

```

%*****
% A 2-2-1 or 3-3-1 back-propagation Neural Network
% by Joseph Wunderlich, Ph.D.
%
% 12/11/09:
% Added disabling plotting for speed
% Removed discontinued "flop(s)" function
% 12/10/09:
% Created new file NN2_2009.m
% Added 3-3-1 capability
% Added some great ideas from Matt Drob, Etown CENGR student
% 3/29/04, fixed NN2.m:
%     WcBIAS=WcBIAS+dWcBIAS;
%     WdBIAS=WcBIAS+dWcBIAS;
%     WeBIAS=WcBIAS+dWcBIAS;
%
% Created original files "NN1.m" and "NN2.m" in 1990's
%*****

%***** START TIMER AND INSTRUCTION COUNTER *****
startTIME=cputime;

%***** PICK AN ARCHITECTURE of 2-2-1 or 3-3-1 *****
ARCHITECTURE=1;    %"1" means 2-2-1, "2" means 3-3-1 Network Architecture

%***** 2-2-1 and 3-3-1 INPUT *****
PLOTTING=1;        %Turn plotting on "1" or off "0" for speed
RATE=1;           %Learning Rate
EPOCHcountMAX=4000; %Stop if goal not reached after this many iterations
STOPTolerance=.1; %How close to get to asymptotes at 0 or 1

%Training sets of exemplars for each architecture:
EXEMPLAR_221=[0 0 0; %input1, input2, and desiredoutput for exemplar #1
    0 1 1; %input1, input2, and desiredoutput for exemplar #2
    1 0 1; %input1, input2, and desiredoutput for exemplar #3
    1 1 0]; %input1, input2, and desiredoutput for exemplar #4
EXEMPLAR_331=[0 0 0 0; %input1,2,3 and desiredoutput for exemplar #1
    0 0 1 1; %input1,2,3 and desiredoutput for exemplar #2
    0 1 0 1; %input1,2,3 and desiredoutput for exemplar #3
    0 1 1 1; %input1,2,3 and desiredoutput for exemplar #4
    1 0 0 1; %input1,2,3 and desiredoutput for exemplar #5
    1 0 1 1; %input1,2,3 and desiredoutput for exemplar #6
    1 1 0 1; %input1,2,3 and desiredoutput for exemplar #7
    1 1 1 0]; %input1,2,3 and desiredoutput for exemplar #8

if ARCHITECTURE==1 % START IMPLIMENTING 2-2-1 ARCHITECTURE

%***** 2-2-1 INITIALIZATION *****
Wac=.5; Wad=.6;
Wbc=.7; Wbd=.8;
Wce=.9; Wde=1;
WcBIAS=1; WdBIAS=1; WeBIAS=1;
cBIAS=1; dBIAS=1; eBIAS=1;

```

```

Exemplar1_OutputLAST=[.5 .5 .5]; %just to get it started
Exemplar2_OutputLAST=[.5 .5 .5];
Exemplar3_OutputLAST=[.5 .5 .5];
Exemplar4_OutputLAST=[.5 .5 .5];
EPOCHcount=0;
n=1;

%*****
%***** 2-2-1 MAIN LOOP *****
%*****
while ((EPOCHcount) < EPOCHcountMAX)& ...
    ((abs(Exemplar1_OutputLAST(3)-EXEMPLAR_221(1,3))> STOPtolerance)| ...
    (abs(Exemplar2_OutputLAST(3)-EXEMPLAR_221(2,3))> STOPtolerance)| ...
    (abs(Exemplar3_OutputLAST(3)-EXEMPLAR_221(3,3))> STOPtolerance)| ...
    (abs(Exemplar4_OutputLAST(3)-EXEMPLAR_221(4,3))> STOPtolerance))

EPOCHcount=EPOCHcount+1;
for i=1:4
    Oc=1/(1+exp((-cBIAS*WcBIAS)- EXEMPLAR_221(i,1)*Wac - EXEMPLAR_221(i,2)*Wbc ));
    Od=1/(1+exp((-dBIAS*WdBIAS)- EXEMPLAR_221(i,1)*Wad - EXEMPLAR_221(i,2)*Wbd ));
    Oe=1/(1+exp((-eBIAS*WeBIAS)- Oc*Wce - Od*Wde ));
    if i==1
        Exemplar1_OutputLAST=[EXEMPLAR_221(i,1) EXEMPLAR_221(i,2) Oe];
        if PLOTTING==1
            figure(1);
            plot(EPOCHcount,Oe,'bo');
            hold on;
        end;
    elseif i==2
        Exemplar2_OutputLAST=[EXEMPLAR_221(i,1) EXEMPLAR_221(i,2) Oe];
        if PLOTTING==1
            figure(1);
            plot(EPOCHcount,Oe,'r. ');
            hold on;
        end;
    elseif i==3
        Exemplar3_OutputLAST=[EXEMPLAR_221(i,1) EXEMPLAR_221(i,2) Oe];
        if PLOTTING==1
            figure(1);
            plot(EPOCHcount,Oe,'y. ');
            hold on;
        end;
    else
        Exemplar4_OutputLAST=[EXEMPLAR_221(i,1) EXEMPLAR_221(i,2) Oe];
        if PLOTTING==1
            figure(1);
            plot(EPOCHcount,Oe,'go');
            hold on;
        end;
    end;
end;

Exemplars_OutputLAST=[EPOCHcount/10000 Exemplar1_OutputLAST; ...
    EPOCHcount/10000 Exemplar2_OutputLAST; ...

