SMAI-ASSIGNMENT 2

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Abstract. The document is written to answer the following questions

(1) Prove that the single-sample perceptron algorithm will always converge to a solution if one exists.
(2) Implement Perceptron-based Linear Discriminant Functions, that is, Single-sample perceptron, Single-sample perceptron with margin, Relaxation algorithm with margin, Widrow-Hoff or Least Mean Squared (LMS) Rule
(3) Implement a simple supervised, feed-forward, back-propagation network for the problem of optical character recognition for digits 0 and 7.

1. Proof of Convergence of Perceptron

Let the data be Linearly separable and let $\hat{a}$ be solution vector perpendicular to the required plain. So, we know that $\hat{a}^t y_i > 0 \; \forall \; i$.

The Gradient Descent Equation is:,

$a(k+1) = a(k) + y^k$

We subtracting $\alpha\hat{a}$ from both sides,

$a(k+1) - \alpha\hat{a} = a(k) - \alpha\hat{a} + y^k$

Squaring both sides

$||a(k+1) - \alpha\hat{a}||^2 = ||a(k) - \alpha\hat{a} + y^k||^2$

$||a(k+1) - \alpha\hat{a}||^2 = ||a(k) - \alpha\hat{a}||^2 + ||y^k||^2 + 2(a(k) - \alpha\hat{a})^t y^k$

y^k was a misclassified point. Hence $\hat{a}^t y^k \leq 0$, so:

$||a(k+1) - \alpha\hat{a}||^2 \leq ||a(k) - \alpha\hat{a}||^2 + ||y^k||^2 - 2\alpha\hat{a}^t y^k$

Now, $a^t y^k > 0$. Also,

We define β as the maximum length of the pattern vector. ie. $\beta^2 = max_i ||y_i||^2$. As this is a positive value, this is the maximum we can achieve from the second term.

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We define γ as the smaller inner product of the $\hat{a}$ with any pattern vector. ie. $\gamma = min_i[\hat{a}^i y_i]$. This is the minimum we can achieve from the third term which can be subtracted.

Hence our equation becomes,

$||a(k+1) - \alpha\hat{a}||^2 \leq ||a(k) - \alpha\hat{a}||^2 - 2\alpha\gamma + \beta^2$

$\alpha was a random constant so let$

$\alpha = \beta^2/\gamma$.

Our equation reduces to,

$||a(k+1) - \alpha\hat{a}||^2 \leq ||a(k) - \alpha\hat{a}||^2 - \beta^2$

Say that after some k_0 steps, the equation converges, ie. $||a(k_0+1) - \alpha\hat{a}||^2 = 0$, hence,

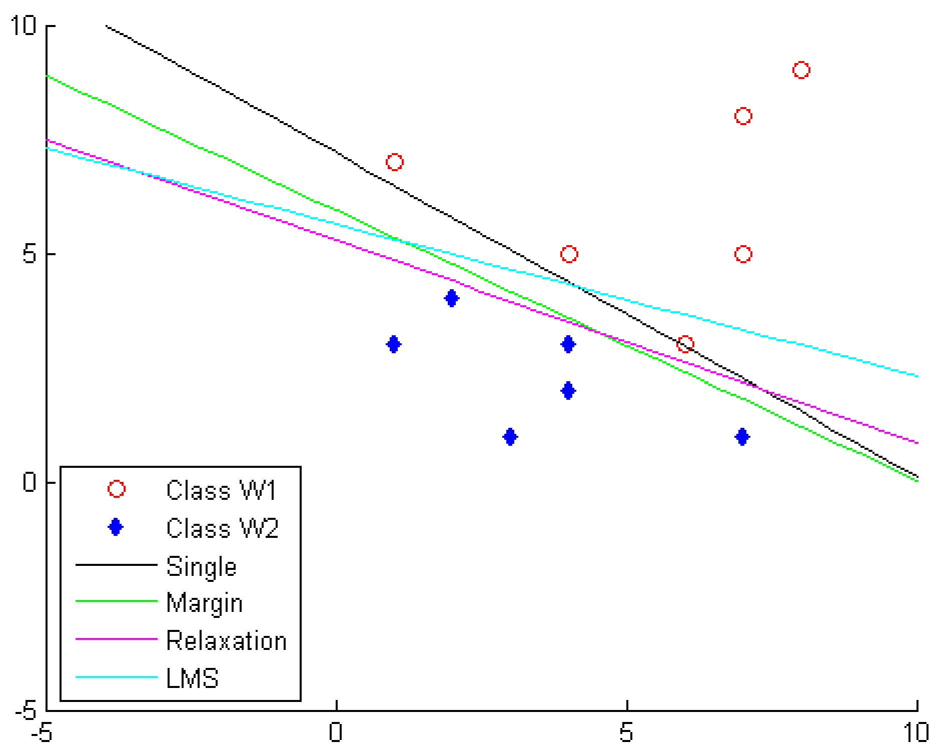
$0 \leq ||a(k) - \alpha\hat{a}||^2 - k_0\beta^2$

