Module III : Multilayer Perceptron & Feedforward Neural Networks: error backpropagation supervised learning

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Examples in this document can be found in the source bundle attached to this document (or on github repository: https://github.com/pawelc/neuralnet) and can be run after installing torch7 machine learning library: http://torch.ch/ (I use LUA programming language and efficient implementation of tensors from this library to implement neural networks algorithms implemented in my library). I used this library because currently it is havily used by Google DeepMind, Facebook so it is worth to learn it. It provides transparent usage of advanced numerical libraries like BLASS and JIT compilation to very efficient code which can execute on CPUs or GPUs. To run template (Rnw) for this document one has to set variable neuralNetProjectLocation.

Exercise 1

Implement a 2-layer perceptron network (2 neurons in the input layer + 1 output unit) together with its learning algorithm. Train the network on XOR problem.

I implemented the neural network and the backpropagation algorithm to train network for this exercise. In this example I used required architecture with tanh activations where positive output from the output neuron means +1 and negative -1. The script training this network can be found in the source bundle src/NeuralNet/exercises/module3/ex1.lua. The script is documented. By running it:

```
>        ex1Output <- runLua("module3/ex1.lua")
```

we get following output (The last weight in each vector of weights for a given neuron belong to the bias):

```
>        ex1Output

 [1] "WARN Logger: changing loglevel from DEBUG to INFO"
 [2] "INFO Before learning RMSE: 1.107655"
 [3] "INFO Running learner 1000 epochs"
 [4] "INFO After learning RMSE: 0.033803"
 [5] "INFO Trained answer for input: -1,1 is  0.9718"
 [6] "[torch.DoubleTensor of dimension 1]"
 [7] ""
 [8] "INFO Trained answer for input: 1,-1 is  0.9718"
 [9] "[torch.DoubleTensor of dimension 1]"
[10] ""
[11] "INFO Trained answer for input: -1,-1 is -0.9610"
[12] "[torch.DoubleTensor of dimension 1]"
[13] ""
[14] "INFO Trained answer for input: 1,1 is -0.9619"
[15] "[torch.DoubleTensor of dimension 1]"
[16] ""
[17] "INFO Weights in the first hidden layer:"
[18] " 1.4357  1.4364  1.2482"
[19] "-1.6774 -1.6788  1.5484"
[20] "[torch.DoubleTensor of dimension 2x3]"
[21] ""
[22] "INFO Weights in the output layer:"
[23] " 2.4190  2.3965 -2.1170"
[24] "[torch.DoubleTensor of dimension 1x3]"
[25] ""
```

The network fitted the data perfectly if assume the output bigger then 0 means 1 and output smaller then 0 means -1.

Exercise 2

Derive function forms of derivatives for 3 activation functions: linear, unipolar logistic and hyperbolic tangent. Express the derivatives using output values y_i^l rather than inputs or weights. This will speed up the subsequent computations.

Linear:

$$\varphi(v) = v$$
$$\varphi'(v) = 1$$

Unipolar logistic:

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

$$\varphi'(v) = \frac{\exp(-v)}{(1 + \exp(-v))^2} = \frac{\exp(-v)}{1 + \exp(-v)} \times \frac{1}{1 + \exp(-v)} = y \times \left(\frac{1 + \exp(-v)}{1 + \exp(-v)} - \frac{\exp(-v)}{1 + exp(-v)}\right) = y(1 - y)$$

hyperbolic tangent:

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

$$\varphi'(v) = \frac{(\exp(x) + \exp(-x))(\exp(x) + \exp(-x)) - (\exp(x) - \exp(-x))(\exp(x) - \exp(-x))}{(\exp(x) + \exp(-x))^2} = 1 - \tanh^2(v) = (1 - y)(1 + y)$$

Exercise 3

Implement 3-layer feed forward neural network with the back- propagation algorithm (two layers with hyperbolic tangent unit + output layer with linear activations). Train on Nonlinear Dynamic Plant benchmark.

