ARTIFICIAL NEURAL NETWORKS

Scholastic Video Book Series

Artificial Neural Networks

Part 3

(Back Propagation)

(with English Narrations)

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Artificial Neural Networks - #3

Back-Propagation

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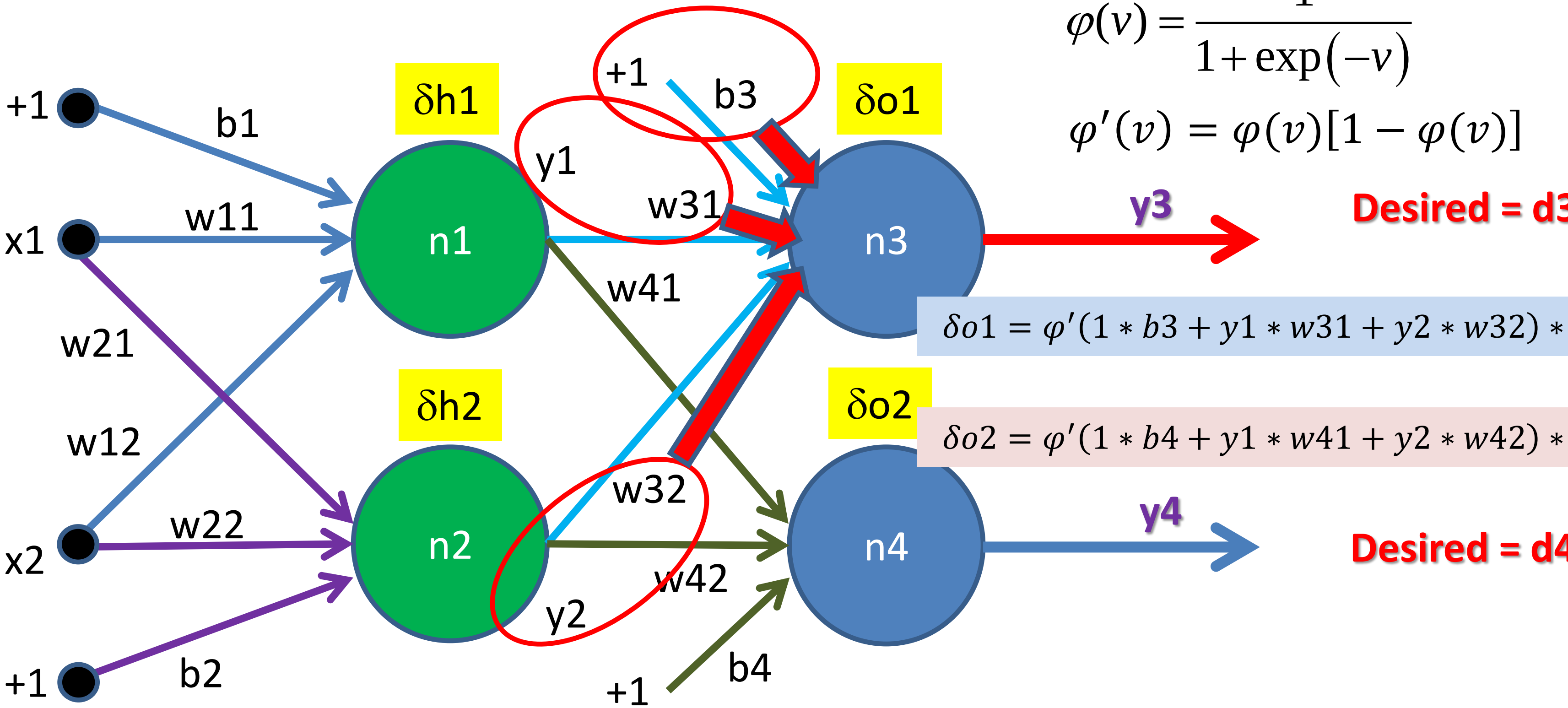
Back-Propagation Algorithm

- **Step 1:** Calculate the local gradients (δo1, δo2, δh1 and δh2) for the nodes in the network.

$$\varphi(v) = \frac{1}{1+\exp(-v)}$$

$$\varphi'(v) = \varphi(v)[1-\varphi(v)]$$



$$\delta o1 = \varphi'(1 * b3 + y1 * w31 + y2 * w32) * (d3 - y3)$$

$$\delta o2 = \varphi'(1 * b4 + y1 * w41 + y2 * w42) * (d4 - y4)$$

$$\delta h1 = \varphi'(1 * b1 + x1 * w11 + x2 * w12)(\delta o1 * w31 + \delta o2 * w41)$$

$$\delta h2 = \varphi'(1 * b2 + x1 * w21 + x2 * w22)(\delta o1 * w32 + \delta o2 * w42)$$