or we can write it as

$k_0 = ||a(1) - \alpha\hat{a}||^2/\beta^2$

2. LDF - Gradient Descent Algorithm

2.1. Graph




```
a1 : For single sample
a2 : For single sample with margin
a3 : For Relaxed
a4 : For LMS

Round 1
a = randi(5,[1,size(dataFinal,1)])
a1 =

   -2.9500    0.2900    0.4100

Elapsed time is 0.005273 seconds.
```

```
a = randi(5,[1,size(dataFinal,1)])
a2 =

   -5.9300    0.5900    1.0000

Elapsed time is 0.013373 seconds.


a = [-1,1,1];
a3 =

   -1.2917    0.1083    0.2451

Elapsed time is 0.915025 seconds.


a = [-1,1,1];
a4 =

   -1.5246    0.0898    0.2704

Elapsed time is 0.433580 seconds.


Round 2
a = randi(5,[1,size(dataFinal,1)])
a1 =

   -2.9500    0.2800    0.4600

Elapsed time is 0.006685 seconds.

a = randi(5,[1,size(dataFinal,1)])
a2 =

   -5.6500    0.5700    0.9400

Elapsed time is 0.011457 seconds.

a = [-5,1,1]
a3 =

   -5.0753    0.5898    0.8480

Elapsed time is 0.854140 seconds.
```

```
a = [-5,1,1]
a4 =

   -5.0480    0.6693    0.6749

Elapsed time is 0.003884 seconds.


Round 3

a = randi(5,[1,size(dataFinal,1)])
a1 =

   -3.2000    0.2200    0.6700

Elapsed time is 0.007913 seconds.

a = randi(5,[1,size(dataFinal,1)])
a2 =

   -6.2000    0.5700    1.1200

Elapsed time is 0.011992 seconds.

a = [1,1,1]
a3 =

   -5.0753    0.5898    0.8480

Elapsed time is 0.829555 seconds.

a = [1,1,1]
a4 =

    0.6437   -0.1371    0.0696

Elapsed time is 0.019652 seconds.
But the answer obtained is not correct.

As one can see the time is almost same for any initial value of A for a1 and a2.
The time taken by a3 has a little dependence on A.
The time taken by a4 varies greatly with the initial value of A. If A is closer to a minimum then it
Even though this may lead to wrong output.
```

```
ADDING DIFFERENT MARGIN

Round 1

b = 0.5
a2 =

   -5.7100    0.5500    1.0000

Elapsed time is 0.013883 seconds.

b = 0.1
a3 =

   -1.2917    0.1083    0.2451

Elapsed time is 0.932693 seconds.

Round 2
b = 1.5
a2 =

  -14.9100    1.5500    2.3800

Elapsed time is 0.033113 seconds.

b = 1.1
a3 =

   -5.8612    0.6099    0.9103

Elapsed time is 1.243246 seconds.

Round 3
b = 0.05
a2 =

   -3.1200    0.2100    0.6500

Elapsed time is 0.010261 seconds.

b = 0.01
```

```
a3 =

   -1.2819    0.0810    0.2800

Elapsed time is 0.809574 seconds.

As one can see the time is greatly dependent on the value of the margin. Higher value of margin usual
In almost all the cases a2 is much faster than a3.
```

