learning letters
```

```
# ------------------------------------------------
def letter_to_array(letter):        '''
Convert a letter to a numpy array '''
shape = len(letter), len(letter[0])        Z =
np.zeros(shape, dtype=int)        for row in
range(Z.shape[0]):            for column in
range(Z.shape[1]):                if
letter[row][column] == '#':
Z[row][column] = 1        return Z     def
print_letter(Z):
    ''' Print an array as if it was a letter'''
for row in range(Z.shape[0]):            for
col in range(Z.shape[1]):
        if Z[row,col]:
            print( '#', end="" )
else:                print( ' ',
end="" )            print( )


A = letter_to_array( [' #### ',
                    '#    #',
                    '#    #',
                    '######',
                    '#    #',
                    '#    #',
                    '#    #'] )
B = letter_to_array( ['##### ',
                    '#    #',
                    '#    #',
                    '##### ',
                    '#    #',
                    '#    #',
                    '##### '] )
```

```
C = letter_to_array( [' #### ',
                      '#    #',
                      '#     ',
                      '#     ',
                      '#     ',
                      '#    #',
                      ' #### '] )
D = letter_to_array( ['##### ',
                      '#    #',
                      '#    #',
                      '#    #',
                      '#    #',
                      '#    #',
                      '##### '] )
E  = letter_to_array( ['######',
                      '#     ',
                      '#     ',
                      '####  ',
                      '#     ',
                      '#     ',
                      '######'] )
F  = letter_to_array( ['######',
                      '#     ',
                      '#     ',
                      '####  ',
                      '#     ',
                      '#     ',
                      '#     '] )

   samples = [A,B,C,D,E,F]     network
= ART( 6*7, 10, rho=0.15 )
```

```
for i in range(len(samples)):        Z, k =
network.learn(samples[i].ravel())
print("%c"%(ord('A')+i),"-> class",k)
print_letter(Z.reshape(7,6))
```

Output

```
|   O | -> class 0
|  O O| -> class 1
|    O| -> class 1
|  O O| -> class 2
|    O| -> class 1
|  O O| -> class 3
|    O| -> class 1
| OO O| -> class 4
| OO  | -> class 5
| OO O| -> class 6
| OO  | -> class 6
|OOO  | -> class 6
|OO   | -> class 7
|O    | -> class 8
|OO   | -> class 9
|OOO  | -> class 6
|OOOO | -> class None
|OOOOO| -> class None
|O    | -> class 8
| O   | -> class 5
|  O  | -> class 6
|   O | -> class 0
|    O| -> class 1
|  O O| -> class 3
| OO O| -> class None
| OO  | -> class None
```

```
|OOO  | -> class None

|OO   | -> class 9

|OOOO | -> class None

|OOOOO| -> class None

A -> class 0

 ####

#    #

#    #

######

#    #

#    #

#    #

B -> class 0

 ####

#    #

#    #

#####

#    #

#    #

#

C -> class 0

 ####

#    #
#

#

#

#    #


D -> class 0

 ####

#    #

#
```

```
#
#
#   #

E -> class 0
 ####
#
#
#
#
#
F  -> class 0
 ####
#
#
#
#
#
```

Example 2 : Testing ART by creating array dataset import numpy as np # compute sigmoid nonlinearity def sigmoid(x):   output = 1/(1+np.exp(-x))   return output

```
# convert output of sigmoid function to its derivative
def sigmoid_output_to_derivative(output):
   return output*(1-output) #
input dataset
X = np.array([  [0,1],
             [0,1],
             [1,0],
             [1,0] ])
# output dataset             y
= np.array([[0,0,1,1]]).T
```

```
# seed random numbers to make calculation

# deterministic (just a good practice)

np.random.seed(1)

# initialize weights randomly with mean 0

synapse_0 = 2*np.random.random((2,1)) -

1 for iter in range(10000):     # forward

propagation     layer_0 = X

   layer_1 = sigmoid(np.dot(layer_0,synapse_0))

                              # how much did we miss?

                              layer_1_error = layer_1 -

y

   # multiply how much we missed by the

# slope of the sigmoid at the values in l1

   layer_1_delta = layer_1_error * sigmoid_output_to_derivative(layer_1)

synapse_0_derivative = np.dot(layer_0.T,layer_1_delta)

   # update weights
   synapse_0 -=

synapse_0_derivative print ("Output

After Training:") print (layer_1)
```

Output

```
Output After Training:

[[0.00505119]

 [0.00505119]

 [0.99494905]

 [0.99494905]]
```

---------------------------X-------------------------

Example 3: By providing data pattern

```
import math import sys

N = 4 # Number of components in an input vector.

M = 3 # Max number of clusters to be formed.

VIGILANCE = 0.4

PATTERNS = 7
```

```
TRAINING_PATTERNS = 4 # Use this many for training, the rest are for tests.

PATTERN_ARRAY = [[1, 1, 0, 0],

            [0, 0, 0, 1],

            [1, 0, 0, 0],

            [0, 0, 1, 1],

            [0, 1, 0, 0],

            [0, 0, 1, 0],

            [1, 0, 1, 0]]

class ART1_Example1:

  def _init_(self, inputSize, numClusters, vigilance, numPatterns, numTraining, patternArray):

    self.mInputSize = inputSize

self.mNumClusters = numClusters

self.mVigilance = vigilance

self.mNumPatterns = numPatterns

self.mNumTraining = numTraining

self.mPatterns = patternArray          self.bw = []

# Bottom-up weights.   self.tw = [] # Top-down

weights.

    self.f1a = [] # Input layer.

self.f1b = [] # Interface layer.

    self.f2 = []     return     def

initialize_arrays(self):     # Initialize

bottom-up weight matrix.

sys.stdout.write("Weights initialized to:")

for i in range(self.mNumClusters):

      self.bw.append([0.0] * self.mInputSize)

for j in range(self.mInputSize):

        self.bw[i][j] = 1.0 / (1.0 +

self.mInputSize)

sys.stdout.write(str(self.bw[i][j]) + ", ")

sys.stdout.write("\n")

sys.stdout.write("\n")          # Initialize top-
```

```
down weight matrix.         for i in
range(self.mNumClusters):
        self.tw.append([0.0] * self.mInputSize)
for j in range(self.mInputSize):
            self.tw[i][j] = 1.0
            sys.stdout.write(str(self.tw[i][j]) + ",
")                    sys.stdout.write("\n")
sys.stdout.write("\n")              self.f1a = [0.0] *
self.mInputSize         self.f1b = [0.0] *
self.mInputSize         self.f2 = [0.0] *
self.mNumClusters
     return         def
get_vector_sum(self, nodeArray):
     total   =   0    length   =
len(nodeArray)     for   i    in
range(length):

        total += nodeArray[i]
return total        def
get_maximum(self, nodeArray):
     maximum = 0;
foundNewMaximum = False;
length = len(nodeArray)
done = False              while not
done:
        foundNewMaximum = False           for i in
range(length):              if i != maximum:
if nodeArray[i] > nodeArray[maximum]:
maximum = i
                foundNewMaximum = True
if foundNewMaximum == False:
```