The script training this network can be found in the source bundle src/NeuralNet/exercises/module3/ex3.lua. The data is split for into cross validation data(10-fold cross validation used) and test data. Using 10-fold cross validation I select best hyper parameters which are in this case sizes of hidden layers. The search is done using complete grid search (please look at output of the script below). The best model selected by the grid search on 10-fold cross validation is then assessed on the separate test data.
Running the script:

```
>          ex3Output <- runLua("module3/ex3.lua")
```

we get following output:

```
>          ex3Output
```

```
 [1] "WARNLogger: changing loglevel from DEBUG to INFO"
 [2] "INFOFor params: layer1Size -> 1, layer2Size -> 1 average validation RMSE is 0.233495"
 [3] "INFOFor params: layer1Size -> 2, layer2Size -> 1 average validation RMSE is 0.212731"
 [4] "INFOFor params: layer1Size -> 3, layer2Size -> 1 average validation RMSE is 0.162836"
 [5] "INFOFor params: layer1Size -> 4, layer2Size -> 1 average validation RMSE is 0.115725"
 [6] "INFOFor params: layer1Size -> 5, layer2Size -> 1 average validation RMSE is 0.079816"
 [7] "INFOFor params: layer1Size -> 6, layer2Size -> 1 average validation RMSE is 0.067574"
 [8] "INFOFor params: layer1Size -> 7, layer2Size -> 1 average validation RMSE is 0.069766"
 [9] "INFOFor params: layer1Size -> 8, layer2Size -> 1 average validation RMSE is 0.095138"
[10] "INFOFor params: layer1Size -> 9, layer2Size -> 1 average validation RMSE is 0.056535"
[11] "INFOFor params: layer1Size -> 10, layer2Size -> 1 average validation RMSE is 0.061198"
[12] "INFOFor params: layer1Size -> 1, layer2Size -> 2 average validation RMSE is 0.226738"
[13] "INFOFor params: layer1Size -> 2, layer2Size -> 2 average validation RMSE is 0.123836"
[14] "INFOFor params: layer1Size -> 3, layer2Size -> 2 average validation RMSE is 0.073470"
[15] "INFOFor params: layer1Size -> 4, layer2Size -> 2 average validation RMSE is 0.053349"
[16] "INFOFor params: layer1Size -> 5, layer2Size -> 2 average validation RMSE is 0.050475"
[17] "INFOFor params: layer1Size -> 6, layer2Size -> 2 average validation RMSE is 0.053750"
[18] "INFOFor params: layer1Size -> 7, layer2Size -> 2 average validation RMSE is 0.037249"
[19] "INFOFor params: layer1Size -> 8, layer2Size -> 2 average validation RMSE is 0.044606"
[20] "INFOFor params: layer1Size -> 9, layer2Size -> 2 average validation RMSE is 0.029585"
[21] "INFOFor params: layer1Size -> 10, layer2Size -> 2 average validation RMSE is 0.035245"
[22] "INFOFor params: layer1Size -> 1, layer2Size -> 3 average validation RMSE is 0.221613"
[23] "INFOFor params: layer1Size -> 2, layer2Size -> 3 average validation RMSE is 0.123623"
[24] "INFOFor params: layer1Size -> 3, layer2Size -> 3 average validation RMSE is 0.094887"
[25] "INFOFor params: layer1Size -> 4, layer2Size -> 3 average validation RMSE is 0.055103"
[26] "INFOFor params: layer1Size -> 5, layer2Size -> 3 average validation RMSE is 0.041657"
[27] "INFOFor params: layer1Size -> 6, layer2Size -> 3 average validation RMSE is 0.038535"
```

```
[28] "INFOFor params: layer1Size -> 7, layer2Size -> 3 average validation RMSE is 0.029009"
[29] "INFOFor params: layer1Size -> 8, layer2Size -> 3 average validation RMSE is 0.039861"
[30] "INFOFor params: layer1Size -> 9, layer2Size -> 3 average validation RMSE is 0.035159"
