Perceptron Training Procedure

## Binary Threshold Neuron

$$
1 \times 2.51+1 \times 0.13+0 \times-1.27+\ldots+1 \times 0.09+-0.5=2.23
$$

Output unit:

Input units:

$$
2.23 \geq 0
$$

Weighted connections:



Input Pattern

## Perceptrons

- Binary threshold neurons
- Studied by Frank Rosenblatt of Cornell in early 1960's
- Perceptron training procedure



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1. present an input pattern target $=1$


## Perceptrons

- Binary threshold neurons
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- Perceptron training procedure

1. present an input pattern target $=1$
2. compute output value
```
if sum \geq0: output = 1
if sum < 0: output = 0
```



## Perceptrons

- Binary threshold neurons
- Studied by Frank Rosenblatt of Cornell in early 1960's
- Perceptron training procedure

1. present an input pattern
2. compute output value

$$
\text { output }=\Theta(\text { sum of inputs } \times \text { weights }+ \text { bias })
$$

3. compare output to target value

$$
\text { error }=\text { target }- \text { output }
$$



## Perceptrons

- Binary threshold neurons
- Studied by Frank Rosenblatt of Cornell in early 1960's
- Perceptron training procedure

1. present an input pattern
2. compute output value

$$
\text { output }=\Theta(\text { sum of inputs } \times \text { weights }+ \text { bias })
$$