2.2. Code

```
clear;
clc;
data1 = [1,1,7;1,6,3;1,7,8;1,8,9;1,4,5;1,7,5]';
data2 = -[1,3,1;1,4,3;1,2,4;1,7,1;1,1,3;1,4,2]';
dataFinal = [data1,data2];

scatter(data1(2,:),  data1(3,:),'r'),axis([-5,10,-5,10]),hold on;
scatter(-data2(2,:),-data2(3,:),'b','d','filled'),axis([-5,10,-5,10]);

x = -10:0.5:10;
tic,a1 = Single(dataFinal),toc;
tic,a2 = Margin(dataFinal),toc;
tic,a3 = Relax(dataFinal),toc;
tic,a4 = LMS(dataFinal),toc;

y1 = (a1(1)+a1(2)*x)/(-a1(3));
plot(x,y1,'k'),axis([-5,10,-5,10]);
y2 = (a2(1)+a2(2)*x)/(-a2(3));
plot(x,y2,'g'),axis([-5,10,-5,10]);
y3 = (a3(1)+a3(2)*x)/(-a3(3));
plot(x,y3,'m'),axis([-5,10,-5,10]);
y4 = (a4(1)+a4(2)*x)/(-a4(3));
plot(x,y4,'c'),axis([-5,10,-5,10]);
legend('Class W1','Class W2', 'Single', 'Margin', 'Relaxation',
    'LMS','Location','southwest'),hold off;


% In case of linearly classifiable data we asume a model G(x) = A*Y .
% So for properly classifying the points we need to determine the
    correct
% value of A. For this we first define an error function J and then
    try and
% minimize it. Now using the technique of Gradiant Decent we update
    the value of A.
%
% A(k+1) = A(k) + (ETA)*J';
```

```
% J' is the derivate of the error function we are trying to minimize and ETA is the learning rate.
% Depending on our choice of J our algorithm changes.
```

```
function [ a ] = Relax( dataFinal )
%UNTITLED9 Summary of this function goes here
%   Detailed explanation goes here
    a = [-1,1,1];
    n = 0.1;            %learning rate
    b = 0.1;              %margin
    thres = 100000;
    check = zeros(length(dataFinal),1);
    for i = 0:thres
        j = 1+mod(i,length(dataFinal));
        q = a*dataFinal(:,j);
        if q < b
            a = a + n*(((b-q)^2)/(norm(dataFinal(:,j)')^2))*(dataFinal(:,j)');
            check(j)=0;
        else
            check(j)=1;
        end
        if sum(check) == length(check)
            break;
        end
    end
end

% Till the previous algorithm more weightage was give to outliers. So to
% correct this issue it is normalized with norm of the distence. Also the
% concept of relaxation is introduced. If there is under relaxation then
% the learning is slow but if there is over relaxation then it may
% overshoot.
% J' is (((AY-B)^2)/(|Y|^2))*Yk;

% This process was comparitively computationally expensive. But this
% algorithm also gave correct results and this algorithm has the capacity
% to hendle far off cases.
```

```
function [ a ] = LMS( dataFinal )
%UNTITLED8 Summary of this function goes here
%   Detailed explanation goes here
    a = [-1,1,1];         % selected after trying for MANY possible a's.
    % a = randi(5,[1,size(data,1)]);
```

```
    n = 0.0005;            %learning rate
    % b = randi(5,[1,size(data,2)]);
    b = ones(1,size(dataFinal,2));
    thres = 0.000025;
    check = zeros(length(dataFinal),1);
    j =1;
    i =0;
    while norm((n)*dataFinal(:,j)'*(a*dataFinal(:,j) - b(j))) > thres
        j = 1+mod(i,length(dataFinal));
        a = a - (n)*dataFinal(:,j)'*(a*dataFinal(:,j) - b(j));
        i = i+1;
    end
end

% Untill now all the algorithms that we saw used misclassified sample for
% updation purpose. This had a major issue as due to this outliers etc
% had large influence. So to correct this issue this method was introduced.
% In this method all the points are concidered. It is assumed that each
% poiint has a distence bi from the line.
% But as correct distance cant be estimated error is introduced. So,
% e = AY - B;
% Using this we try and update A to get a favorable vector.


% This algorithm give very different results for different initallised
% values. Even then it was not able to correctly identify all the points.
```

```
function [ a ] = Single( dataFinal )
%UNTITLED5 Summary of this function goes here
%   Detailed explanation goes here
    a = randi(5,[1,size(dataFinal,1)]);
    n = 0.09;             %learning rate
    b = 0;                %margin
    thres = 50000;
    check = zeros(length(dataFinal),1);
    for i = 0:thres
        j = 1+mod(i,length(dataFinal));
        q = a*dataFinal(:,j);
        if q <= b
            a = a + n*dataFinal(:,j)';
            check(j)=0;
        else
            check(j)=1;
```

```
        end
        if sum(check) == length(check)
            break;
        end
    end
end
```

```
function [ a ] = Margin( dataFinal )
%UNTITLED5 Summary of this function goes here
%   Detailed explanation goes here
    a = randi(5,[1,size(dataFinal,1)]);
    n = 0.09;             %learning rate
    b = 0.5;                 %margin
    thres = 50000;
    check = zeros(length(dataFinal),1);
    for i = 0:thres
        j = 1+mod(i,length(dataFinal));
        q = a*dataFinal(:,j);
        if q <= b
            a = a + n*dataFinal(:,j)';
            check(j)=0;
        else
            check(j)=1;
        end
        if sum(check) == length(check)
            break;
        end
    end
end

% This is a little improvement of the previous techique. In this algorithm
% the concept margin is introduced so that the partitioning line is not too
% close to the points. This helps in obtaining a more general line .
% So our J is AY - b.

% This methos also gave very efficient results and was able to classify the
% results correctly in a short time. It is also computationally not that
% expensive. But if the data set was not as good as the one provided then
% this algorithm might not have such results.
% As a margin was kept it gave pretty good seperation line.
```

