Module 4.8: Backpropagation: Pseudo code

Finally, we have all the pieces of the puzzle

Finally, we have all the pieces of the puzzle

$$\nabla_{a_L} \mathscr{L}(\theta) \quad \text{(gradient w.r.t. output layer)}$$

Finally, we have all the pieces of the puzzle

$$\nabla_{a_L}\mathscr{L}(\theta) \quad \text{(gradient w.r.t. output layer)}$$

$$\nabla_{h_k}\mathscr{L}(\theta), \nabla_{a_k}\mathscr{L}(\theta) \quad \text{(gradient w.r.t. hidden layers } 0 < k < L\text{)}$$

Finally, we have all the pieces of the puzzle

$$\nabla_{a_L}\mathscr{L}(\theta) \quad \text{(gradient w.r.t. output layer)}$$

$$\nabla_{h_k}\mathscr{L}(\theta), \nabla_{a_k}\mathscr{L}(\theta) \quad \text{(gradient w.r.t. hidden layers } 0 < k < L\text{)}$$

$$\nabla_{W_k}\mathscr{L}(\theta), \nabla_{b_k}\mathscr{L}(\theta) \quad \text{(gradient w.r.t. weights and biases)}$$

Finally, we have all the pieces of the puzzle

$$\nabla_{a_L}\mathscr{L}(\theta) \quad \text{(gradient w.r.t. output layer)}$$

$$\nabla_{h_k}\mathscr{L}(\theta), \nabla_{a_k}\mathscr{L}(\theta) \quad \text{(gradient w.r.t. hidden layers } 0 < k < L\text{)}$$

$$\nabla_{W_k}\mathscr{L}(\theta), \nabla_{b_k}\mathscr{L}(\theta) \quad \text{(gradient w.r.t. weights and biases)}$$

We can now write the full learning algorithm

Algorithm: gradient_descent()

$t \leftarrow 0;$

$max\_iterations \leftarrow 1000;$

$Initialize \quad \theta_0 = [W_1^0, ..., W_L^0, b_1^0, ..., b_L^0];$

Algorithm: gradient_descent()

$t \leftarrow 0$;

$max\_iterations \leftarrow 1000$;

$Initialize \quad \theta_0 = [W_1^0, ..., W_L^0, b_1^0, ..., b_L^0]$;

while t++ $< max\_iterations$ **do**

end

Algorithm: gradient_descent()

$t \leftarrow 0;$

$max\_iterations \leftarrow 1000;$

$Initialize \quad \theta_0 = [W_1^0, ..., W_L^0, b_1^0, ..., b_L^0];$

while t++ $< max\_iterations$ **do**

$\quad h_1, h_2, ..., h_{L-1}, a_1, a_2, ..., a_L, \hat{y} = forward\_propagation(\theta_t);$

end

Algorithm: gradient_descent()

$t \leftarrow 0$;

$max\_iterations \leftarrow 1000$;

$Initialize \quad \theta_0 = [W_1^0, ..., W_L^0, b_1^0, ..., b_L^0]$;

while t++ $< max\_iterations$ **do**

$\quad h_1, h_2, ..., h_{L-1}, a_1, a_2, ..., a_L, \hat{y} = forward\_propagation(\theta_t)$;

$\quad \nabla\theta_t = backward\_propagation(h_1, h_2, ..., h_{L-1}, a_1, a_2, ..., a_L, \hat{y})$;

end

Algorithm: gradient_descent()

$t \leftarrow 0$;

$max\_iterations \leftarrow 1000$;

$Initialize \quad \theta_0 = [W_1^0, ..., W_L^0, b_1^0, ..., b_L^0]$;

while $t{+}{+} < max\_iterations$ **do**

$\quad h_1, h_2, ..., h_{L-1}, a_1, a_2, ..., a_L, \hat{y} = forward\_propagation(\theta_t)$;