3. compare output to target value

$$
\text { error }=\text { target }- \text { output }
$$

4. if incorrect, adjust weights and bias

$$
\begin{aligned}
& \text { target }=1 \\
& \text { error }=1-0=1
\end{aligned}
$$



```
weight_adjustment = \varepsilon }\times\mathrm{ input }\times\mathrm{ error
bias_adjustment = \varepsilon }\times\mathrm{ error

\section*{Perceptrons}
- Binary threshold neurons
- Studied by Frank Rosenblatt of Cornell in early 1960's
- Perceptron training procedure
1. present an input pattern
2. compute output value
\[
\text { output }=\Theta(\text { sum of inputs } \times \text { weights }+ \text { bias })
\]
3. compare output to target value
\[
\text { error }=\text { target }- \text { output }
\]
4. if incorrect, adjust weights and bias weight_adjustment \(=\varepsilon \times\) input \(\times\) error

5. repeat until all input patterns give the correct output value

\section*{Perceptron Training Example}


\section*{Compute Output for Pattern 00}

Input Target Output
Learning rate \(\varepsilon=0.2\)
\(00 \Rightarrow 1 \quad 1\) ok
\(01 \Rightarrow 0\)
\(10 \Rightarrow 1\)
\(11 \Rightarrow 0\)

\[
0 \times 0.2+0 \times-0.1+0.1=0.1 \geq 0 \quad \text { output }=1
\]

\section*{Compute Output for Pattern 01}
Input Target Output
Learning rate \(\varepsilon=0.2\)
\[
\begin{aligned}
& 00 \Rightarrow 1 \\
& 01 \Rightarrow 0
\end{aligned}
\]
1 ok
\(10 \Rightarrow 1\)
\(11 \Rightarrow 0\)
\(10 \Rightarrow 1\)
\(11 \Rightarrow 0\)
1 wrong
\(0 \times 0.2+1 \times-0.1+0.1=0 \geq 0 \quad\) output \(=1\)

\section*{Compute Output for Pattern 01}
Input Target Output

Learning rate \(\varepsilon=0.2\)
\(0 \Rightarrow 1\)
1 ok
\(01 \Rightarrow 0\)
1 wrong
\(10 \Rightarrow 1\)
\(11 \Rightarrow 0\)
\[
\text { error }=\text { target }- \text { output }=0-1=-1
\]

\section*{Compute Output for Pattern 01}
Input Target Output
\(00 \Rightarrow 1 \quad 1\) ok
1 wrong
\(10 \Rightarrow 1\)
\(11 \Rightarrow 0\)
\[
\begin{aligned}
& 0 \quad 0 \Rightarrow 1 \\
& 01 \Rightarrow 0
\end{aligned}
\]

Learning rate \(\varepsilon=0.2\)

\[
\text { error }=\text { target }- \text { output }=0-1=-1
\]
amount to change weight \({ }_{1}\)
\[
=\varepsilon \times \text { error } \times \text { input }_{1}=0.2 \times-1 \times 0=0
\]

\section*{Compute Output for Pattern 01}
Input Target Output
\(00 \Rightarrow 1 \quad 1\) ok
1 wrong
\(10 \Rightarrow 1\)
\(11 \Rightarrow 0\)
\[
\begin{aligned}
& 00 \Rightarrow 1 \\
& 01 \Rightarrow 0
\end{aligned}
\]

Learning rate \(\varepsilon=0.2\)

error \(=\) target - output \(=0-1=-1\)
amount to change weight \({ }_{1}\)
\[
=\varepsilon \times \text { error } \times \text { input }_{1}=0.2 \times-1 \times 0=0
\]
new value of weight \({ }_{1}\)
\[
=0.2+0=0.2
\]

\section*{Compute Output for Pattern 01}
Input Target Output
\(00 \Rightarrow 1 \quad 1\) ok
1 wrong
\(10 \Rightarrow 1\)
\(11 \Rightarrow 0\)
\[
\begin{aligned}
& 00 \Rightarrow 1 \\
& 01 \Rightarrow 0
\end{aligned}
\]

Learning rate \(\varepsilon=0.2\)

\[
\text { error }=\text { target }- \text { output }=0-1=-1
\]
amount to change weight \({ }_{2}\)
\[
=\varepsilon \times \text { error } \times \text { input }_{2}=0.2 \times-1 \times 1=-0.2
\]

\section*{Compute Output for Pattern 01}
Input Target
\(0 \Rightarrow 1\)
\(01 \Rightarrow 0\)
\(10 \Rightarrow 1\)
\(11 \Rightarrow 0\)

1 ok

1 wrong
Output

Learning rate \(\varepsilon=0.2\)