```
done = True return maximum def
test_for_reset(self, activationSum, inputSum, f2Max):
    doReset = False if(float(activationSum) /
float(inputSum) >= self.mVigilance): doReset = False #
Candidate is accepted. else: self.f2[f2Max] = -1.0 #
Inhibit. doReset = True # Candidate is rejected.
    return doReset def update_weights(self,
activationSum, f2Max):
    # Update bw(f2Max) for i
in range(self.mInputSize):
        self.bw[f2Max][i] = (2.0 * float(self.f1b[i])) / (1.0 + float(activationSum))
for i in range(self.mNumClusters): for j in range(self.mInputSize):
            sys.stdout.write(str(self.bw[i][j]) + ",
") sys.stdout.write("\n")
sys.stdout.write("\n") # Update
tw(f2Max) for i in range(self.mInputSize):
        self.tw[f2Max][i] = self.f1b[i]
for i in range(self.mNumClusters):
for j in range(self.mInputSize):
            sys.stdout.write(str(self.tw[i][j]) + ",
") sys.stdout.write("\n")
sys.stdout.write("\n") return def
ART1(self): inputSum = 0
activationSum = 0 f2Max = 0 reset =
True
    sys.stdout.write("Begin ART1:\n")
for k in range(self.mNumPatterns):
        sys.stdout.write("Vector: " + str(k) + "\n\n")
        # Initialize f2 layer activations to 0.0
for i in range(self.mNumClusters):
self.f2[i] = 0.0
```

```
        # Input pattern() to f1 layer.

for i in range(self.mInputSize):

          self.f1a[i] = self.mPatterns[k][i]

# Compute sum of input pattern.

        inputSum = self.get_vector_sum(self.f1a)

        sys.stdout.write("InputSum (si) = " + str(inputSum) + "\n\n")

# Compute activations for each node in the f1 layer.

        # Send input signal from f1a to the fF1b layer.

for i in range(self.mInputSize):

          self.f1b[i] = self.f1a[i]

        # Compute net input for each node in the f2

layer.          for i in range(self.mNumClusters):

for j in range(self.mInputSize):

            self.f2[i] += self.bw[i][j] *

float(self.f1a[j])

sys.stdout.write(str(self.f2[i]) + ", ")

sys.stdout.write("\n")          sys.stdout.write("\n")

reset = True          while reset == True:

          # Determine the largest value of the f2 nodes.

f2Max = self.get_maximum(self.f2)

          # Recompute the f1a to f1b activations (perform AND function)

for i in range(self.mInputSize):

            sys.stdout.write(str(self.f1b[i]) + " * " + str(self.tw[f2Max][i]) + " = " + str(self.f1b[i] *
self.tw[f2Max][i]) + "\n")

            self.f1b[i] = self.f1a[i] *  math.floor(self.tw[f2Max][i])

                        # Compute sum of input pattern.

                        activationSum =

self.get_vector_sum(self.f1b)

          sys.stdout.write("ActivationSum (x(i)) = " + str(activationSum) + "\n\n")

reset = self.test_for_reset(activationSum, inputSum, f2Max)                    # Only

use number of TRAINING_PATTERNS for training, the rest are tests.

        if k < self.mNumTraining:
```

```
self.update_weights(activationSum, f2Max)

sys.stdout.write("Vector #" + str(k) + " belongs to cluster #" + str(f2Max) + "\n\n")

return      def print_results(self):

    sys.stdout.write("Final weight

values:\n")          for i in

range(self.mNumClusters):          for j in

range(self.mInputSize):

        sys.stdout.write(str(self.bw[i][j]) + ", ")

sys.stdout.write("\n")

    sys.stdout.write("\n")

for i in range(self.mNumClusters):

for j in range(self.mInputSize):

        sys.stdout.write(str(self.tw[i][j]) + ",

")          sys.stdout.write("\n")

sys.stdout.write("\n")      return if _name___

== '__main__':

  art1 = ART1_Example1(N, M, VIGILANCE, PATTERNS, TRAINING_PATTERNS,
PATTERN_ARRAY)

  art1.initialize_arrays()

art1.ART1()