[31] "INFOFor params: layer1Size -> 10, layer2Size -> 3 average validation RMSE is 0.026122"
[32] "INFOFor params: layer1Size -> 1, layer2Size -> 4 average validation RMSE is 0.225672"
[33] "INFOFor params: layer1Size -> 2, layer2Size -> 4 average validation RMSE is 0.119211"
[34] "INFOFor params: layer1Size -> 3, layer2Size -> 4 average validation RMSE is 0.085098"
[35] "INFOFor params: layer1Size -> 4, layer2Size -> 4 average validation RMSE is 0.051875"
[36] "INFOFor params: layer1Size -> 5, layer2Size -> 4 average validation RMSE is 0.038344"
[37] "INFOFor params: layer1Size -> 6, layer2Size -> 4 average validation RMSE is 0.028379"
[38] "INFOFor params: layer1Size -> 7, layer2Size -> 4 average validation RMSE is 0.031275"
[39] "INFOFor params: layer1Size -> 8, layer2Size -> 4 average validation RMSE is 0.024451"
[40] "INFOFor params: layer1Size -> 9, layer2Size -> 4 average validation RMSE is 0.025637"
[41] "INFOFor params: layer1Size -> 10, layer2Size -> 4 average validation RMSE is 0.024466"
[42] "INFOFor params: layer1Size -> 1, layer2Size -> 5 average validation RMSE is 0.230661"
[43] "INFOFor params: layer1Size -> 2, layer2Size -> 5 average validation RMSE is 0.126148"
[44] "INFOFor params: layer1Size -> 3, layer2Size -> 5 average validation RMSE is 0.080966"
[45] "INFOFor params: layer1Size -> 4, layer2Size -> 5 average validation RMSE is 0.038767"
[46] "INFOFor params: layer1Size -> 5, layer2Size -> 5 average validation RMSE is 0.037963"
[47] "INFOFor params: layer1Size -> 6, layer2Size -> 5 average validation RMSE is 0.026567"
[48] "INFOFor params: layer1Size -> 7, layer2Size -> 5 average validation RMSE is 0.038907"
[49] "INFOFor params: layer1Size -> 8, layer2Size -> 5 average validation RMSE is 0.035783"
[50] "INFOFor params: layer1Size -> 9, layer2Size -> 5 average validation RMSE is 0.020799"
[51] "INFOFor params: layer1Size -> 10, layer2Size -> 5 average validation RMSE is 0.027070"
[52] "INFOFor params: layer1Size -> 1, layer2Size -> 6 average validation RMSE is 0.229757"
[53] "INFOFor params: layer1Size -> 2, layer2Size -> 6 average validation RMSE is 0.130194"
[54] "INFOFor params: layer1Size -> 3, layer2Size -> 6 average validation RMSE is 0.037068"
[55] "INFOFor params: layer1Size -> 4, layer2Size -> 6 average validation RMSE is 0.033966"
[56] "INFOFor params: layer1Size -> 5, layer2Size -> 6 average validation RMSE is 0.040081"
[57] "INFOFor params: layer1Size -> 6, layer2Size -> 6 average validation RMSE is 0.041708"
[58] "INFOFor params: layer1Size -> 7, layer2Size -> 6 average validation RMSE is 0.029734"
[59] "INFOFor params: layer1Size -> 8, layer2Size -> 6 average validation RMSE is 0.030330"
[60] "INFOFor params: layer1Size -> 9, layer2Size -> 6 average validation RMSE is 0.028635"
[61] "INFOFor params: layer1Size -> 10, layer2Size -> 6 average validation RMSE is 0.026061"
[62] "INFOFor params: layer1Size -> 1, layer2Size -> 7 average validation RMSE is 0.225827"
[63] "INFOFor params: layer1Size -> 2, layer2Size -> 7 average validation RMSE is 0.125186"
[64] "INFOFor params: layer1Size -> 3, layer2Size -> 7 average validation RMSE is 0.072770"
[65] "INFOFor params: layer1Size -> 4, layer2Size -> 7 average validation RMSE is 0.048542"
[66] "INFOFor params: layer1Size -> 5, layer2Size -> 7 average validation RMSE is 0.028885"