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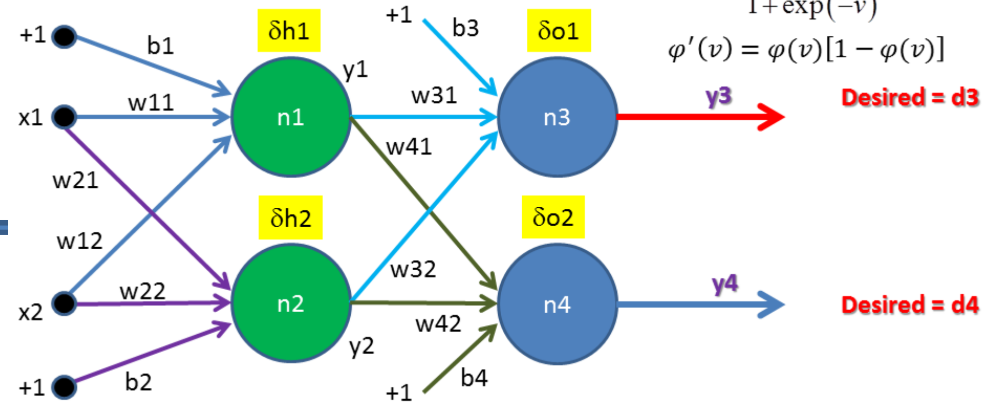
Back-Propagation Algorithm

$$\varphi(v) = \frac{1}{1+\exp(-v)}$$

$$\varphi'(v) = \varphi(v)[1-\varphi(v)]$$



- **Step 2:** Adjust the weights of the network using the learning rule:
- $\boldsymbol{w(n+1) = w(n) + \alpha * w(n-1) + \eta * \delta(n) * y}$
- $w31(n+1) = w31(n) + \alpha * w31(n-1) + \eta * \delta o1(n) * y1$
- $w41(n+1) = w41(n) + \alpha * w41(n-1) + \eta * \delta o2(n) * y1$
- $w32(n+1) = w32(n) + \alpha * w32(n-1) + \eta * \delta o1(n) * y2$
- $w42(n+1) = w42(n) + \alpha * w42(n-1) + \eta * \delta o2(n) * y2$
- $w11(n+1) = w11(n) + \alpha * w11(n-1) + \eta * \delta h1(n) * x1$
- $w21(n+1) = w21(n) + \alpha * w21(n-1) + \eta * \delta h2(n) * x1$
- $w12(n+1) = w12(n) + \alpha * w12(n-1) + \eta * \delta h1(n) * x2$
- $w22(n+1) = w22(n) + \alpha * w22(n-1) + \eta * \delta h2(n) * x2$
- $b3(n+1) = b3(n) + \alpha * b3(n-1) + \eta * \delta o1(n) * 1$
- $b4(n+1) = b4(n) + \alpha * b4(n-1) + \eta * \delta o2(n) * 1$
- $b1(n+1) = b1(n) + \alpha * b1(n-1) + \eta * \delta h1(n) * 1$
- $b2(n+1) = b2(n) + \alpha * b2(n-1) + \eta * \delta h2(n) * 1$