```

```
EPOCHcount/10000 Exemplar3_OutputLAST; ...
EPOCHcount/10000 Exemplar4_OutputLAST]
```

```
error=EXEMPLAR_221(i,3)-Oe;
errorprop=error*Oe*(1-Oe);
```

```
dWeBIAS=RATE*errorprop*eBIAS;
dWce= RATE*errorprop*Oc;
dWde= RATE*errorprop*Od;
```

```
dWcBIAS=RATE*Oc*(1-Oc)*(errorprop*Wce)*cBIAS;
dWac= RATE*Oc*(1-Oc)*(errorprop*Wce)*EXEMPLAR_221(i,1);
dWbc= RATE*Oc*(1-Oc)*(errorprop*Wce)*EXEMPLAR_221(i,2);
dWdBIAS=RATE*Od*(1-Od)*(errorprop*Wde)*dBIAS;
dWad= RATE*Od*(1-Od)*(errorprop*Wde)*EXEMPLAR_221(i,1);
dWbd= RATE*Od*(1-Od)*(errorprop*Wde)*EXEMPLAR_221(i,2);
```

```
Wac=Wac+dWac;
Wad=Wad+dWad;
Wbc=Wbc+dWbc;
Wbd=Wbd+dWbd;
Wce=Wce+dWce;
Wde=Wde+dWde;
WcBIAS=WcBIAS+dWcBIAS;
WdBIAS=WdBIAS+dWdBIAS;
WeBIAS=WeBIAS+dWeBIAS;
Wdisplay=[Wac Wad Wbc Wbd Wce Wde WcBIAS WdBIAS WeBIAS];
```

```
n=n+1;
```

```
end;
end;
```

```
EPOCHcount
endTIME=cputime-startTIME
```

```
if PLOTTING==1
```

```
figure(1); %open figure window #1
% axis([-120 335 -50 300]); %define x and y axis for figure window #1
title(['LEARNING RATE =',num2str(RATE), ' Stopping tolerance = ',num2str(STOPtolerance),' ' ...
num2str(endTIME), ' secs of CPU time ']);
xlabel('LEARNING EPOCHS');
ylabel('2-2-1 NEURAL NETWORK OUTPUT');
h = legend('00 input','01 input','10 input','11 input',4);
hold on;
```

```
end;
%*****
%***** END 2-2-1 MAIN LOOP
%*****
%*****
%***** END 2-2-1 ARCHITECTURE
```

```
%*****
*****
```

```
%*****
*****
```

```
%***** BEGIN 3-3-1 ARCHITECTURE
```

```
elseif ARCHITECTURE==2 % START IMPLIMENTING 3-3-1 ARCHITECTURE
```

```
%***** 3-3-1 INITIALIZATION *****
```

```
%Weight Values
```

```
%A,B,C are input layer neurons
```

```
%D,E,F are hidden layer neurons
```

```
%G is output layer neuron
```

```
Wad= .4; Wae= .45; Waf= .5;
```

```
Wbd= .55; Wbe= .6; Wbf= .65;
```

```
Wcd= .7; Wce= .75; Wcf= .8;
```

```
Wdg= .85; Weg= .9; Wfg= .63;
```

```
%Bias values (MAY BE CHANGED BASED ON a concurrent SITUATION)
```

```
dBIAS= 1; WdBIAS=1;
```

```
eBIAS= 1; WeBIAS=1;
```

```
fBIAS= 1; WfBIAS=1;
```

```
gBIAS= 1; WgBIAS=1;
```

```
Exemplar1_OutputLAST=[.5 .5 .5 .5]; %just to get it started
```

```
Exemplar2_OutputLAST=[.5 .5 .5 .5];
```

```
Exemplar3_OutputLAST=[.5 .5 .5 .5];
```

```
Exemplar4_OutputLAST=[.5 .5 .5 .5];
```

```
Exemplar5_OutputLAST=[.5 .5 .5 .5];
```

```
Exemplar6_OutputLAST=[.5 .5 .5 .5];
```

```
Exemplar7_OutputLAST=[.5 .5 .5 .5];
```

```
Exemplar8_OutputLAST=[.5 .5 .5 .5];
```

```
EPOCHcount=0;
```

```
n=1;
```

```
%*****
```

```
%***** 3-3-1 MAIN LOOP
```

```
%*****
```

```
while ((EPOCHcount) < EPOCHcountMAX)& ...
```

```
    ((abs(Exemplar1_OutputLAST(4)-EXEMPLAR_331(1,4))> STOPtolerance)| ...
```

```
    (abs(Exemplar2_OutputLAST(4)-EXEMPLAR_331(2,4))> STOPtolerance)| ...
```

```