\[
\text { error }=\text { target }- \text { output }=0-1=-1
\]
amount to change weight \({ }_{2}\)
\[
=\varepsilon \times \text { error } \times \text { input }_{2}=0.2 \times-1 \times 1=-0.2
\]
new value of weight \({ }_{2}\)
\[
=-0.1+-0.2=-0.3
\]

\section*{Compute Output for Pattern 01}
Input Target Output
Learning rate \(\varepsilon=0.2\)
\(00 \Rightarrow 1\)
\(01 \Rightarrow 0\)
1 ok
1 wrong
\(10 \Rightarrow 1\)
\(11 \Rightarrow 0\)

error \(=\) target - output \(=0-1=-1\)
amount to change bias
\[
=\varepsilon \times \text { error }=0.2 \times-1=-0.2
\]

\section*{Compute Output for Pattern 01}

Input Target Output
\(00 \Rightarrow 1\)
1 ok
\(01 \Rightarrow 0\)
1 wrong
\(10 \Rightarrow 1\)
\(11 \Rightarrow 0\)
error \(=\) target - output \(=0-1=-1\)
amount to change bias
\[
=\varepsilon \times \text { error }=0.2 \times-1=-0.2
\]
new value of bias
\[
=0.1+-0.2=-0.1
\]

\section*{Compute Output for Pattern 10}
\[
\begin{aligned}
& \text { Input Target Output } \\
& \text { Learning rate } \varepsilon=0.2 \\
& \begin{array}{l}
00 \Rightarrow 1 \\
01 \Rightarrow 0
\end{array} \\
& 1 \text { ok } \\
& 1 \text { wrong } \\
& 10 \Rightarrow 1 \quad 1 \text { ok } \\
& 11 \Rightarrow 0 \\
& 1 \times 0.2+0 \times-0.3+-0.1=0.1 \geq 0 \quad \text { output }=1
\end{aligned}
\]

\section*{Compute Output for Pattern 11}
\[
\begin{aligned}
& \text { Input Target Output } \\
& \text { Learning rate } \varepsilon=0.2 \\
& 00 \Rightarrow 1 \quad 1 \text { ok } \\
& 01 \Rightarrow 0 \\
& 1 \text { wrong } \\
& 10 \Rightarrow 1 \\
& 1 \text { ok } \\
& 11 \Rightarrow 0 \\
& 0 \text { ok } \\
& 1 \times 0.2+1 \times-0.3+-0.1=-0.2<0 \text { output }=0
\end{aligned}
\]

\section*{Compute Output for Pattern 00}
\[
\begin{aligned}
& \text { Input } \quad \text { Target } \\
& 00 \Rightarrow 1 \\
& 01 \Rightarrow 0 \\
& 01 \\
& 10 \Rightarrow 1 \\
& 11 \Rightarrow 0 \\
& 10
\end{aligned}
\]

\section*{Compute Output for Pattern 00}
Input Target Output Learning rate \(\varepsilon=0.2\)
\(00 \Rightarrow 1\)
0 wrong
\(01 \Rightarrow 0\)
\(10 \Rightarrow 1\)
\(11 \Rightarrow 0\)
\[
\text { error }=\text { target }- \text { output }=1-0=1
\]

\section*{Compute Output for Pattern 00}
Input Target Output
\(00 \Rightarrow 1 \quad 0\) wrong
\(01 \Rightarrow 0\)
\(10 \Rightarrow 1\)
\(01 \Rightarrow 0\)
\(10 \Rightarrow 1\)
\(11 \Rightarrow 0\)

Learning rate \(\varepsilon=0.2\)

error \(=\) target - output \(=1-0=1\)
amount to change weight \({ }_{1}\)
\[
=\varepsilon \times \text { error } \times \text { input }_{1}=0.2 \times 1 \times 0=0
\]

\section*{Compute Output for Pattern 00}

Input Target
\(00 \Rightarrow 1\)
0 wrong
\(01 \Rightarrow 0\)
\(10 \Rightarrow 1\)
\(11 \Rightarrow 0\)
Output
error \(=\) target - output \(=1-0=1\)
amount to change weight \({ }_{1}\)
\[
=\varepsilon \times \text { error } \times \text { input }_{1}=0.2 \times 1 \times 0=\mathbf{0}
\]
new value of weight \({ }_{1}\)
\[
=0.2+0=0.2
\]

Learning rate \(\varepsilon=0.2\)


\section*{Compute Output for Pattern 00}
Input Target Output
\(00 \Rightarrow 1 \quad 0\) wrong
\(01 \Rightarrow 0\)
\(10 \Rightarrow 1\)
\(01 \Rightarrow 0\)
\(10 \Rightarrow 1\)
\(11 \Rightarrow 0\)

Learning rate \(\varepsilon=0.2\)

error \(=\) target - output \(=1-0=1\)
amount to change weight \({ }_{2}\)
\[
=\varepsilon \times \text { error } \times \text { input }_{2}=0.2 \times 1 \times 0=0