art1.print_results()
```

Output

```
Python 3.7.4 (tags/v3.7.4:e09359112e, Jul  8 2019, 19:29:22) [MSC v.1916 32 bit (Intel)] on
win32 Type "help", "copyright", "credits" or "license()" for more information. >>>
== RESTART: E:/SPDT/MSCSem1/Soft Computing/MSC/MSC/Practical6/Pract6B_3.py ==
Weights initialized to:0.2, 0.2, 0.2, 0.2,
0.2, 0.2, 0.2, 0.2,  0.2,
0.2, 0.2, 0.2,  1.0,
1.0, 1.0, 1.0,  1.0,
1.0, 1.0, 1.0,
1.0, 1.0, 1.0, 1.0,
Begin ART1:
Vector: 0
InputSum (si) = 2
0.2, 0.4, 0.4, 0.4,  0.2,
0.4, 0.4, 0.4,
```

0.2, 0.4, 0.4, 0.4,
1 * 1.0 = 1.0
1 * 1.0 = 1.0
0 * 1.0 = 0.0
0 * 1.0 = 0.0
ActivationSum (x(i)) = 2
0.6666666666666666, 0.6666666666666666, 0.0, 0.0,
0.2, 0.2, 0.2, 0.2,
0.2, 0.2, 0.2, 0.2,
1, 1, 0, 0,
1.0, 1.0, 1.0, 1.0,
1.0, 1.0, 1.0, 1.0,
Vector #0 belongs to cluster #0
Vector: 1
InputSum (si) = 1
0.0, 0.0, 0.0, 0.0, 0.0,
0.0, 0.0, 0.2,
0.0, 0.0, 0.0, 0.2,
0 * 1.0 = 0.0
0 * 1.0 = 0.0
0 * 1.0 = 0.0
1 * 1.0 = 1.0
ActivationSum (x(i)) = 1
0.6666666666666666, 0.6666666666666666, 0.0, 0.0,
0.0, 0.0, 0.0, 1.0,
0.2, 0.2, 0.2, 0.2,
1, 1, 0, 0,
0, 0, 0, 1,
1.0, 1.0, 1.0, 1.0,
Vector #1 belongs to cluster #1
Vector: 2
InputSum (si) = 1
0.6666666666666666, 0.6666666666666666, 0.6666666666666666, 0.6666666666666666,
0.0, 0.0, 0.0, 0.0,
0.2, 0.2, 0.2, 0.2,
1 * 1 = 1
0 * 1 = 0
0 * 0 = 0
0 * 0 = 0
ActivationSum (x(i)) = 1
1.0, 0.0, 0.0, 0.0, 0.0,
0.0, 0.0, 1.0,
0.2, 0.2, 0.2, 0.2,
1, 0, 0, 0,
0, 0, 0, 1,
1.0, 1.0, 1.0, 1.0,
Vector #2 belongs to cluster #0
Vector: 3

InputSum (si) = 2
0.0, 0.0, 0.0, 0.0, 0.0,
0.0, 0.0, 1.0,
0.0, 0.0, 0.2, 0.4,
0 * 0 = 0
0 * 0 = 0
1 * 0 = 0
1 * 1 = 1
ActivationSum (x(i)) = 1
1.0, 0.0, 0.0, 0.0, 0.0,
0.0, 0.0, 1.0,
0.2, 0.2, 0.2, 0.2,
1, 0, 0, 0,
0, 0, 0, 1,
1.0, 1.0, 1.0, 1.0,
Vector #3 belongs to cluster #1
Vector: 4

InputSum (si) = 1
0.0, 0.0, 0.0, 0.0, 0.0,
0.0, 0.0, 0.0,
0.0, 0.2, 0.2, 0.2,
0 * 1.0 = 0.0
1 * 1.0 = 1.0
0 * 1.0 = 0.0
0 * 1.0 = 0.0
ActivationSum (x(i)) = 1
Vector #4 belongs to cluster #2
Vector: 5
InputSum (si) = 1
0.0, 0.0, 0.0, 0.0, 0.0,
0.0, 0.0, 0.0,
0.0, 0.0, 0.2, 0.2,
0 * 1.0 = 0.0
0 * 1.0 = 0.0
1 * 1.0 = 1.0
0 * 1.0 = 0.0
ActivationSum (x(i)) = 1
Vector #5 belongs to cluster #2
Vector: 6
InputSum (si) = 2
1.0, 1.0, 1.0, 1.0, 0.0,
0.0, 0.0, 0.0,
0.2, 0.2, 0.4, 0.4,
1 * 1 = 1
0 * 0 = 0
1 * 0 = 0
0 * 0 = 0

ActivationSum (x(i)) = 1

Vector #6 belongs to cluster #0
Final weight values:
1.0, 0.0, 0.0, 0.0, 0.0,
0.0, 0.0, 1.0,
0.2, 0.2, 0.2, 0.2,
1, 0, 0, 0,
0, 0, 0, 1,
1.0, 1.0, 1.0, 1.0,

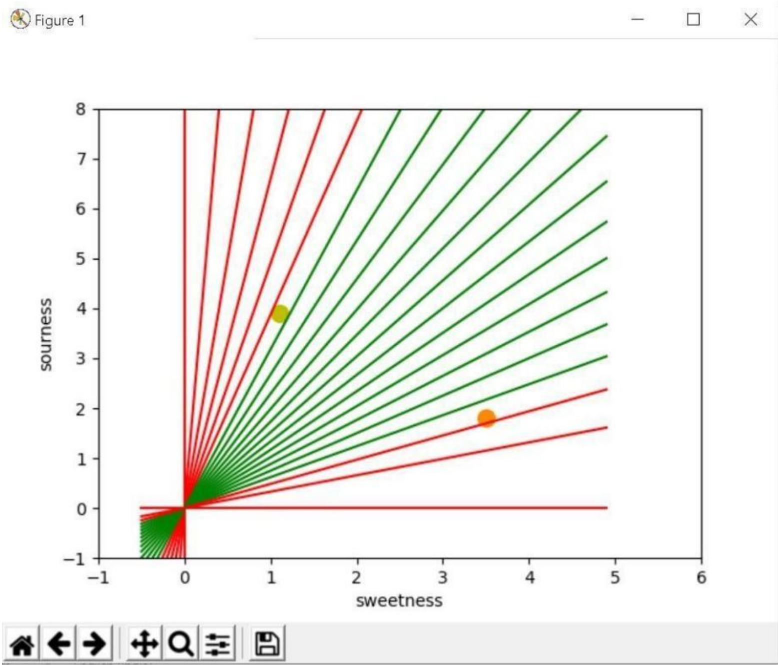
Practical 7 A.

Write a program for Linear separation.

Python Code :

```
import numpy as np import
matplotlib.pyplot as plt  def
create_distance_function(a, b, c):
""" 0 = ax + by + c """      def
distance(x, y):          """ returns tuple
(d, pos)             d is the distance
          If pos == -1 point is below the line,
          0 on the line and +1 if above the line
      """          nom = a * x + b * y + c          if
nom == 0:              pos = 0          elif (nom<0 and
b<0) or (nom>0 and b>0):
          pos = -1
else:
          pos = 1
      return (np.absolute(nom) / np.sqrt( a ** 2 + b ** 2),
pos)     return distance     points = [ (3.5, 1.8), (1.1, 3.9) ] fig,
ax = plt.subplots() ax.set_xlabel("sweetness")
ax.set_ylabel("sourness") ax.set_xlim([-1, 6]) ax.set_ylim([-
1, 8]) X = np.arange(-0.5, 5, 0.1) colors = ["r", ""] # for the
samples size = 10 for (index, (x, y)) in enumerate(points):
if index== 0:
      ax.plot(x, y, "o",
color="darkorange",
markersize=size)     else:
      ax.plot(x, y, "oy",
markersize=size) step = 0.05 for x
in np.arange(0, 1+step, step):
slope = np.tan(np.arccos(x))
   dist4line1 = create_distance_function(slope, -1, 0)
   #print("x: ", x, "slope: ", slope)
   Y = slope * X
results = []     for
point in points:
results.append(dist4l
ine1(*point))
   #print(slope, results)     if
(results[0][1] != results[1][1]):
ax.plot(X, Y, "g-")     else:
ax.plot(X, Y, "r-")
plt.show()
```

Output:



B. Write a program for Hopfield network model for associative memory.

Python Code :

```
import numpy as np import matplotlib.pyplot as plt  import tempfile import
argparse ##############################################
#
# Some patterns that we use for testing
#
##############################################
strings = [] strings.append(""" ..X..
.X.X.
X...X
.X.X.
..X..""")

strings.append("""
..X..
..X..
..X..
..X..
..X..""")
strings.append("""
.....
.....
XXXXX
.....
.....""")

strings.append("""
X....
.X...
..X..
```

```
....X""")
strings.append("""
....X
...X.
..X..
.X...
X....""")
##############################################
#
# Some utility functions
#
##############################################
#
# Convert a string as above into a
# 5 x 5 matrix # def
string_to_matrix(s):
    x = np.zeros(shape=(5,5),
dtype=float)     for i in range(len(s)):
row, col = i // 5, i % 5         x[row][col]
= -1 if s[i] == 'X' else 1     return x #
# and back # def
matrix_to_string(m):
    s = ""
    for i in range(5):         for j in
range(5):             s = s + ('X' if m[i][j]
< 0 else '')         s = s + chr(10)
return s class HopfieldNetwork:
    #
    # Initialize a Hopfield network with N
    # neurons
    #     def
__init__(self, N):
```