$\quad \nabla\theta_t = backward\_propagation(h_1, h_2, ..., h_{L-1}, a_1, a_2, ..., a_L, \hat{y})$;

$\quad \theta_{t+1} \leftarrow \theta_t - \eta\nabla\theta_t$;

end

Algorithm: forward_propagation(θ)

Algorithm: forward_propagation(θ)

for $k = 1$ *to* $L - 1$ **do**

end

Algorithm: forward_propagation(θ)

for $k = 1$ *to* $L - 1$ **do**

$\quad a_k = b_k + W_k h_{k-1}$;

end

Algorithm: forward_propagation(θ)

for $k = 1$ *to* $L - 1$ **do**

$a_k = b_k + W_k h_{k-1}$;

$h_k = g(a_k)$;

end

Algorithm: forward_propagation(θ)

for $k = 1$ *to* $L - 1$ **do**

$a_k = b_k + W_k h_{k-1};$

$h_k = g(a_k);$

end

$a_L = b_L + W_L h_{L-1};$

Algorithm: forward_propagation(θ)

for $k = 1$ *to* $L - 1$ **do**

$a_k = b_k + W_k h_{k-1};$

$h_k = g(a_k);$

end

$a_L = b_L + W_L h_{L-1};$

$\hat{y} = O(a_L);$

Just do a forward propagation and compute all h_i's, a_i's and $f(x)$

Algorithm: back_propagation($h_1, h_2, ..., h_{L-1}, a_1, a_2, ..., a_L, \hat{y}$)

//Compute output gradient ;

Just do a forward propagation and compute all h_i's, a_i's and $f(x)$

Algorithm: back_propagation($h_1, h_2, ..., h_{L-1}, a_1, a_2, ..., a_L, \hat{y}$)

//Compute output gradient ;

$\nabla_{a_L} \mathscr{L}(\theta) = -(e(y) - f(x))$;

Just do a forward propagation and compute all h_i's, a_i's and $f(x)$

Algorithm: back_propagation($h_1, h_2, ..., h_{L-1}, a_1, a_2, ..., a_L, \hat{y}$)

//Compute output gradient ;

$\nabla_{a_L} \mathscr{L}(\theta) = -(e(y) - f(x))$;

for $k = L$ *to* 1 **do**

end

Just do a forward propagation and compute all h_i's, a_i's and $f(x)$

Algorithm: back_propagation($h_1, h_2, ..., h_{L-1}, a_1, a_2, ..., a_L, \hat{y}$)

//Compute output gradient ;

$\nabla_{a_L} \mathscr{L}(\theta) = -(e(y) - f(x))$;

for $k = L$ *to* 1 **do**

    // Compute gradients w.r.t. parameters ;

end

Just do a forward propagation and compute all h_i's, a_i's and $f(x)$

Algorithm: back_propagation($h_1, h_2, ..., h_{L-1}, a_1, a_2, ..., a_L, \hat{y}$)

//Compute output gradient ;

$\nabla_{a_L} \mathscr{L}(\theta) = -(e(y) - f(x))$;

for $k = L$ *to* 1 **do**

// Compute gradients w.r.t. parameters ;

$\nabla_{W_k} \mathscr{L}(\theta) = \nabla_{a_k} \mathscr{L}(\theta) h_{k-1}^T$;

end

Just do a forward propagation and compute all h_i's, a_i's and $f(x)$

Algorithm: back_propagation$(h_1, h_2, ..., h_{L-1}, a_1, a_2, ..., a_L, \hat{y})$

//Compute output gradient ;

$\nabla_{a_L} \mathscr{L}(\theta) = -(e(y) - f(x))$;

for $k = L$ *to* 1 **do**

// Compute gradients w.r.t. parameters ;

$\nabla_{W_k} \mathscr{L}(\theta) = \nabla_{a_k} \mathscr{L}(\theta) h_{k-1}^T$;