\]

\section*{Compute Output for Pattern 00}

Input Target Output
\(00 \Rightarrow 1 \quad 0\) wrong
\(01 \Rightarrow 0\)
\(10 \Rightarrow 1\)
\(11 \Rightarrow 0\)

Learning rate \(\varepsilon=0.2\)

error \(=\) target - output \(=1-0=1\)
amount to change weight \({ }_{2}\)
\[
=\varepsilon \times \text { error } \times \text { input }_{2}=0.2 \times 1 \times 0=0
\]
new value of weight \({ }_{2}\)
\[
=-0.3+0=-0.3
\]

\section*{Compute Output for Pattern 00}
Input Target Output
\(00 \Rightarrow 1 \quad 0\) wrong
\(01 \Rightarrow 0\)
\(10 \Rightarrow 1\)
\(01 \Rightarrow 0\)
\(10 \Rightarrow 1\)
\(11 \Rightarrow 0\)

Learning rate \(\varepsilon=0.2\)

\[
\text { error }=\text { target }- \text { output }=1-0=1
\]
amount to change bias
\[
=\varepsilon \times \text { error }=0.2 \times 1=0.2
\]

\section*{Compute Output for Pattern 00}

Input Target Output
\(00 \Rightarrow 1 \quad 0\) wrong
\(01 \Rightarrow 0\)
\(10 \Rightarrow 1\)
\(11 \Rightarrow 0\)

Learning rate \(\varepsilon=0.2\)

error \(=\) target - output \(=1-0=1\)
amount to change bias
\[
=\varepsilon \times \text { error }=0.2 \times 1=0.2
\]
new value of bias
\[
=-0.1+0.2=0.1
\]

\section*{Compute Output for Pattern 01}
\[
\begin{aligned}
& \text { Input Target Output Learning rate } \varepsilon=0.2 \\
& 00 \Rightarrow 1 \quad 0 \text { wrong } \\
& 01 \Rightarrow 0 \\
& 0 \text { ok } \\
& 10 \Rightarrow 1 \\
& 11 \Rightarrow 0 \\
& 0 \times 0.2+1 \times-0.3+0.1=-0.2<0 \quad \text { output }=0
\end{aligned}
\]

\section*{Compute Output for Pattern 10}
\[
\begin{aligned}
& \text { Input Target Output Learning rate } \varepsilon=0.2 \\
& 00 \Rightarrow 1 \quad 0 \text { wrong } \\
& 01 \Rightarrow 0 \quad 0 \text { ok } \\
& 10 \Rightarrow 1 \quad 1 \text { ok } \\
& 11 \Rightarrow 0 \\
& 1 \times 0.2+0 \times-0.3+0.1=0.3 \geq 0 \quad \text { output }=1
\end{aligned}
\]

\section*{Compute Output for Pattern 11}
\[
\begin{aligned}
& \text { Input Target Output Learning rate } \varepsilon=0.2 \\
& 00 \Rightarrow 1 \quad 0 \text { wrong } \\
& 01 \Rightarrow 0 \quad 0 \text { ok } \\
& 10 \Rightarrow 1 \\
& 1 \text { ok } \\
& 11 \Rightarrow 0 \quad 1 \text { wrong } \\
& 1 \times 0.2+1 \times-0.3+0.1=0 \geq 0 \quad \text { output }=1
\end{aligned}
\]

\section*{Compute Output for Pattern 11}

Input Target Output
\[
\begin{array}{lll}
0 & 0 \Rightarrow 1 & 0 \text { wrong } \\
01 \Rightarrow 0 & & 0 \text { ok } \\
1 & 0 \Rightarrow 1 & 1 \text { ok } \\
1 & 1 \Rightarrow 0 & 1 \text { wrong }
\end{array}
\]
Learning rate \(\varepsilon=0.2\)
\[
\text { error }=\text { target }- \text { output }=0-1=-1
\]

\section*{Compute Output for Pattern 11}

Input Target
\(00 \Rightarrow 1\)
0 wrong
\(01 \Rightarrow 0\)
0 ok
1 ok
1 wrong

Learning rate \(\varepsilon=0.2\)

\[
\text { error }=\text { target }- \text { output }=0-1=-1
\]
amount to change weight \({ }_{1}\)
\[
=\varepsilon \times \text { error } \times \text { input }_{1}=0.2 \times-1 \times 1=-\mathbf{0 . 2}
\]

\section*{Compute Output for Pattern 11}
Input Target Output

\[
00 \Rightarrow 1
\]

\[
0 \text { wrong }
\]

\[
01 \Rightarrow 0
\]

\[
0 \text { ok }
\]

\[
10 \Rightarrow 1
\]

\[
1 \text { ok }
\]

\[
11 \Rightarrow 0
\]

\[
1 \text { wrong }
\]
\[
\text { error }=\text { target }- \text { output }=0-1=-1
\]
amount to change weight \({ }_{1}\)
\[