3. Neural Network

```
clear;
clc;
a = fopen('optdigits-orig.cv');
i = 1;
while ~feof(a)
    if mod(i,33)==0
        sbl_v(i/33,:)=fgetl(a);
    else
        data_v(i,:)=fgetl(a);
    end
i=i+1;
end
a = fopen('optdigits-orig.tra');
i = 1;
while ~feof(a)
    if mod(i,33)==0
        sbl_t(i/33,:)=fgetl(a);
    else
        data_t(i,:)=fgetl(a);
    end
i=i+1;
end

sbl_t = sbl_t(:,2);
sbl_v = sbl_v(:,2);

a = data_t == '1';
data_t(a) = 255;
a = data_t == '0';
data_t(a) = 0;
a = data_v == '1';
data_v(a) = 255;
a = data_v == '0';
data_v(a) = 0;
data_t = double(data_t);
data_v = double(data_v);

a = find(sbl_t == '7' | sbl_t == '0');
train = zeros(8,9,length(a));
for i = 1:length(a)
    if sbl_t(a(i)) == '7'
        b = 1;
    else
        b = 0;
    end
```

```
    train(:,1:8,i) =
    imresize(data_t((a(i)-1)*33+1:a(i)*33-1,:),0.25);
    train(:,9,i) = b;
end
a = find(sbl_v == '7' | sbl_v == '0');
validate = zeros(8,9,length(a));
for i = 1:length(a)
    if sbl_v(a(i)) == '7'
        b = 1;
    else
        b = 0;
    end
    validate(:,1:8,i) =
    imresize(data_v((a(i)-1)*33+1:a(i)*33-1,:),0.25);
    validate(:,9,i) = b;
end
clear data_t;
clear data_v;
clear sbl_t;
clear sbl_v;
clear a;
clear b;
clear i;
```

```
clear;
clc;
load ./Q3_data.mat;
t = train;
v = validate;

d = size(t,1)*(size(t,2)-1) +1;          % because 8X8 + x0;
nH = 39;
c = 2;
n = 0.1;
iter = 100;
thres = 10;

Wij = unifrnd(-1/sqrt(d),1/sqrt(d),d,nH);
Wjk = unifrnd(-1/sqrt(nH),1/sqrt(nH),nH,c);
netj = zeros(nH,1);
netk = zeros(c,1);
error = zeros(1,size(v,3));
e = zeros(1,size(v,3));

for j = 1:iter
    for i = 1:size(t,3)
        X = 1;
        X(2:d) = t(:,1:8,i);                % 1Xd
        netj = (X*Wij);                     % 1Xd.dXnH => 1XnH
```

```
        Y = (1+exp(-netj)).^(-1);                  % 1XnH
        netk = (Y*Wjk);                        % 1XnH.nHXc => 1Xc

        Z = (1+exp(-netk)).^(-1);
        if t(1,end,i) == 1
            tc = [1,1];
        else
            tc = [0,0];
        end
        if  (norm(Z)> 0.4 & t(1,end,i) == 1) | (norm(Z)<= 0.4 & t(1,end,i) == 0)
            e(i) = 0;
        else
            e(i) = 1;
        end
        Dk = ((tc-Z).*(Z.*(1-Z)));
        Wjk = Wjk + n*Y'*Dk;
        Dj = ((Dk*Wjk').*(Y.*(1-Y)));
        Wij = Wij + n*X'*Dj;
    end
    if sum(e) < thres
        break;
    end
end

for i = 1:size(v,3)
    X = 1;
    X(2:d) = v(:,1:8,i);                   % 1Xd
    netj = (X*Wij);                        % 1Xd.dXnH => 1XnH

    Y = (1+exp(-netj)).^(-1);                  % 1XnH
    netk = (Y*Wjk);                        % 1XnH.nHXc => 1Xc

    Z = (1+exp(-netk)).^(-1);
    if  (norm(Z)> 0.5 & v(1,end,i) == 1) | (norm(Z)<= 0.5 & v(1,end,i) == 0)
        error(i) = 0;
    else
        error(i) = 1;
    end
end
q = find(error == 1);
fprintf('Number of misclassified "7": %d\n',sum(v(1,end,q)));
fprintf('Total misclassified samples: %d\n',length(q));
fprintf(': %d\n',length(q));
```