```
    self.N = N        self.W =
np.zeros((N,N))        self.s =
np.zeros((N,1))
  #
  # Apply the Hebbian learning rule. The argument is a matrix S
  # which contains one sample state per row
  #    def
train(self, S):
    self.W = np.matmul(S.transpose(), S)
  #
  # Run one simulation step
  #    def
runStep(self):
    i = np.random.randint(0,self.N)
a = np.matmul(self.W[i,:], self.s)
if a < 0:
      self.s[i] = -1
else:
      self.s[i] = 1
  #
  # Starting with a given state, execute the update rule
  # N times and return the resulting state
  #    def run(self, state,
steps):
    self.s = state
for i in range(steps):
self.runStep()
return self.s
##################################################
#
# Parse arguments
#
```

```
################################################# def
get_args():
  parser = argparse.ArgumentParser()   parser.add_argument("--
memories",
           type=int,
default=3,
           help="Number of patterns to learn")   parser.add_argument("--
epochs",
           type=int,
default=6,          help="Number
of epochs")   parser.add_argument("--
iterations",
           type=int,
default=20,
           help="Number of iterations per epoch")          parser.add_argument("--
errors",
           type=int,
default=5,
           help="Number of error that we add to each sample")   parser.add_argument("--
save",
           type=int,
           default=0,
help="Save output")   return
parser.parse_args()
################################################
#
# Main
#
#################################################
#
# Read parameters
```

```
# args =
get_args()
#
# Number of epochs. After each
# epoch, we capture one image
# epochs =
args.epochs
#
# Number of iterations
# per epoch
#
iterations = args.iterations
#
# Number of bits that we flip in each sample
# errors =
args.errors
#
# Number of patterns that we try to memorize
#
memories = args.memories
#
# Init network
#
HN = HopfieldNetwork(5*5)
#
# Prepare sample data and train network
# M = [] for _ in
range(memories):
   M.append(string_to_matrix(strings[_].replace(chr(10), '')).reshape(1,5*5))
S = np.concatenate(M)
HN.train(S)
#
```

```
# Run the network and display results

#

fig = plt.figure()      for pic

in range(memories):

    state = (S[pic,:].reshape(25,1)).copy()

    #

    # Display original pattern

    #

    ax = fig.add_subplot(memories,epochs + 1,

1+pic*(epochs+1))      ax.set_xticks([],[])      ax.set_yticks([],[])

    ax.imshow(state.reshape(5,5), "binary_r")

    #

    # Flip a few bits

    #

    state = state.copy()

for i in range(errors):

        index = np.random.randint(0,25)

state[index][0] = state[index][0]*(-1)

    #

    # Run network and display the current state
    # at the beginning of each epoch

    #      for i in range(epochs):          ax =

fig.add_subplot(memories,epochs + 1, i+2+pic*(epochs+1))

ax.set_xticks([],[])          ax.set_yticks([],[])

        ax.imshow(state.reshape(5,5), "binary_r")

state = HN.run(state, iterations)

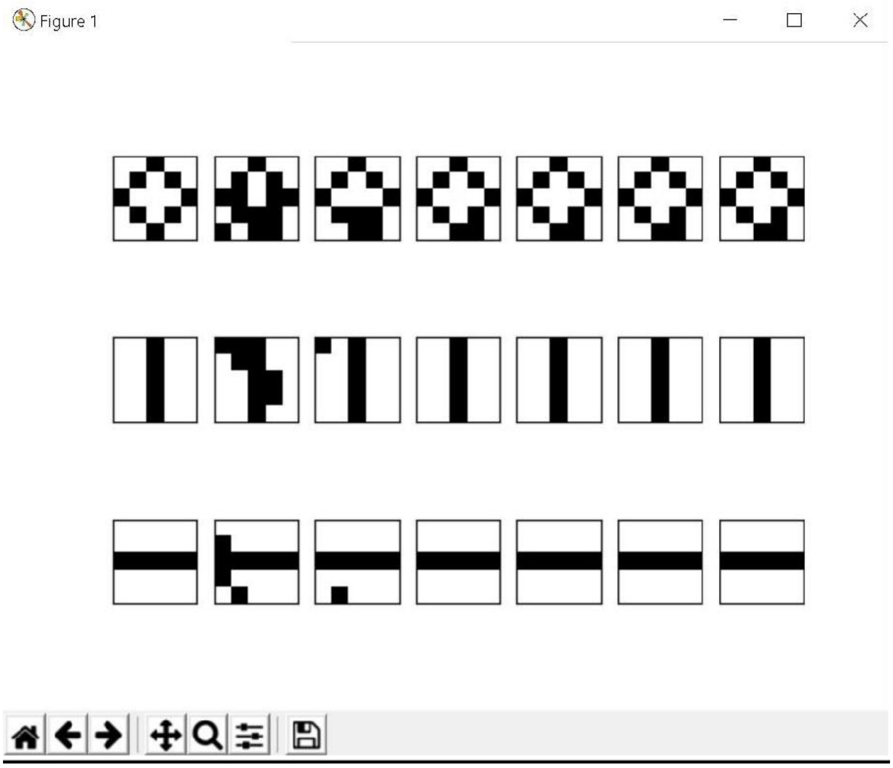

if 1 == args.save:

    outfile = tempfile.mktemp() +

"_Hopfield.png"      print("Using outfile ",

outfile)      plt.savefig(outfile) plt.show()
```

Output:



Practical 8

A. Membership and Identity Operators | in, not in,

Python Code

```
# Python program to illustrate
# Finding common member in
list  # using 'in' operator
list1=[1,2,3,4,5]  list2=[6,7,8,9]
for item in list1:   if item in list2:
        print("overlapping")           else:
 print("not overlapping")
```

Output not
overlapping

Python Code

```
# Python program to illustrate
# Finding common member in list
# without using 'in' operator

# Define a function() that takes two lists  def
overlapping(list1,list2):

 c=0  d=0  for
i in list1:
        c+=1
 for i in list2:
        d+=1  for i in range(0,c):
for j in range(0,d):
if(list1[i]==list2[j]):
                        return
1  return 0 list1=[1,2,3,4,5]
list2=[6,7,8,9]
if(overlapping(list1,list2)):
print("overlapping")   else:
print("not overlapping")
```

Output

not overlapping

Python Code:

```
# Python program to illustrate
# not 'in' operator  x = 24 y =
20
list = [10, 20, 30, 40, 50 ];

if ( x not in list ):
```

```
    print ("x is NOT present in given list")
else:    print ("x is present in given list")
if ( y in list
):
    print ("y is present in given list") else:
print ("y is NOT present in given list")
```

Output

x is NOT present in given list
y is present in given list

B. Membership and Identity Operators is, is not

Python Code

```
# Python program to illustrate the
use  # of 'is' identity operator  x = 5
if (type(x) is int):
        print ("true")  else:
          print ("false")
```

Output

true

Python Code

```
# Python program to illustrate
the  # use of 'is not' identity
operator  x = 5.2 if (type(x) is
not int):
        print ("true")  else:
          print ("false")
```

Output

true

Practical 9

A. Find ratios using fuzzy logic

Python Code:

```
# Python code showing all the ratios together,
# make sure you have installed fuzzywuzzy module

from fuzzywuzzy import fuzz
from fuzzywuzzy import process

s1 = "I love GeeksforGeeks" s2 = "I am loving GeeksforGeeks" print
("FuzzyWuzzy Ratio: ", fuzz.ratio(s1, s2)) print ("FuzzyWuzzy
PartialRatio: ", fuzz.partial_ratio(s1, s2)) print ("FuzzyWuzzy
TokenSortRatio: ", fuzz.token_sort_ratio(s1, s2)) print ("FuzzyWuzzy
TokenSetRatio: ", fuzz.token_set_ratio(s1, s2)) print ("FuzzyWuzzy
WRatio: ", fuzz.WRatio(s1, s2),'\n\n')

# for process library,  query
= 'geeks for geeks'
choices = ['geek for geek', 'geek geek', 'g. for geeks']  print
("List of ratios: ")
print (process.extract(query, choices), '\n')
print ("Best among the above list: ",process.extractOne(query, choices))
```

Output

```
FuzzyWuzzy Ratio:  84
FuzzyWuzzy PartialRatio:  85
FuzzyWuzzy TokenSortRatio:  84
FuzzyWuzzy TokenSetRatio:  86
FuzzyWuzzy WRatio:  84
List of ratios:
[('g. for geeks', 95), ('geek for geek', 93), ('geek geek', 86)]

Best among the above list:  ('g. for geeks', 95)
```

B. Solve Tipping problem using fuzzy logic.

Python Code

```
"""
==========================================
Fuzzy Control Systems: The Tipping Problem
==========================================
The 'tipping problem' is commonly used to illustrate the power of fuzzy logic principles to generate complex
behavior from a compact, intuitive set of expert rules.
If you're new to the world of fuzzy control systems, you might want to check out the `Fuzzy Control
Primer <../userguide/fuzzy_control_primer.html>`_ before reading through this worked example. The
Tipping Problem
-------------
Let's create a fuzzy control system which models how you might choose to tip at a restaurant.  When tipping,
you consider the service and food quality, rated between 0 and 10.  You use this to leave a tip of between 0
and 25%.
We would formulate this problem as:
* Antecednets (Inputs)
  - `service`
* Universe (ie, crisp value range): How good was the service of the wait
  staff, on a scale of 0 to 10?
* Fuzzy set (ie, fuzzy value range): poor, acceptable, amazing
  - `food quality`
* Universe: How tasty was the food, on a scale of 0 to 10?
* Fuzzy set: bad, decent, great
* Consequents (Outputs)
  - `tip`
* Universe: How much should we tip, on a scale of 0% to 25%       *
  Fuzzy set: low, medium, high
* Rules
-         IF the *service* was good  *or* the *food quality* was
good,   THEN the tip will be high.
-         IF the *service* was average, THEN the tip will be
medium.    - IF the *service* was poor *and* the *food quality*
was poor      THEN the tip will be low.
* Usage
  - If I tell this controller that I rated:
* the service as 9.8, and
* the quality as 6.5,
  - it would recommend I leave:
    * a 20.2% tip.
Creating the Tipping Controller Using the skfuzzy control API
-----------------------------------------
We can use the `skfuzzy` control system API to model this.  First, let's define
fuzzy variables
"""
import numpy as np import
skfuzzy as fuzz
from skfuzzy import control as ctrl
# New Antecedent/Consequent objects hold universe variables and membership
```

```
# functions quality = ctrl.Antecedent(np.arange(0, 11,
1), 'quality') service = ctrl.Antecedent(np.arange(0, 11,
1), 'service') tip = ctrl.Consequent(np.arange(0, 26, 1),
'tip')

# Auto-membership function population is possible with .automf(3, 5, or 7)
quality.automf(3)
service.automf(3)

# Custom membership functions can be built interactively with a familiar,
# Pythonic API
tip['low'] = fuzz.trimf(tip.universe, [0, 0, 13]) tip['medium']
= fuzz.trimf(tip.universe, [0, 13, 25]) tip['high'] =
fuzz.trimf(tip.universe, [13, 25, 25])

"""
To help understand what the membership looks like, use the ``view`` methods. """

# You can see how these look with .view()
quality['average'].view()
"""
.. image:: PLOT2RST.current_figure
"""
service.view()
"""
.. image:: PLOT2RST.current_figure
"""
tip.view()
"""
.. image:: PLOT2RST.current_figure

Fuzzy rules
-------
Now, to make these triangles useful, we define the *fuzzy relationship* between input and output variables.
For the purposes of our example, consider three simple rules:
1. If the food is poor OR the service is poor, then the tip will be low
2. If the service is average, then the tip will be medium
3. If the food is good OR the service is good, then the tip will be high.
Most people would agree on these rules, but the rules are fuzzy. Mapping the imprecise rules into a defined,
actionable tip is a challenge. This is the kind of task at which fuzzy logic excels. """

rule1 = ctrl.Rule(quality['poor'] | service['poor'], tip['low'])
rule2 = ctrl.Rule(service['average'], tip['medium'])
rule3 = ctrl.Rule(service['good'] | quality['good'], tip['high'])

rule1.view()

"""
.. image:: PLOT2RST.current_figure
```

```
Control System Creation and Simulation
-------------------------
Now that we have our rules defined, we can simply create a control system via:
"""
tipping_ctrl = ctrl.ControlSystem([rule1, rule2, rule3])

"""
In order to simulate this control system, we will create a
``ControlSystemSimulation``. Think of this object representing our controller applied to a specific set of
cirucmstances. For tipping, this might be tipping Sharon at the local brew-pub. We would create another
``ControlSystemSimulation`` when we're trying to apply our ``tipping_ctrl`` for Travis at the cafe because
the inputs would be different.
"""
tipping = ctrl.ControlSystemSimulation(tipping_ctrl) """
We can now simulate our control system by simply specifying the inputs and calling the ``compute``
method. Suppose we rated the quality 6.5 out of 10 and the service 9.8 of 10.
"""
# Pass inputs to the ControlSystem using Antecedent labels with Pythonic API #
Note: if you like passing many inputs all at once, use .inputs(dict_of_data)
tipping.input['quality'] = 6.5
tipping.input['service'] = 9.8

# Crunch the numbers
tipping.compute()

"""
Once computed, we can view the result as well as visualize it.
""" print
(tipping.output['tip'])
tip.view(sim=tipping)