=\varepsilon \times \text { error } \times \text { input }_{1}=0.2 \times-1 \times 1=-\mathbf{0 . 2}
\]
new value of weight \({ }_{1}\)
\[
=0.2+-0.2=0
\]

\section*{Compute Output for Pattern 11}
Input Target Output
\(00 \Rightarrow 1\)
0 wrong
0 ok
\(10 \Rightarrow 1\)
1 ok
\(11 \Rightarrow 0\)
1 wrong
Learning rate \(\varepsilon=0.2\)
\[
01 \Rightarrow 0
\]
error \(=\) target - output \(=0-1=-1\)
amount to change weight \({ }_{2}\)
\[
=\varepsilon \times \text { error } \times \text { input }_{2}=0.2 \times-1 \times 1=-0.2
\]

\section*{Compute Output for Pattern 11}
Input Target Output

\[
00 \Rightarrow 1
\]

\[
0 \text { wrong }
\]

\[
01 \Rightarrow 0
\]

\[
0 \text { ok }
\]

\(10 \Rightarrow 1\)

\[
1 \text { ok }
\]

\[
11 \Rightarrow 0
\]

\[
1 \text { wrong }
\]
error \(=\) target - output \(=0-1=-1\)
amount to change weight \({ }_{2}\)
\[
=\varepsilon \times \text { error } \times \text { input }_{2}=0.2 \times-1 \times 1=-\mathbf{0 . 2}
\]
new value of weight \({ }_{2}\)
\[
=-0.3+-0.2=-0.5
\]

\section*{Compute Output for Pattern 11}
\[
\begin{aligned}
& \text { Input Target Output Learning rate } \varepsilon=0.2 \\
& 00 \Rightarrow 1 \\
& 0 \text { wrong } \\
& 01 \Rightarrow 0 \\
& 0 \text { ok } \\
& 1 \text { ok } \\
& 1 \text { wrong } \\
& 10 \Rightarrow 1 \\
& 11 \Rightarrow 0 \\
& \text { error }=\text { target }- \text { output }=0-1=-1 \\
& \text { amount to change bias } \\
& =\varepsilon \times \text { error }=0.2 \times-1=-0.2
\end{aligned}
\]

\section*{Compute Output for Pattern 11}
Input Target Output
\[
\begin{aligned}
& 00 \Rightarrow 1 \\
& 01 \Rightarrow 0
\end{aligned}
\]
0 wrong
0 wro
0 ok
\(10 \Rightarrow 1\)
1 ok
\(11 \Rightarrow 0\)
1 wrong

Learning rate \(\varepsilon=0.2\)
error \(=\) target - output \(=0-1=-1\)
amount to change bias
\[
=\varepsilon \times \text { error }=0.2 \times-1=-0.2
\]
new value of bias
\[
=0.1+-0.2=-0.1
\]

\section*{Compute Output for Pattern 00}
\[
\begin{aligned}
& \text { Input } \\
& \text { Target } \\
& 00 \Rightarrow 1
\end{aligned}
\]

\section*{Compute Output for Pattern 00}
Input Target Output Learning rate \(\varepsilon=0.2\)
\[
00 \Rightarrow 1 \quad 0 \text { wrong }
\]
\(01 \Rightarrow 0\)
\(10 \Rightarrow 1\)
\(11 \Rightarrow 0\)

\[
\text { error }=\text { target }- \text { output }=1-0=1
\]

\section*{Compute Output for Pattern 00}

Input Target Output
\(00 \Rightarrow 1 \quad 0\) wrong
\(01 \Rightarrow 0\)
\(10 \Rightarrow 1\)
\(11 \Rightarrow 0\)
amount to change weight \({ }_{1}\)
\[
=\varepsilon \times \text { error } \times \text { input }_{1}=0.2 \times 1 \times 0=0
\]

\section*{Compute Output for Pattern 00}

Input Target
\(00 \Rightarrow 1\)
\(01 \Rightarrow 0\)
\(10 \Rightarrow 1\)
\(11 \Rightarrow 0\)

Output
0 wrong
error \(=\) target - output \(=1-0=1\)
amount to change weight \({ }_{1}\)
\[
=\varepsilon \times \text { error } \times \text { input }_{1}=0.2 \times 1 \times 0=0
\]
new value of weight \({ }_{1}\)
\[
=0+0=0
\]

\section*{Compute Output for Pattern 00}
Input Target Output
\[
\begin{aligned}
& 00 \Rightarrow 1 \quad 0 \text { wrong } \\
& 01 \Rightarrow 0 \\
& 10 \Rightarrow 1 \\
& 11 \Rightarrow 0
\end{aligned}
\]

Learning rate \(\varepsilon=0.2\)
\[
\text { error }=\text { target }- \text { output }=1-0=1
\]
\[
\text { amount to change weight }{ }_{2}
\]
\[
=\varepsilon \times \text { error } \times \text { input }_{2}=0.2 \times 1 \times 0=0