For the purpose of recognizing letters '0' and '7'
Since the number of training samples was 390 I decided to use 39 hidden states.

Wij is 65X39:

0.00852377110196400 0.0168167108194295 0.0906906995135764 -0.0341521508520852
0.00915446012818496 -0.0768488757602270 0.0502128894586879 0.0279794871327043
0.0621662893305959 0.0759595787983735 0.105897485065351 0.0225581981968135
0.117390193773649 0.0214895782727926 -0.102615639285905 -0.0620640004927365
-0.0754294689332468 -0.0178795726500848 -0.0110213735800909 0.0727804090855225
-0.0439326189495888 0.00715505421676795 -0.0875192492853352 -0.0310464378044200
0.109104246623387 0.0316997788661457 -0.0117638930064226 0.0371779579678653
-0.0980467288909962 0.0637766875999936 -0.00738271533583162 0.102774214462131
0.0867514018326965 -0.0982989098190917 0.0850625005994987 0.0588708982926175
0.0776162569032200 0.123112547436863 -0.0543850089758245
0.0595261495178468 0.00714056952943048 0.0811628260928037 -0.0543772358575069
0.0604521855394331 -0.00463698755753382 0.0149190270129171 -0.00962944054533800
0.0348426394699797 0.105751071978376 -0.00130163968318400 -0.0932268375130779
0.0605169515811133 0.113086409361776 -0.105243020771068 -0.0918293699951344
0.0633270255349999 0.0276696150246281 0.0551462743085977 0.0609341949144762
0.0309797976289314 0.122647670708964 -0.0962274418719907 -0.0644266090832099
-0.0869059280930350 -0.0830993920358655 0.0315682349228637 -0.0687050112872726
-0.0788778677112658 -0.0894439736089960 -0.0555879414724181 0.111940823629141
-0.102190073481889 0.115545801728561 0.0729077843414233 0.0529256065176578
-0.0688455307960449 0.101037817289172 -0.0965540374183246
-0.109830646143318 0.0643703207794488 -0.0510154309450226 -0.111173648015054
-0.104774750720731 -0.0512938753621463 -0.0830650986088040 -0.120837949145864
-0.0633115424174788 0.0630578449510213 0.0577851075628820 0.0501532617037082
-0.0201904223622786 -0.0870993633519403 0.103613592078124 -0.0134111986724326
-0.123415622604114 -0.0284690187788827 0.111677824945701 -0.109004834976096
-0.0303006290010616 -0.0721013123039012 0.0441962771640571 -0.00625855068888152
-0.0296402637734693 0.00543342804006497 0.0366871065203631 -0.0827904583583095
0.0916374172128980 -0.00170096551716990 0.0908825317463318 -0.0264418823150248
0.0484401807211761 0.0687638588174358 -0.0529297910571880 -0.0207345205815580
0.0774297023751123 -0.0674558460383876 0.0288951106614635
-0.0775996271336807 -0.0354858986491108 0.0629885797464172 0.00329630169952517
0.00366246233055242 0.0927470099417445 0.0246810386538579 0.0397235116995779
-0.108078142634465 -0.121952161062692 -0.0100547123556675 0.111037991501745
0.0464084145353480 0.0967093501366771 -0.00670515450603525 0.101880141465277
0.00630307902247911 -0.0832242425839677 0.0336513946901884 -0.0340988001202030
0.0246847402122981 0.0270451310606321 -0.106392477300683 0.0737746673311120
0.0444435754981999 0.0470601757378302 -0.127280448215099 0.108799655935066
0.0189361108794941 0.0979002756323457 0.0566501830871377 0.123363766078253
-0.0211705114952527 -0.0158793591601205 0.0195125379740267 0.0807670769482862
0.124674283331374 0.0745102561387080 0.0601811156435985
0.000771526493604177 0.0630723614547452 0.0674020062402522 -0.0444395094839052
-0.107461400179258 -0.120991075915206 -0.0903457458305285 -0.0292480171837627
-0.0328254138786684 -0.0679071115991326 -0.0554740791000339 -0.120848877603020