$\nabla_{b_k} \mathscr{L}(\theta) = \nabla_{a_k} \mathscr{L}(\theta)$;

end

Just do a forward propagation and compute all h_i's, a_i's and $f(x)$

Algorithm: back_propagation($h_1, h_2, ..., h_{L-1}, a_1, a_2, ..., a_L, \hat{y}$)

//Compute output gradient ;

$\nabla_{a_L} \mathscr{L}(\theta) = -(e(y) - f(x))$;

for $k = L$ *to* 1 **do**

   // Compute gradients w.r.t. parameters ;

   $\nabla_{W_k} \mathscr{L}(\theta) = \nabla_{a_k} \mathscr{L}(\theta) h_{k-1}^T$;

   $\nabla_{b_k} \mathscr{L}(\theta) = \nabla_{a_k} \mathscr{L}(\theta)$;

   // Compute gradients w.r.t. layer below ;

end

Just do a forward propagation and compute all h_i's, a_i's and $f(x)$

Algorithm: back_propagation($h_1, h_2, ..., h_{L-1}, a_1, a_2, ..., a_L, \hat{y}$)

//Compute output gradient ;

$\nabla_{a_L} \mathscr{L}(\theta) = -(e(y) - f(x))$;

for $k = L$ *to* 1 **do**

// Compute gradients w.r.t. parameters ;

$\nabla_{W_k} \mathscr{L}(\theta) = \nabla_{a_k} \mathscr{L}(\theta) h_{k-1}^T$;

$\nabla_{b_k} \mathscr{L}(\theta) = \nabla_{a_k} \mathscr{L}(\theta)$;

// Compute gradients w.r.t. layer below ;

$\nabla_{h_{k-1}} \mathscr{L}(\theta) = W_k^T (\nabla_{a_k} \mathscr{L}(\theta))$;

end

Just do a forward propagation and compute all h_i's, a_i's and $f(x)$

Algorithm: back_propagation($h_1, h_2, ..., h_{L-1}, a_1, a_2, ..., a_L, \hat{y}$)

//Compute output gradient ;

$\nabla_{a_L} \mathscr{L}(\theta) = -(e(y) - f(x))$;

for $k = L$ *to* 1 **do**

// Compute gradients w.r.t. parameters ;

$\nabla_{W_k} \mathscr{L}(\theta) = \nabla_{a_k} \mathscr{L}(\theta) h_{k-1}^T$;

$\nabla_{b_k} \mathscr{L}(\theta) = \nabla_{a_k} \mathscr{L}(\theta)$;

// Compute gradients w.r.t. layer below ;

$\nabla_{h_{k-1}} \mathscr{L}(\theta) = W_k^T (\nabla_{a_k} \mathscr{L}(\theta))$;

// Compute gradients w.r.t. layer below (pre-activation);

end

Just do a forward propagation and compute all h_i's, a_i's and $f(x)$

Algorithm: back_propagation($h_1, h_2, ..., h_{L-1}, a_1, a_2, ..., a_L, \hat{y}$)

//Compute output gradient ;

$\nabla_{a_L}\mathscr{L}(\theta) = -(e(y) - f(x))$;

for $k = L$ *to* 1 **do**

  // Compute gradients w.r.t. parameters ;

  $\nabla_{W_k}\mathscr{L}(\theta) = \nabla_{a_k}\mathscr{L}(\theta) h_{k-1}^T$;

  $\nabla_{b_k}\mathscr{L}(\theta) = \nabla_{a_k}\mathscr{L}(\theta)$;

  // Compute gradients w.r.t. layer below ;

  $\nabla_{h_{k-1}}\mathscr{L}(\theta) = W_k^T(\nabla_{a_k}\mathscr{L}(\theta))$;

  // Compute gradients w.r.t. layer below (pre-activation);

  $\nabla_{a_{k-1}}\mathscr{L}(\theta) = \nabla_{h_{k-1}}\mathscr{L}(\theta) \odot [\ldots, g'(a_{k-1,j}), \ldots]$;

end