\]

\section*{Compute Output for Pattern 00}

Input Target
\(00 \Rightarrow 1\)
\(01 \Rightarrow 0\)
\(10 \Rightarrow 1\)
\(11 \Rightarrow 0\)

Output
0 wrong

Learning rate \(\varepsilon=0.2\)

error \(=\) target - output \(=1-0=1\)
amount to change weight \({ }_{2}\)
\[
=\varepsilon \times \text { error } \times \text { input }_{2}=0.2 \times 1 \times 0=0
\]
new value of weight \({ }_{2}\)
\[
=-0.5+0=-0.5
\]

\section*{Compute Output for Pattern 00}
Input Target Output
\(00 \Rightarrow 1 \quad 0\) wrong
\(01 \Rightarrow 0\)
\(10 \Rightarrow 1\)
\(01 \Rightarrow 0\)
\(10 \Rightarrow 1\)
\(11 \Rightarrow 0\)

Learning rate \(\varepsilon=0.2\)

error \(=\) target - output \(=1-0=1\)
amount to change bias
\[
=\varepsilon \times \text { error }=0.2 \times 1=0.2
\]

\section*{Compute Output for Pattern 00}

Input Target
\(00 \Rightarrow 1\)
0 wrong
\(01 \Rightarrow 0\)
\(10 \Rightarrow 1\)
\(11 \Rightarrow 0\)
Output
error \(=\) target - output \(=1-0=1\)
amount to change bias
\[
=\varepsilon \times \text { error }=0.2 \times 1=0.2
\]
new value of bias
\[
=-0.1+0.2=0.1
\]

Learning rate \(\varepsilon=0.2\)


\section*{Compute Output for Pattern 01}
\[
\begin{aligned}
& \text { Input Target Output Learning rate } \varepsilon=0.2 \\
& 00 \Rightarrow 1 \quad 0 \text { wrong } \\
& 01 \Rightarrow 0 \\
& 0 \text { ok } \\
& 10 \Rightarrow 1 \\
& 11 \Rightarrow 0 \\
& 0 \times 0+1 \times-0.5+0.1=-0.4<0 \quad \text { output }=0
\end{aligned}
\]

\section*{Compute Output for Pattern 10}
\[
\begin{aligned}
& \text { Input } \begin{array}{l}
\text { Target } \\
00 \Rightarrow 1
\end{array} \begin{array}{l}
\text { Output } \\
01 \Rightarrow 0
\end{array} \quad 0 \text { wrong } \\
& 01 \Rightarrow 1 \\
& 10 \Rightarrow 0 \\
& 11 \Rightarrow 0+0 \times-0.5+0.1=0.1 \geq 0 \quad \text { output }=1
\end{aligned}
\]

\section*{Compute Output for Pattern 11}
\[
\begin{aligned}
& \text { Input } \\
& \begin{array}{l}
\text { Target } \\
00 \Rightarrow 1
\end{array} \\
& \begin{array}{l}
\text { Output }
\end{array} \\
& 01 \Rightarrow 0
\end{aligned}
\]

\section*{Compute Output for Pattern 00}
\[
\begin{aligned}
& \text { Input } \quad \text { Target } \\
& 00 \Rightarrow 1 \\
& 01 \Rightarrow 0 \\
& 01
\end{aligned}
\]

\section*{Compute Output for Pattern 01}
\[
\begin{aligned}
& \text { Input Target Output } \\
& 00 \Rightarrow 1 \quad 1 \text { ok } \\
& 01 \Rightarrow 0 \\
& 0 \text { ok } \\
& 10 \Rightarrow 1 \\
& 11 \Rightarrow 0 \\
& 0 \times 0+1 \times-0.5+0.1=-0.4<0 \quad \text { output }=0
\end{aligned}
\]

\section*{Compute Output for Pattern 10}
\[
\begin{aligned}
& \text { Input Target Output } \\
& \text { Learning rate } \varepsilon=0.2 \\
& 00 \Rightarrow 1 \quad 1 \text { ok } \\
& 01 \Rightarrow 0 \\
& 0 \text { ok } \\
& 10 \Rightarrow 1 \\
& 1 \text { ok } \\
& 11 \Rightarrow 0 \\
& 1 \times 0+0 \times-0.5+0.1=0.1 \geq 0 \quad \text { output }=1
\end{aligned}
\]

\section*{Compute Output for Pattern 11}
\[
\begin{aligned}
& \text { Input Target Output } \\
& \text { Learning rate } \varepsilon=0.2 \\
& 00 \Rightarrow 1 \quad 1 \text { ok } \\
& 01 \Rightarrow 0 \\
& 0 \text { ok } \\
& 10 \Rightarrow 1 \\
& 1 \text { ok } \\
& 11 \Rightarrow 0 \\
& 0 \text { ok } \\
& 1 \times 0+1 \times-0.5+0.1=-0.4<0 \quad \text { output }=0
\end{aligned}
\]

\section*{Compute Output for Pattern 11}
```