-0.00398370138512121 0.125916167422714 0.0511030084448825 -0.120662612974428
0.119034558869075 -0.0640480667925480 0.108543865352031 -0.0121778929587795
-0.0550411125496900 -0.00121992069175365 0.0805420814576100 0.0865317399464556
-0.0300564171047141 -0.0371411208113495 0.0773612724774837 -0.0146339639866768
0.0273743897122442 0.119507102684527 -0.0794815827612957 -0.0221955544467394
0.0778139810070930 -0.0635178473499188 -0.0297182995620084 -0.116792421664673
0.101766585048175 -0.0762905789613109 0.00577663947121729
0.0656997492593389 -0.0268145279764803 -0.0794321800960416 -0.0861326197951385
0.0515174733662804 -0.00767662216288724 0.0706992585159704 -0.0165994071711150
-0.0704443412241681 0.104373311659247 -0.0430183111445995 -0.0909120565165855
-0.100163130039258 -0.00424921266980874 -0.0634305064563423 0.0710232434514293
0.0245715250640044 -0.0623743535012955 -0.0904713120619718 -0.0976898586561737
0.0371194125430887 -0.0631011509696530 0.0990569802842190 0.0400480420760457
0.0949605731951244 -0.108789889133778 -0.135677986558041 -0.0901516255466302
-0.0325153731039242 -0.0328981297430227 -0.0858194335235291 -0.111817493331378
0.0740351662477605 0.0973412994403843 -0.0426854699356086 0.00771293235178319
0.0574413130848932 -0.112278653935024 -0.00561654970096530
0.00673480907344132 0.0146967492884145 0.0426178435184212 0.0848511120394312
-0.0190663807051949 -0.106461767346641 0.0821994072939906 0.0230547250694670
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Wjk is 39X2

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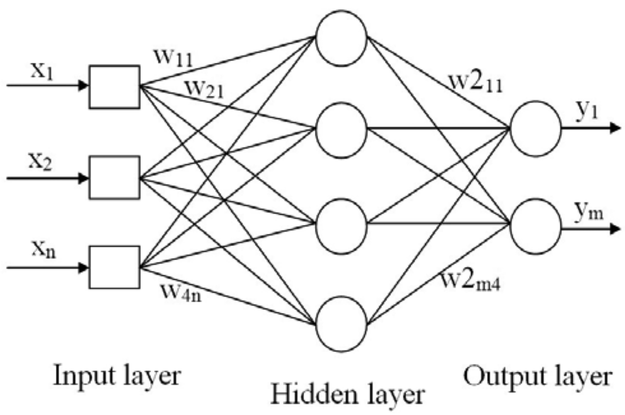
0.487463939772401 0.258201209972127

With the help of these weights I was able to get ZERO error in most of the cases(Weights are initial


Procedure followed:
-First the data was extracted from the files taken from the online resouce.
-Then it was normalized and converted into favourable format.
-After some testing and using m/10 (m = # test cases) 39 was chosen as nH.
-Some random initial weights were picjed and then used for forward mapping.
-Using the training data and back propagation technique some weights were learned.
-They helped in classifying the incoming test cases.
```

3.1. Diagram


x1
x2
xn
w11
w21
w4n
w211
w2m4
y1
ym
Input layer
Hidden layer
Output layer