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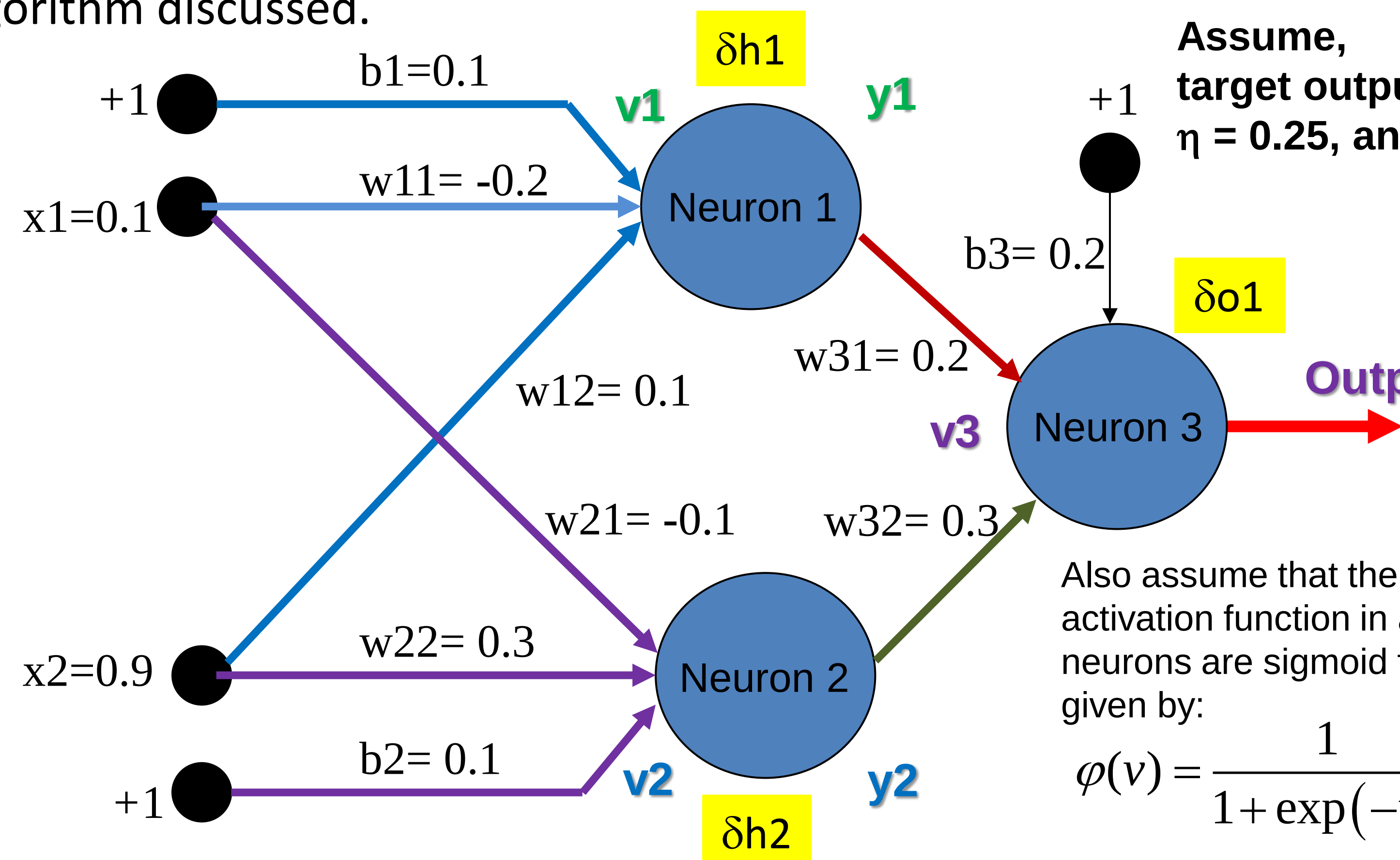
Back-Propagation - Example

- Let's perform a complete forward and backward sweep of the feedforward network (2-2-1 architecture) shown below using the back propagation algorithm discussed.



Assume,
target output = 0.9,
η = 0.25, and α=0.0001

Also assume that the activation function in all 3 neurons are sigmoid functions given by:

$$\varphi(v) = \frac{1}{1+\exp(-v)}$$

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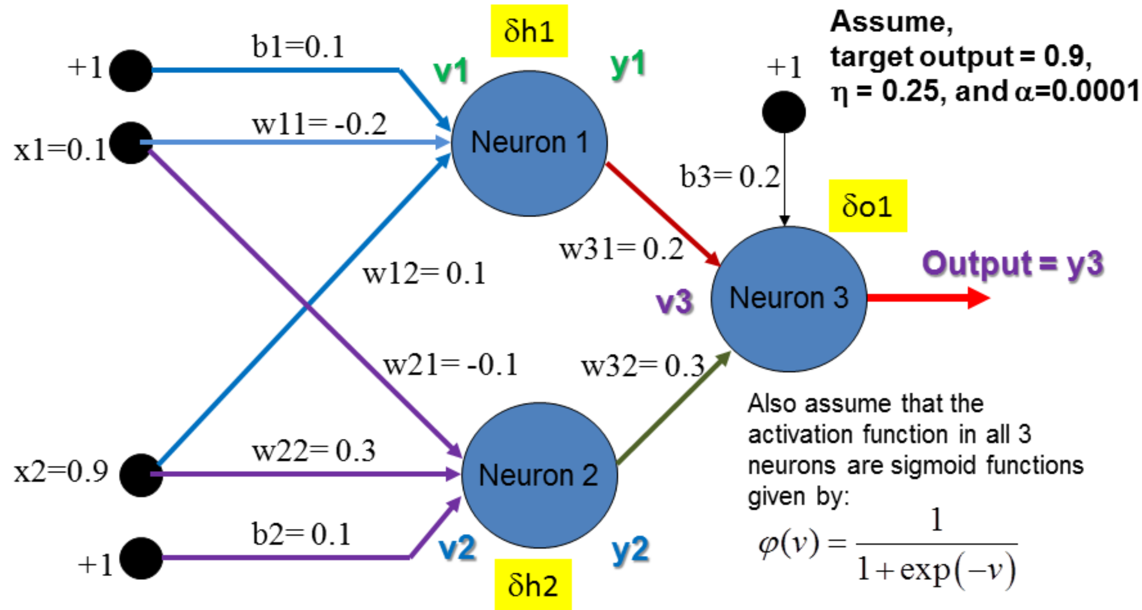