[67] "INFOFor params: layer1Size -> 6, layer2Size -> 7 average validation RMSE is 0.034074"
[68] "INFOFor params: layer1Size -> 7, layer2Size -> 7 average validation RMSE is 0.024432"
[69] "INFOFor params: layer1Size -> 8, layer2Size -> 7 average validation RMSE is 0.023082"
[70] "INFOFor params: layer1Size -> 9, layer2Size -> 7 average validation RMSE is 0.021715"
[71] "INFOFor params: layer1Size -> 10, layer2Size -> 7 average validation RMSE is 0.024163"
[72] "INFOFor params: layer1Size -> 1, layer2Size -> 8 average validation RMSE is 0.224132"
[73] "INFOFor params: layer1Size -> 2, layer2Size -> 8 average validation RMSE is 0.117684"
[74] "INFOFor params: layer1Size -> 3, layer2Size -> 8 average validation RMSE is 0.039444"
[75] "INFOFor params: layer1Size -> 4, layer2Size -> 8 average validation RMSE is 0.036283"
[76] "INFOFor params: layer1Size -> 5, layer2Size -> 8 average validation RMSE is 0.029890"
[77] "INFOFor params: layer1Size -> 6, layer2Size -> 8 average validation RMSE is 0.033943"
[78] "INFOFor params: layer1Size -> 7, layer2Size -> 8 average validation RMSE is 0.022760"
[79] "INFOFor params: layer1Size -> 8, layer2Size -> 8 average validation RMSE is 0.028617"
[80] "INFOFor params: layer1Size -> 9, layer2Size -> 8 average validation RMSE is 0.028491"
[81] "INFOFor params: layer1Size -> 10, layer2Size -> 8 average validation RMSE is 0.024740"
[82] "INFOFor params: layer1Size -> 1, layer2Size -> 9 average validation RMSE is 0.245657"
[83] "INFOFor params: layer1Size -> 2, layer2Size -> 9 average validation RMSE is 0.118628"
[84] "INFOFor params: layer1Size -> 3, layer2Size -> 9 average validation RMSE is 0.046145"
[85] "INFOFor params: layer1Size -> 4, layer2Size -> 9 average validation RMSE is 0.049904"
[86] "INFOFor params: layer1Size -> 5, layer2Size -> 9 average validation RMSE is 0.037459"
[87] "INFOFor params: layer1Size -> 6, layer2Size -> 9 average validation RMSE is 0.024081"
[88] "INFOFor params: layer1Size -> 7, layer2Size -> 9 average validation RMSE is 0.030596"
[89] "INFOFor params: layer1Size -> 8, layer2Size -> 9 average validation RMSE is 0.032224"
[90] "INFOFor params: layer1Size -> 9, layer2Size -> 9 average validation RMSE is 0.032109"
[91] "INFOFor params: layer1Size -> 10, layer2Size -> 9 average validation RMSE is 0.028357"
[92] "INFOFor params: layer1Size -> 1, layer2Size -> 10 average validation RMSE is 0.223075"
[93] "INFOFor params: layer1Size -> 2, layer2Size -> 10 average validation RMSE is 0.117603"
```

```
 [94] "INFOFor params: layer1Size -> 3, layer2Size -> 10 average validation RMSE is 0.041750"
 [95] "INFOFor params: layer1Size -> 4, layer2Size -> 10 average validation RMSE is 0.042132"
 [96] "INFOFor params: layer1Size -> 5, layer2Size -> 10 average validation RMSE is 0.026118"
 [97] "INFOFor params: layer1Size -> 6, layer2Size -> 10 average validation RMSE is 0.023624"
 [98] "INFOFor params: layer1Size -> 7, layer2Size -> 10 average validation RMSE is 0.028188"
 [99] "INFOFor params: layer1Size -> 8, layer2Size -> 10 average validation RMSE is 0.024084"
[100] "INFOFor params: layer1Size -> 9, layer2Size -> 10 average validation RMSE is 0.022754"
[101] "INFOFor params: layer1Size -> 10, layer2Size -> 10 average validation RMSE is 0.025415"
[102] "INFOSelected model with params: layer2Size -> 5, layer1Size -> 9, "
[103] "performance: validRmse -> 0.020799276990103, testRmse -> 0.024122719698277"
```