    (abs(Exemplar3_OutputLAST(4)-EXEMPLAR_331(3,4))> STOPtolerance)| ...
```

```
    (abs(Exemplar4_OutputLAST(4)-EXEMPLAR_331(4,4))> STOPtolerance)| ...
```

```
    (abs(Exemplar5_OutputLAST(4)-EXEMPLAR_331(5,4))> STOPtolerance)| ...
```

```
    (abs(Exemplar6_OutputLAST(4)-EXEMPLAR_331(6,4))> STOPtolerance)| ...
```

```
    (abs(Exemplar7_OutputLAST(4)-EXEMPLAR_331(7,4))> STOPtolerance)| ...
```

```
    (abs(Exemplar8_OutputLAST(4)-EXEMPLAR_331(8,4))> STOPtolerance))
```

```
EPOCHcount=EPOCHcount+1;
```

```
for i=1:8
```

```
Od=1/(1+exp((-dBIAS*WdBIAS)- EXEMPLAR_331(i,1)*Wad - EXEMPLAR_331(i,2)*Wbd - EXEMPLAR_331(i,3)*Wcd ));
```

```
Oe=1/(1+exp((-eBIAS*WeBIAS)- EXEMPLAR_331(i,1)*Wae - EXEMPLAR_331(i,2)*Wbe - EXEMPLAR_331(i,3)*Wce ));
```

```
Of=1/(1+exp((-fBIAS*WfBIAS)- EXEMPLAR_331(i,1)*Waf - EXEMPLAR_331(i,2)*Wbf - EXEMPLAR_331(i,3)*Wcf ));  
Og=1/(1+exp((-gBIAS*WgBIAS)- Od*Wdg - Oe*Weg - Of*Wfg ));
```

```
% 'black', 'white', 'red', 'green', 'blue', 'cyan', 'magenta', 'yellow', 'gray', 'lightBlue', 'orange', 'darkGreen'
```

```
if i==1
```

```
Exemplar1_OutputLAST=[EXEMPLAR_331(i,1) EXEMPLAR_331(i,2) EXEMPLAR_331(i,3) Og];
```

```
if PLOTTING==1
```

```
figure(1);
```

```
plot(EPOCHcount,Og,'redo');
```

```
hold on;
```

```
end;
```

```
elseif i==2
```

```
Exemplar2_OutputLAST=[EXEMPLAR_331(i,1) EXEMPLAR_331(i,2) EXEMPLAR_331(i,3) Og];
```

```
if PLOTTING==1
```

```
figure(1);
```

```
plot(EPOCHcount,Og,'black.');
```

```
hold on;
```

```
end;
```

```
elseif i==3
```

```
Exemplar3_OutputLAST=[EXEMPLAR_331(i,1) EXEMPLAR_331(i,2) EXEMPLAR_331(i,3) Og];
```

```
if PLOTTING==1
```

```
figure(1);
```

```
plot(EPOCHcount,Og,'green.');
```

```
hold on;
```

```
end;
```

```
elseif i==4
```

```
Exemplar4_OutputLAST=[EXEMPLAR_331(i,1) EXEMPLAR_331(i,2) EXEMPLAR_331(i,3) Og];
```

```
if PLOTTING==1
```

```
figure(1);
```

```
plot(EPOCHcount,Og,'blue.');
```

```
hold on;
```

```
end;
```

```
elseif i==5
```

```
Exemplar5_OutputLAST=[EXEMPLAR_331(i,1) EXEMPLAR_331(i,2) EXEMPLAR_331(i,3) Og];
```

```
if PLOTTING==1
```

```
figure(1);
```

```
plot(EPOCHcount,Og,'cyan.');
```

```
hold on;
```

```
end;
```

```
elseif i==6
```

```
Exemplar6_OutputLAST=[EXEMPLAR_331(i,1) EXEMPLAR_331(i,2) EXEMPLAR_331(i,3) Og];
```

```
if PLOTTING==1
```

```
figure(1);
```

```
plot(EPOCHcount,Og,'magenta.');
```

```
hold on;
```

```
end;
```

```
elseif i==7
```

```
Exemplar7_OutputLAST=[EXEMPLAR_331(i,1) EXEMPLAR_331(i,2) EXEMPLAR_331(i,3) Og];
```

```
if PLOTTING==1
```

```
figure(1);
```

```
plot(EPOCHcount,Og,'yellow.');
```

```
hold on;
```

```
end;
```

```

else
Exemplar8_OutputLAST=[EXEMPLAR_331(i,1) EXEMPLAR_331(i,2) EXEMPLAR_331(i,3) Og];
if PLOTTING==1
figure(1);
plot(EPOCHcount,Og,'blacko');
hold on;
end;
end;