- $v1 = 1 * b1 + x1 * w11 + x2 * w12 = 1 * 0.1 + 0.1 * (-0.2) + 0.9 * 0.1 = 0.17$
- $y1 = \varphi(v1) = \varphi(0.17) = \frac{1}{1+\exp(-0.17)} = 0.542$
- $v2 = 1 * b2 + x1 * w21 + x2 * w22 = 1 * 0.1 + 0.1 * (-0.1) + 0.9 * 0.3 = 0.36$
- $y2 = \varphi(v2) = \varphi(0.36) = \frac{1}{1+\exp(-0.36)} = 0.589$
- $v3 = 1 * b3 + y1 * w31 + y2 * w32 = 1 * 0.2 + 0.542 * 0.2 + 0.589 * 0.3 = 0.485$
- $y3 = \varphi(v3) = \varphi(0.485) = \frac{1}{1+\exp(-0.485)} = 0.619$
- Therefore: $e = d3 - y3 = 0.9 - 0.619 = 0.281$

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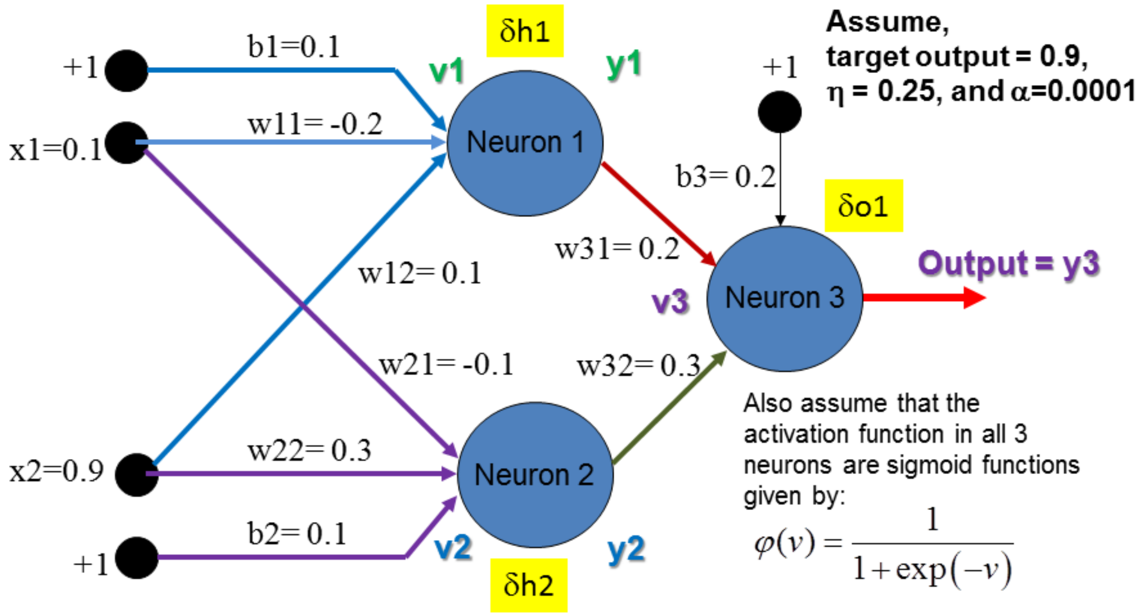
- $v1 = 0.17,\ y1 = 0.542$
- $v2 = 0.36, y2 = 0.589$
- $v3 = 0.485, y3 = 0.619$
- $e = 0.281$



- $\delta o1 = \varphi'(v3) * (d3 - y3) = \varphi'(0.4851) * 0.281 = \varphi(0.4851)[1 - \varphi(0.4851)] * 0.281 = 0.619[1 - 0.619] * 0.281 = 0.0663$

- $\delta h1 = \varphi'(v1) * (\delta o1 * w31) = \varphi'(0.17) * (0.0663 * 0.2) = \varphi(0.17)[1 - \varphi(0.17)] * 0.01362 = 0.542[1 - 0.542] * 0.01362$=0.0033

- $\delta h2 = \varphi'(v2) * (\delta o1 * w32) = \varphi'(0.36) * (0.0663 * 0.3) = \varphi(0.36)[1 - \varphi(0.36)] * 0.01989 = 0.589[1 - 0.589] * 0.01989$=0.0049