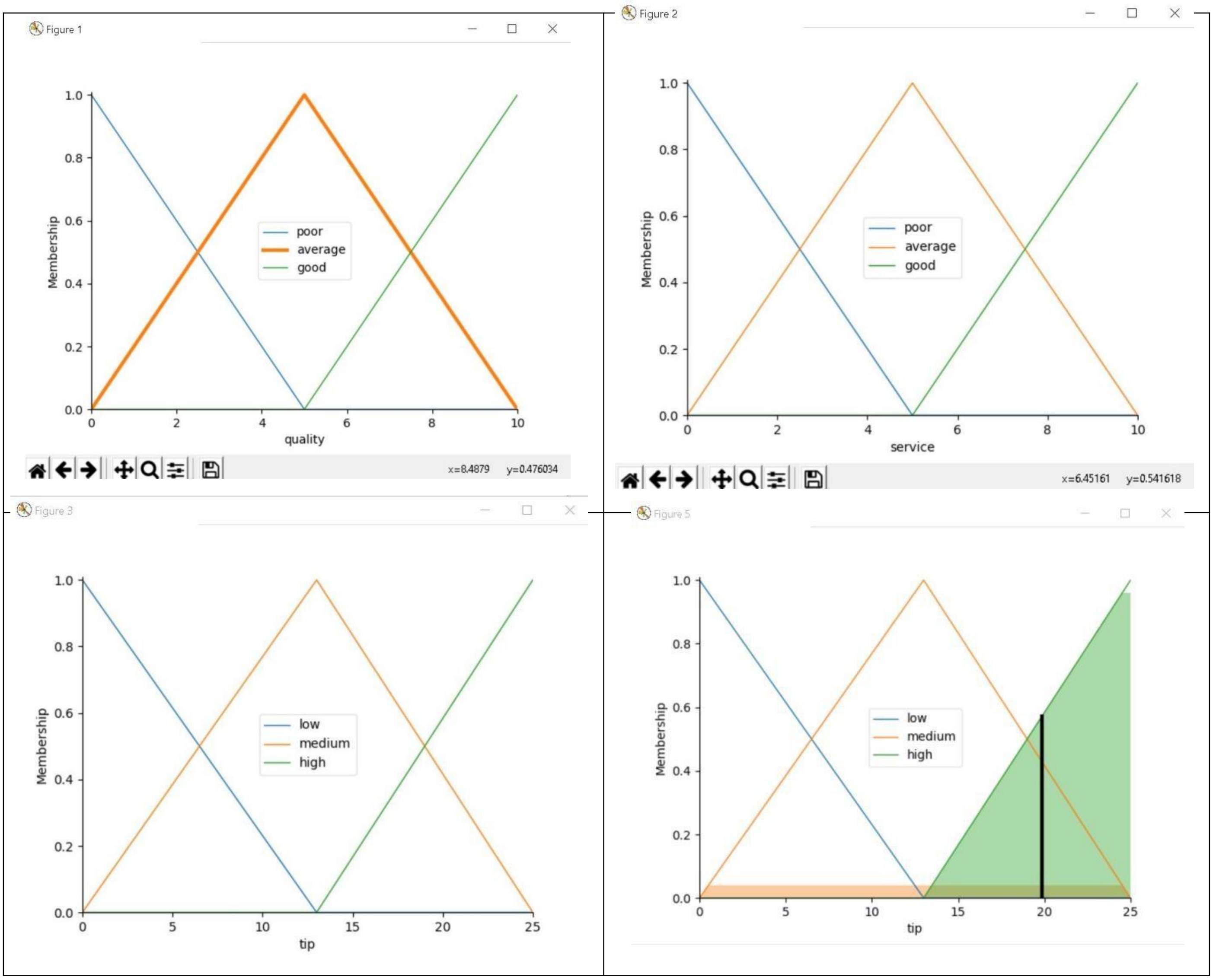
"""
.. image:: PLOT2RST.current_figure

The resulting suggested tip is **20.24%**.

Final thoughts
---------
The power of fuzzy systems is allowing complicated, intuitive behavior based on a sparse system of rules
with minimal overhead. Note our membership function universes were coarse, only defined at the
integers, but ``fuzz.interp_membership`` allowed the effective resolution to increase on demand. This
system can respond to arbitrarily small changes in inputs, and the processing burden is minimal. """
```

Output

19.847607361963192



Practical 10

A. Implementation of Simple genetic algorithm.

B. Python Code

```
import random

# Number of individuals in each generation
POPULATION_SIZE = 100

# Valid genes
GENES = '''abcdefghijklmnopqrstuvwxyzABCDEFGHIJKLMNOP
QRSTUVWXYZ 1234567890, .-;:_!"#%&/()=?@${[]}'''

# Target string to be generated
TARGET = "I love GeeksforGeeks"

class Individual(object):
    '''
    Class representing individual in population
    '''
    def __init__(self, chromosome):
self.chromosome = chromosome
        self.fitness = self.cal_fitness()

    @classmethod      def
mutated_genes(self):
        '''
        create random genes for mutation
        '''
        global GENES          gene =
random.choice(GENES)          return
gene

    @classmethod      def
create_gnome(self):
        '''
        create chromosome or string of genes
        '''
        global TARGET
gnome_len = len(TARGET)
        return [self.mutated_genes() for _ in range(gnome_len)]

    def mate(self, par2):
        '''
        Perform mating and produce new offspring
        '''

        # chromosome for offspring
```

```
        for gp1, gp2 in zip(self.chromosome, par2.chromosome):

            # random probability
            prob = random.random()

            # if prob is less than 0.45, insert gene
            # from parent 1
if prob < 0.45:
                child_chromosome.append(gp1)

            # if prob is between 0.45 and 0.90, insert
            # gene from parent 2
elif prob < 0.90:
                child_chromosome.append(gp2)

            # otherwise insert random gene(mutate),
            # for maintaining diversity
else:
                child_chromosome.append(self.mutated_genes())

        # create new Individual(offspring) using
# generated chromosome for offspring
        return Individual(child_chromosome)

    def cal_fitness(self):
        '''
        Calculate fittness score, it is the number of
characters in string which differ from target           string.
        '''
        global TARGET           fitness = 0          for gs,
gt in zip(self.chromosome, TARGET):
            if gs != gt: fitness+= 1
return fitness

# Driver code  def
main():
    global POPULATION_SIZE

    #current generation
    generation = 1

    found = False
    population = []

    # create initial population       for _ in
range(POPULATION_SIZE):
gnome = Individual.create_gnome()
population.append(Individual(gnome))
```

```
    while not found:

        # sort the population in increasing order of fitness score
population = sorted(population, key = lambda x:x.fitness)

        # if the individual having lowest fitness score ie.
        # 0 then we know that we have reached to the target
        # and break the loop           if
population[0].fitness <= 0:
found = True              break

        # Otherwise generate new offsprings for new generation
new_generation = []

        # Perform Elitism, that mean 10% of fittest population
        # goes to the next generation           s =
int((10*POPULATION_SIZE)/100)
        new_generation.extend(population[:s])