```

```

Exemplars_OutputLAST=[EPOCHcount/10000 Exemplar1_OutputLAST; ...
EPOCHcount/10000 Exemplar2_OutputLAST; ...
EPOCHcount/10000 Exemplar3_OutputLAST; ...
EPOCHcount/10000 Exemplar4_OutputLAST; ...
EPOCHcount/10000 Exemplar5_OutputLAST; ...
EPOCHcount/10000 Exemplar6_OutputLAST; ...
EPOCHcount/10000 Exemplar7_OutputLAST; ...
EPOCHcount/10000 Exemplar8_OutputLAST]

```

```

error=EXEMPLAR_331(i,4)-Og;
errorprop=error*Og*(1-Og);

```

```

dWgBIAS=RATE*errorprop*gBIAS;
dWdg= RATE*errorprop*Od;
dWeg= RATE*errorprop*Oe;
dWfg= RATE*errorprop*Of;

```

```

dWdBIAS=RATE*Od*(1-Od)*(errorprop*Wdg)*dBIAS;
dWad= RATE*Od*(1-Od)*(errorprop*Wdg)*EXEMPLAR_331(i,1);
dWbd= RATE*Od*(1-Od)*(errorprop*Wdg)*EXEMPLAR_331(i,2);
dWcd= RATE*Od*(1-Od)*(errorprop*Wdg)*EXEMPLAR_331(i,3);

```

```

dWeBIAS=RATE*Oe*(1-Oe)*(errorprop*Weg)*eBIAS;
dWae= RATE*Oe*(1-Oe)*(errorprop*Weg)*EXEMPLAR_331(i,1);
dWbe= RATE*Oe*(1-Oe)*(errorprop*Weg)*EXEMPLAR_331(i,2);
dWce= RATE*Oe*(1-Oe)*(errorprop*Weg)*EXEMPLAR_331(i,3);

```

```

dWfBIAS=RATE*Of*(1-Of)*(errorprop*Wfg)*fBIAS;
dWaf= RATE*Of*(1-Of)*(errorprop*Wfg)*EXEMPLAR_331(i,1);
dWbf= RATE*Of*(1-Of)*(errorprop*Wfg)*EXEMPLAR_331(i,2);
dWcf= RATE*Of*(1-Of)*(errorprop*Wfg)*EXEMPLAR_331(i,3);

```

```

Wad=Wad+dWad; Wbd=Wbd+dWbd; Wcd=Wcd+dWcd;
Wae=Wae+dWae; Wbe=Wbe+dWbe; Wce=Wce+dWce;
Waf=Waf+dWaf; Wbf=Wbf+dWbf; Wcf=Wcf+dWcf;

```

```

Wdg=Wdg+dWdg; Weg=Weg+dWeg; Wfg=Wfg+dWfg;
WdBIAS=WdBIAS+dWdBIAS;
WeBIAS=WeBIAS+dWeBIAS;
WfBIAS=WfBIAS+dWfBIAS;
WgBIAS=WgBIAS+dWgBIAS;

```

```

Wdisplay=[Wad Wbd Wcd Wae Wbe Wce Waf Wbf Wcf Wdg Weg Wfg WdBIAS WeBIAS WfBIAS WgBIAS];

```

```

n=n+1;

```

```

end;
end;

EPOCHcount
endTIME=cputime-startTIME

if PLOTTING==1
    figure(1);          %open figure window #1
    % axis([-120 335 -50 300]); %define x and y axis for figure window #1
    title(['LEARNING RATE =',num2str(RATE), ' Stopping tolerance = ',num2str(STOPtolerance),' ' ...
        num2str(endTIME), ' secs of CPU time ']);
    xlabel('LEARNING EPOCHS');
    ylabel('3-3-1 NEURAL NETWORK OUTPUT');
    h = legend('000 input','001 input','010 input','011 input','100 input','101 input','110 input','111 input',8);
    hold on;
end;
%*****
*
%***** END 3-3-1 MAIN LOOP
%*****
*

%***** END 3-3-1 ARCHITECTURE
%*****
*
end;

```