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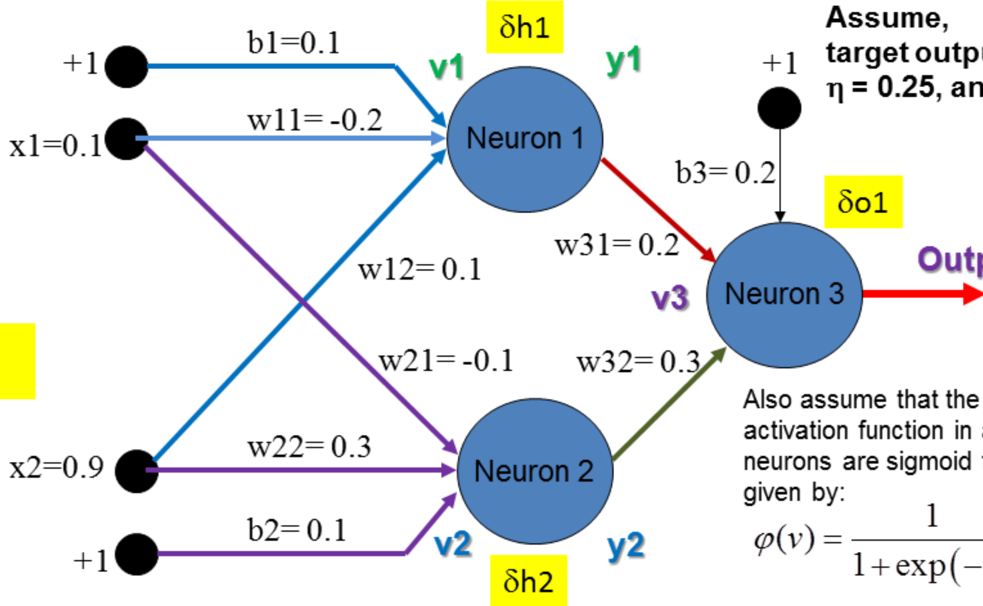

Assume,
target output = 0.9,
η = 0.25, and α=0.0001

Also assume that the activation function in all 3 neurons are sigmoid functions given by:

$$\varphi(v) = \frac{1}{1+\exp(-v)}$$

- $y1 = 0.542, \ y2 = 0.589$
- $\delta o1 = 0.0663,$
- $\delta h1 = 0.0033$
- $\delta h2 = 0.0049$

- **Step 2:** Adjust the weights of the network using the learning rule:
- $\boldsymbol{w(n+1) = w(n) + \alpha * w(n-1) + \eta * \delta(n) * y}$
- $w31(n+1) = w31(n) + \alpha * w31(n-1) + \eta * \delta o1(n) * y1$
- $w31(n+1) = 0.2 + 0.0001 * 0.2 + 0.25 * 0.0663 * 0.542 = 0.2090$
- $w32(n+1) = w32(n) + \alpha * w32(n-1) + \eta * \delta o1(n) * y2$
- $w32(n+1) = 0.3 + 0.0001 * 0.3 + 0.25 * 0.0663 * 0.589 = 0.3098$

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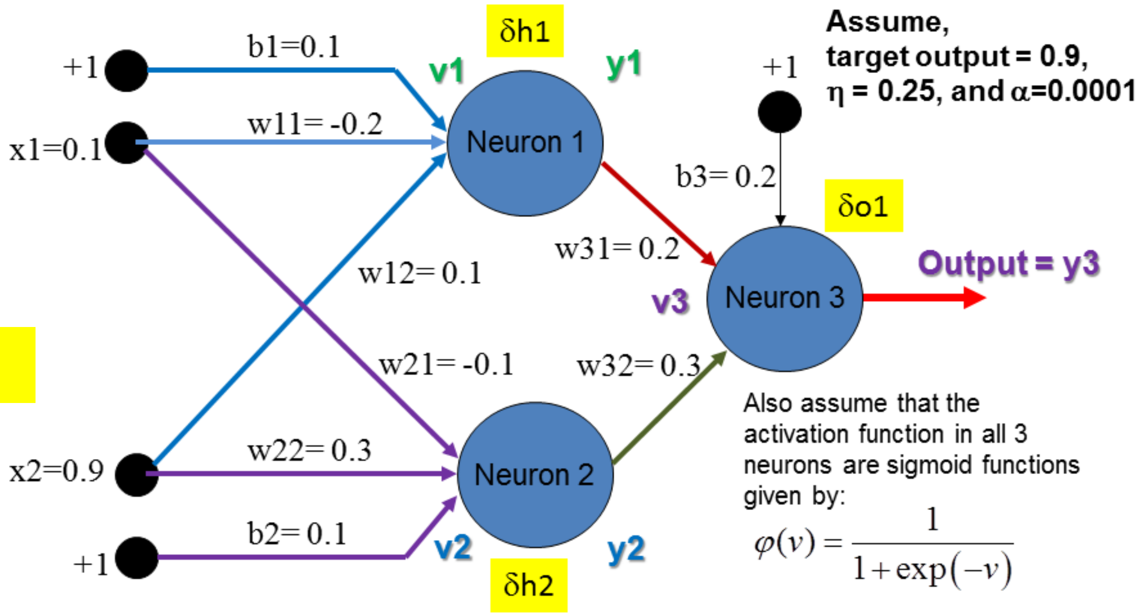
- $y1 = 0.542,\ y2 = 0.589$
- $\delta o1 = 0.0663,$
- $\delta h1 = 0.0033$
- $\delta h2 = 0.0049$