        # From 50% of fittest population, Individuals
        # will mate to produce offspring           s
= int((90*POPULATION_SIZE)/100)
for _ in range(s):
            parent1 = random.choice(population[:50])
parent2 = random.choice(population[:50])              child
= parent1.mate(parent2)
            new_generation.append(child)

        population = new_generation

        print("Generation: {}\tString: {}\tFitness:
{}".format(generation,"".join(population[0].chromosome), population[0].fitness))

        generation += 1

    print("Generation: {}\tString: {}\tFitness: {}".format(generation,
"".join(population[0].chromosome), population[0].fitness))

if _name___== '_main_':
    main()
```

Output :

Generation: 2 String: I%hQ8zp]@x6,oZ!fL@} Fitness: 18 Generation: 3 String: I-h1]z 75x=,o2=FL@
Fitness: 17
Generation: 4 String: I#hinz /(FC6kor=fZ } Fitness: 16 Generation: 5 String: I#hinz /(FC6kor=fZ } Fitness: 16 Generation: 6 String: I-lQ8A @-]P=CorXft@
Fitness: 15
Generation: 7 String: d-lt]J @e;asCor=F/gk Fitness: 14 Generation: 8 String: d-lt]J @e;asCor=F/gk Fitness: 14 Generation: 9 String: /-ldvP kme5G,orG-a@
Fitness: 13
Generation: 10 String: I[P}vN xeC=,orGe"6t Fitness: 12
Generation: 11 String: I[l}vN (e]=,orGe18Q Fitness: 11 Generation: 12 String: I[l}vN (e]=,orGe18Q Fitness: 11
Generation: 13 String: d1lovz @ee5s4orGbM@ Fitness: 10
Generation: 14 String: d1lovz @ee5s4orGbM@ Fitness: 10
Generation: 15 String: d1lovz @ee5s4orGbM@ Fitness: 10
Generation: 16 String: I-lnve HJe5s,orGe@@Q Fitness: 9
Generation: 17 String: I-lnve HJe5s,orGe@@Q Fitness: 9
Generation: 18 String: I loDN Fee5skorGeM8 Fitness: 8 Generation: 19 String: I lov: Fee]s,orGe1g
Fitness: 7
Generation: 20 String: I lov: Fee]s,orGe1g Fitness: 7
Generation: 21 String: I lov: Fee]s,orGe1g Fitness: 7
Generation: 22 String: I lov @eeYs,orGeen Fitness: 6
Generation: 23 String: I lov @eeYs,orGeen Fitness: 6
Generation: 24 String: I lov @eeYs,orGeen Fitness: 6
Generation: 25 String: I lov @eeYs,orGeen
Fitness: 6

Generation: 26 String: I lovR @eekskorGee;G Fitness: 5
Generation: 27 String: I lovR @eekskorGee;G Fitness: 5
Generation: 28 String: I lovR @eekskorGee;G Fitness: 5
Generation: 29 String: I lovR @eekskorGee;G Fitness: 5
Generation: 30 String: I lovR @eekskorGee;G Fitness: 5
Generation: 31 String: I lovR @eekskorGee;G Fitness: 5
Generation: 32 String: I lovR @eekskorGee;G Fitness: 5
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Generation: 38 String: I lovR @eekskorGee;G Fitness: 5
Generation: 39 String: I lovR @eekskorGee;G Fitness: 5

Generation: 40 String: I lovR @eekskorGee;G Fitness: 5
Generation: 41 String: I lovR @eekskorGee;G Fitness: 5
Generation: 42 String: I lovR @eekskorGee;G Fitness: 5
Generation: 43 String: I lovR @eekskorGee;G Fitness: 5
Generation: 44 String: I lovR @eekskorGee;G Fitness: 5
Generation: 45 String: I lovR @eekskorGee;G Fitness: 5
Generation: 46 String: I lovR @eekskorGee;G Fitness: 5
Generation: 47 String: I lovR @eekskorGee;G Fitness: 5
Generation: 48 String: I love meekskorGee@G Fitness: 4
Generation: 49 String: I love meekskorGee@G Fitness: 4
Generation: 50 String: I love meekskorGee@G Fitness: 4
Generation: 51 String: I love meekskorGee@G Fitness: 4
Generation: 52 String: I love meekskorGee@G Fitness: 4
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Generation: 54 String: I love meekskorGee@G Fitness: 4
Generation: 55 String: I love meekskorGee@G Fitness: 4
Generation: 56 String: I love meekskorGee@G Fitness: 4

Generation: 57 String: I love meeksforGeenF Fitness: 3 Generation: 58 String: I love meeksforGeenF Fitness: 3 Generation: 59 String: I love meeksforGeenF Fitness: 3 Generation: 60 String: I love meeksforGeenF Fitness: 3 Generation: 61 String: I love meeksforGeenF Fitness: 3 Generation: 62 String: I love GeeksforGeenF Fitness: 2 Generation: 63 String: I love GeeksforGeenF Fitness: 2 Generation: 64 String: I love GeeksforGeenF Fitness: 2 Generation: 65 String: I love GeeksforGeenF Fitness: 2 Generation: 66 String: I love GeeksforGeenF Fitness: 2 Generation: 67 String: I love GeeksforGeenF Fitness: 2 Generation: 68 String: I love GeeksforGeenF Fitness: 2 Generation: 69 String: I love GeeksforGeenF Fitness: 2 Generation: 70 String: I love GeeksforGeenF Fitness: 2 Generation: 71 String: I love GeeksforGeenF Fitness: 2 Generation: 72 String: I love GeeksforGeenF Fitness: 2 Generation: 73 String: I love GeeksforGeenF Fitness: 2 Generation: 74 String: I love GeeksforGeenF Fitness: 2 Generation: 75 String: I love GeeksforGeenF Fitness: 2 Generation: 76 String: I love GeeksforGeenF Fitness: 2 Generation: 77 String: I love GeeksforGeenF Fitness: 2 Generation: 78 String: I love GeeksforGeenF Fitness: 2 Generation: 79 String: I love GeeksforGeenF Fitness: 2 Generation: 80 String: I love GeeksforGeenF Fitness: 2 Generation: 81 String: I love GeeksforGeenF Fitness: 2 Generation: 82 String: I love GeeksforGeenF Fitness: 2 Generation: 83 String: I love GeeksforGeenF Fitness: 2 Generation: 84 String: I love GeeksforGeenF Fitness: 2 Generation: 85 String: I love GeeksforGeenF Fitness: 2

Generation: 86 String: I love GeeksforGeenF Fitness: 2 Generation: 87 String: I love GeeksforGeenF Fitness: 2

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Generation: 236    String: I love GeeksforGeek Fitness: 1
Generation: 237    String: I love GeeksforGeek Fitness: 1
Generation: 238    String: I love GeeksforGeeks Fitness: 0
>>>
```