- **Step 2:** Adjust the weights of the network using the learning rule:
- $\boldsymbol{w(n+1) = w(n) + \alpha * w(n-1) + \eta * \delta(n) * y}$
- $w11(n+1) = w11(n) + \alpha * w11(n-1) + \eta * \delta h1(n) * x1$
- $w11(n+1) = (-0.2) + 0.0001 * (-0.2) + 0.25 * 0.0033 * 0.1 = -0.1999$
- $w21(n+1) = w21(n) + \alpha * w21(n-1) + \eta * \delta h2(n) * x1$
- $w21(n+1) = (-0.1) + 0.0001 * (-0.1) + 0.25 * 0.0049 * 0.1 = -0.0999$

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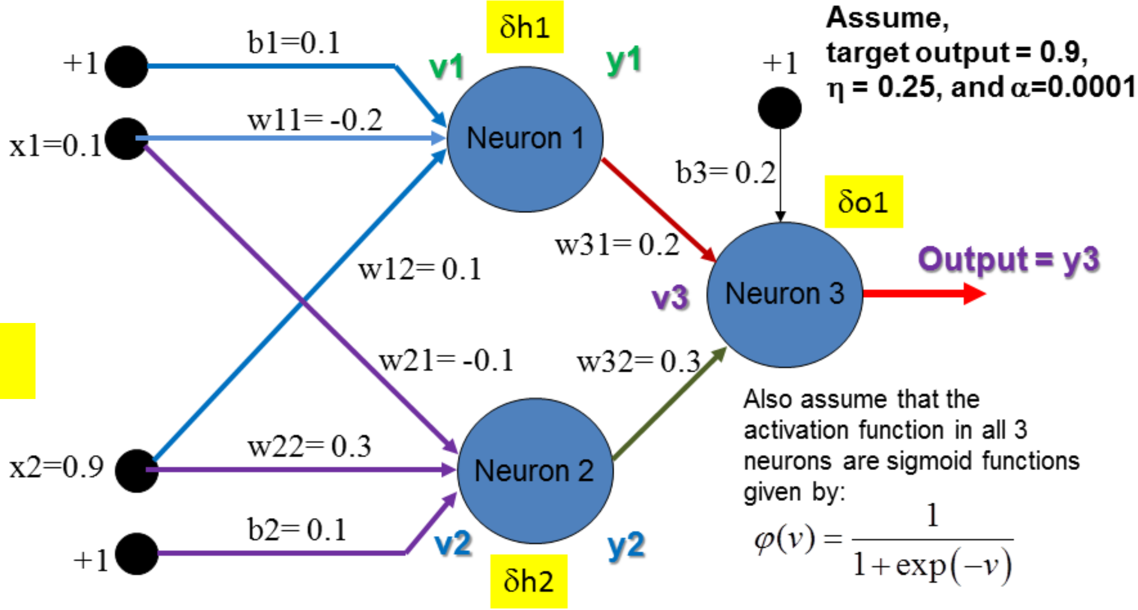

- $y1 = 0.542, \ y2 = 0.589$
- $\delta o1 = 0.0663,$
- $\delta h1 = 0.0033$
- $\delta h2 = 0.0049$

- **Step 2:** Adjust the weights of the network using the learning rule:
- $\boldsymbol{w(n+1) = w(n) + \alpha * w(n-1) + \eta * \delta(n) * y}$
- $w12(n+1) = w12(n) + \alpha * w12(n-1) + \eta * \delta h1(n) * x2$
- $w12(n+1) = 0.1 + 0.0001 * 0.1 + 0.25 * 0.0033 * 0.9 = 0.1008$
- $w22(n+1) = w22(n) + \alpha * w22(n-1) + \eta * \delta h2(n) * x2$
- $w22(n+1) = 0.3 + 0.0001 * 0.3 + 0.25 * 0.0049 * 0.9 = 0.3011$

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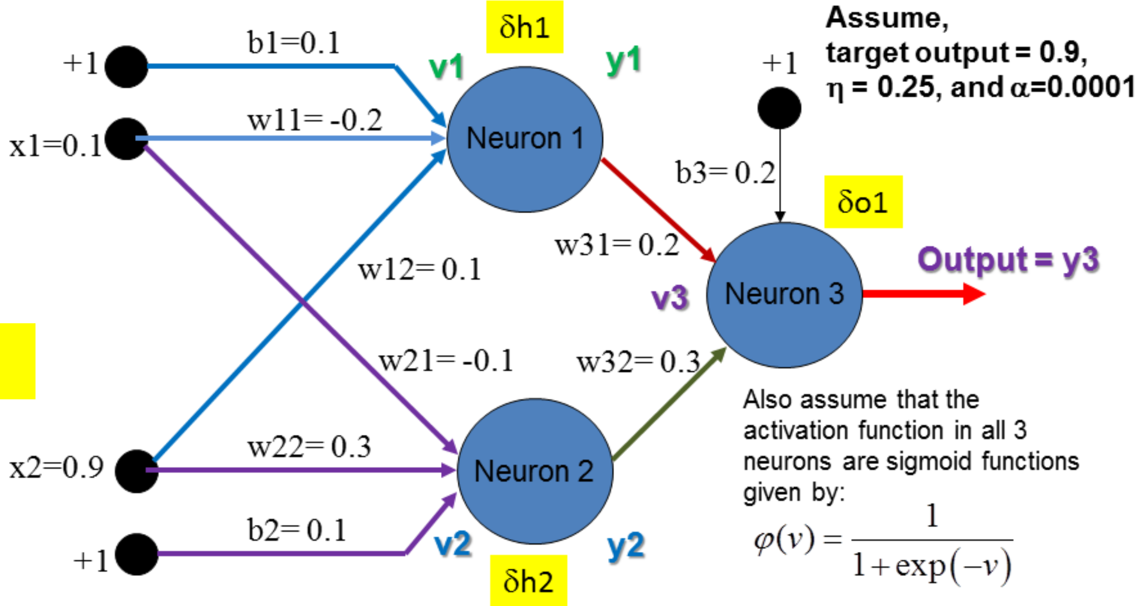
- $y1 = 0.542,\ y2 = 0.589$
- $\delta o1 = 0.0663,$
- $\delta h1 = 0.0033$
- $\delta h2 = 0.0049$



- **Step 2:** Adjust the weights of the network using the learning rule: Click here to see the video http://youtu.be/I2I5ztVfUSE
- $\boldsymbol{b(n+1) = b(n) + \alpha * b(n-1) + \eta * \delta(n) * 1}$
- $b3(n+1) = b3(n) + \alpha * b3(n-1) + \eta * \delta o1(n) * 1$
- $b3(n+1) = 0.2 + 0.0001 * 0.2 + 0.25 * 0.0663 * 1 = 0.2166$
- $b1(n+1) = b1(n) + \alpha * b1(n-1) + \eta * \delta h1(n) * 1$
- $b1(n+1) = 0.1 + 0.0001 * 0.2 + 0.25 * 0.0033 * 1 = 0.1008$
- $b3(n+1) = b3(n) + \alpha * b3(n-1) + \eta * \delta 2(n) * 1$
- $b3(n+1) = 0.1 + 0.0001 * 0.1 + 0.25 * 0.0049 * 1 = 0.1012$

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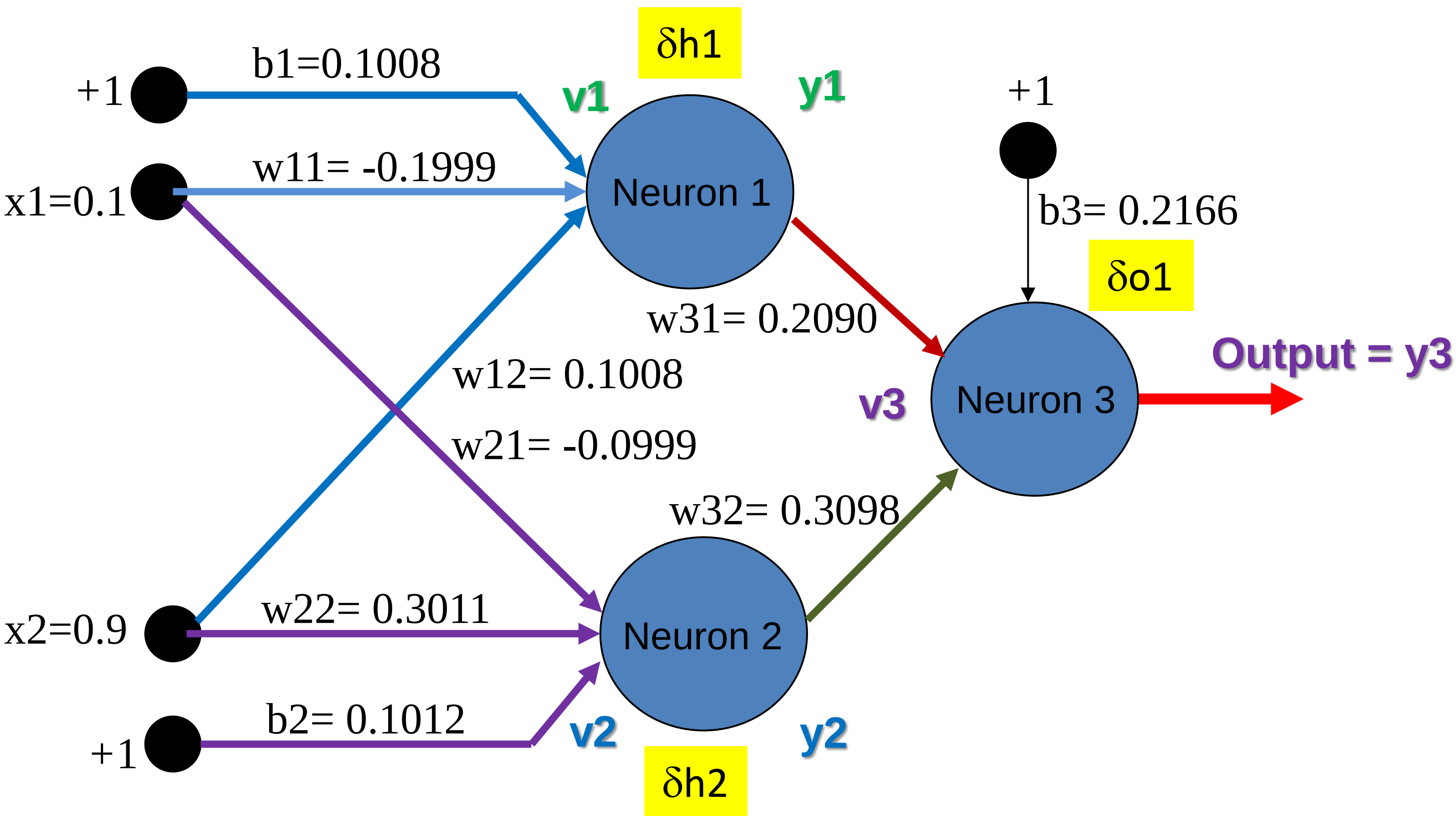
After one Complete Forward & Backward Pass