B. Create two classes: City and Fitness using Genetic algorithm

Python Code

```
"""Applying a genetic algorithm to the travelling salesman problem"
""" import math import random class
City:    def _init_(self, x=None,
y=None):
    self.x = None
self.y = None       if
x is not None:
        self.x = x
else:
        self.x = int(random.random() * 200)
if y is not None:
        self.y = y
else:
        self.y = int(random.random() * 200)
def getX(self):       return self.x       def
getY(self):       return self.y       def
distanceTo(self, city):       xDistance =
abs(self.getX() - city.getX())       yDistance =
abs(self.getY() - city.getY())
    distance = math.sqrt( (xDistance*xDistance) + (yDistance*yDistance) )
return distance       def _repr_(self):
    return str(self.getX()) + ", " + str(self.getY()) class
TourManager:
  destinationCities = []
def addCity(self, city):
    self.destinationCities.append(city)
def getCity(self, index):
    return self.destinationCities[index]
def numberOfCities(self):
    return len(self.destinationCities) class Tour:     def
_init_(self, tourmanager, tour=None):
self.tourmanager = tourmanager       self.tour = []
self.fitness = 0.0       self.distance = 0       if tour is not
None:          self.tour = tour       else:          for i in range(0,
self.tourmanager.numberOfCities()):
self.tour.append(None)        def _len_(self):
    return len(self.tour)        def
__getitem__(self, index):
return self.tour[index]        def
_setitem_(self, key, value):
    self.tour[key] = value       def
_repr_(self):         geneString = "|"
for i in range(0, self.tourSize()):
        geneString += str(self.getCity(i)) + "|"       return geneString
def generateIndividual(self):       for cityIndex in range(0,
self.tourmanager.numberOfCities()):          self.setCity(cityIndex,
self.tourmanager.getCity(cityIndex))
```

```
random.shuffle(self.tour)        def getCity(self, tourPosition):
return self.tour[tourPosition]        def setCity(self, tourPosition,
city):        self.tour[tourPosition] = city        self.fitness = 0.0
self.distance = 0        def getFitness(self):        if self.fitness == 0:
self.fitness = 1/float(self.getDistance())
    return self.fitness        def getDistance(self):
if self.distance == 0:            tourDistance = 0            for
cityIndex in range(0, self.tourSize()):
fromCity = self.getCity(cityIndex)
destinationCity = None              if cityIndex+1 <
self.tourSize():                  destinationCity =
self.getCity(cityIndex+1)              else:
          destinationCity = self.getCity(0)
        tourDistance += fromCity.distanceTo(destinationCity)
      self.distance = tourDistance
return self.distance        def
tourSize(self):
    return len(self.tour)        def containsCity(self, city):
return city in self.tour class Population:    def _init_(self,
tourmanager, populationSize, initialise):
    self.tours = []        for i in range(0,
populationSize):
self.tours.append(None)              if
initialise:            for i in range(0,
populationSize):              newTour =
Tour(tourmanager)
newTour.generateIndividual()
self.saveTour(i, newTour)            def
_setitem_(self, key, value):
    self.tours[key] = value
def __getitem__(self, index):
return self.tours[index]        def
saveTour(self, index, tour):
    self.tours[index] = tour        def getTour(self, index):        return
self.tours[index]        def getFittest(self):        fittest = self.tours[0]        for i in
range(0, self.populationSize()):          if fittest.getFitness() <=
self.getTour(i).getFitness():              fittest = self.getTour(i)        return fittest
def populationSize(self):        return len(self.tours) class GA:    def
_init_(self, tourmanager):          self.tourmanager = tourmanager
self.mutationRate = 0.015        self.tournamentSize = 5        self.elitism = True
def evolvePopulation(self, pop):        newPopulation =
Population(self.tourmanager, pop.populationSize(), False)        elitismOffset = 0
if self.elitism:
      newPopulation.saveTour(0, pop.getFittest())
      elitismOffset = 1              for i in range(elitismOffset,
newPopulation.populationSize()):            parent1 =
self.tournamentSelection(pop)            parent2 =
self.tournamentSelection(pop)            child =
self.crossover(parent1, parent2)          newPopulation.saveTour(i,
```

```
child)            for i in range(elitismOffset,
newPopulation.populationSize()):
        self.mutate(newPopulation.getTour(i))
return newPopulation      def crossover(self, parent1,
parent2):      child = Tour(self.tourmanager)
startPos = int(random.random() * parent1.tourSize())
endPos = int(random.random() * parent1.tourSize())
for i in range(0, child.tourSize()):         if startPos <
endPos and i > startPos and i < endPos:
          child.setCity(i, parent1.getCity(i))
elif startPos > endPos:            if not (i <
startPos and i > endPos):
            child.setCity(i, parent1.getCity(i))
for i in range(0, parent2.tourSize()):
        if not child.containsCity(parent2.getCity(i)):
for ii in range(0, child.tourSize()):              if
child.getCity(ii) == None:
child.setCity(ii, parent2.getCity(i))
              break            return child      def mutate(self,
tour):      for tourPos1 in range(0, tour.tourSize()):
if random.random() < self.mutationRate:             tourPos2
= int(tour.tourSize() * random.random())
city1 = tour.getCity(tourPos1)            city2 =
tour.getCity(tourPos2)
tour.setCity(tourPos2, city1)
tour.setCity(tourPos1, city2)      def
tournamentSelection(self, pop):
      tournament = Population(self.tourmanager, self.tournamentSize, False)
for i in range(0, self.tournamentSize):
        randomId = int(random.random() * pop.populationSize())
tournament.saveTour(i, pop.getTour(randomId))
      fittest = tournament.getFittest()
return fittest if _name___==
'_main_':        tourmanager =
TourManager()      # Create and
add our cities    city = City(60,
200)    tourmanager.addCity(city)
city2 = City(180, 200)
tourmanager.addCity(city2)
city3 = City(80, 180)
tourmanager.addCity(city3)
city4 = City(140, 180)
tourmanager.addCity(city4)
city5 = City(20, 160)
tourmanager.addCity(city5)
city6 = City(100, 160)
tourmanager.addCity(city6)
city7 = City(200, 160)
tourmanager.addCity(city7)
city8 = City(140, 140)
```

```
tourmanager.addCity(city8)
city9 = City(40, 120)
tourmanager.addCity(city9)
city10 = City(100, 120)
tourmanager.addCity(city10)
city11 = City(180, 100)
tourmanager.addCity(city11)
city12 = City(60, 80)
tourmanager.addCity(city12)
city13 = City(120, 80)
tourmanager.addCity(city13)
city14 = City(180, 60)
tourmanager.addCity(city14)
city15 = City(20, 40)
tourmanager.addCity(city15)
city16 = City(100, 40)
tourmanager.addCity(city16)
city17 = City(200, 40)
tourmanager.addCity(city17)
city18 = City(20, 20)
tourmanager.addCity(city18)
city19 = City(60, 20)
tourmanager.addCity(city19)
city20 = City(160, 20)
tourmanager.addCity(city20)
  # Initialize population
  pop = Population(tourmanager, 50, True);
  print ("Initial distance: " + str(pop.getFittest().getDistance()))
  # Evolve population for 50 generations
  ga = GA(tourmanager)    pop =
ga.evolvePopulation(pop)     for i in
range(0, 100):       pop =
ga.evolvePopulation(pop)
  # Print final results
print ("Finished")
  print ("Final distance: " + str(pop.getFittest().getDistance()))
print ("Solution:")
  print (pop.getFittest())
```

Output

Initial distance: 1902.801165633492
Finished
Final distance: 1072.7575103728066 Solution:
|40, 120|20, 160|60, 200|80, 180|180, 200|200, 160|180, 60|200, 40|160, 20|100, 40|60, 20|20, 20|20, 40|120, 80|180, 100|140, 140|140, 180|100, 160|100, 120|60, 80|

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