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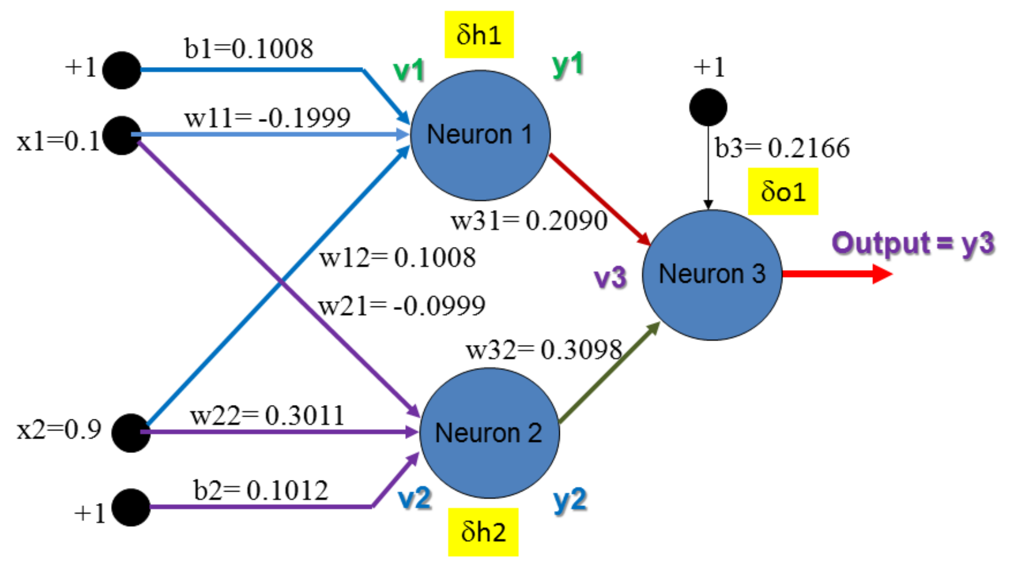
After one Complete Forward & Backward Pass



- $v1 = 0.17 \rightarrow v1 = 0.1715$
- $y1 = 0.542 \rightarrow y1 = 0.5428$
- $v2 = 0.36 \rightarrow v2 = 0.3622$
- $y2 = 0.589 \rightarrow y2 = 0.5896$
- $v3 = 0.4851 \rightarrow v3 = 0.5127$
- $y3 = 0.619 \rightarrow y3 = 0.6254$
- $e = d3 - y3 = 0.9 - 0.619 = 0.281 \rightarrow e = d3 - y3 = 0.9 - 0.6254 = 0.2746$

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After a few more Complete Forward & Backward Passes

- After second pass $e = 0.2683$
- After third pass $e = 0.2623$
- After forth pass $e = 0.2565$
- After 100 passes $e = 0.0693$
- After 200 passes $e = 0.0319$
- After 500 passes $e = 0.0038$

- Error is getting reduced after each pass.

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Artificial Neural Networks - #3

Back Propagation

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END of the Book

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