The cross validation procedure selected model with 5 and 9 layer sizes. As expected the test error is bigger then validation error.

Exercise 4

Implement exponential increasing of the learning rate, and per- form comparative analysis of the improvement on the dataset from Ex. 3.

I again perform grid search but now also updating learning rate exponentially with different parameters. The output of the script shows all validated configurations and selected best model and its generalisation error on test data.

Running the script:

```
>          ex4Output <- runLua("module3/ex4.lua")
```

we get following output:

```
>          ex4Output
```

```
 [1] "WARNLogger: changing loglevel from DEBUG to INFO"
 [2] "INFOFor params: initialLearningRate -> 0.1, expDecayConst -> 0.01, layer2Size -> 4, layer1Size -> 4"
 [3] "average validation RMSE is 0.053583"
 [4] "INFOFor params: initialLearningRate -> 0.1, expDecayConst -> 0.01, layer2Size -> 5, layer1Size -> 4"
 [5] "average validation RMSE is 0.039182"
 [6] "INFOFor params: initialLearningRate -> 0.1, expDecayConst -> 0.01, layer2Size -> 6, layer1Size -> 4"
 [7] "average validation RMSE is 0.044376"
 [8] "INFOFor params: initialLearningRate -> 0.1, expDecayConst -> 0.01, layer2Size -> 7, layer1Size -> 4"
 [9] "average validation RMSE is 0.047706"
[10] "INFOFor params: initialLearningRate -> 0.1, expDecayConst -> 0.01, layer2Size -> 8, layer1Size -> 4"
[11] "average validation RMSE is 0.038853"
[12] "INFOFor params: initialLearningRate -> 0.1, expDecayConst -> 0.01, layer2Size -> 9, layer1Size -> 4"
[13] "average validation RMSE is 0.048048"
[14] "INFOFor params: initialLearningRate -> 0.1, expDecayConst -> 0.01, layer2Size -> 10, layer1Size -> 4"
[15] "average validation RMSE is 0.032075"
[16] "INFOFor params: initialLearningRate -> 0.1, expDecayConst -> 0.01, layer2Size -> 4, layer1Size -> 5"
[17] "average validation RMSE is 0.039969"
[18] "INFOFor params: initialLearningRate -> 0.1, expDecayConst -> 0.01, layer2Size -> 5, layer1Size -> 5"
[19] "average validation RMSE is 0.037319"
[20] "INFOFor params: initialLearningRate -> 0.1, expDecayConst -> 0.01, layer2Size -> 6, layer1Size -> 5"
[21] "average validation RMSE is 0.040249"
[22] "INFOFor params: initialLearningRate -> 0.1, expDecayConst -> 0.01, layer2Size -> 7, layer1Size -> 5"
[23] "average validation RMSE is 0.035647"
[24] "INFOFor params: initialLearningRate -> 0.1, expDecayConst -> 0.01, layer2Size -> 8, layer1Size -> 5"
[25] "average validation RMSE is 0.038005"
[26] "INFOFor params: initialLearningRate -> 0.1, expDecayConst -> 0.01, layer2Size -> 9, layer1Size -> 5"
[27] "average validation RMSE is 0.038429"
[28] "INFOFor params: initialLearningRate -> 0.1, expDecayConst -> 0.01, layer2Size -> 10, layer1Size -> 5"
[29] "average validation RMSE is 0.027806"
[30] "INFOFor params: initialLearningRate -> 0.1, expDecayConst -> 0.01, layer2Size -> 4, layer1Size -> 6"
[31] "average validation RMSE is 0.035638"
[32] "INFOFor params: initialLearningRate -> 0.1, expDecayConst -> 0.01, layer2Size -> 5, layer1Size -> 6"
[33] "average validation RMSE is 0.029516"
[34] "INFOFor params: initialLearningRate -> 0.1, expDecayConst -> 0.01, layer2Size -> 6, layer1Size -> 6"
[35] "average validation RMSE is 0.042741"
[36] "INFOFor params: initialLearningRate -> 0.1, expDecayConst -> 0.01, layer2Size -> 7, layer1Size -> 6"
[37] "average validation RMSE is 0.035443"
[38] "INFOFor params: initialLearningRate -> 0.1, expDecayConst -> 0.01, layer2Size -> 8, layer1Size -> 6"
[39] "average validation RMSE is 0.032903"
```

```
 [40] "INFOFor params: initialLearningRate -> 0.1, expDecayConst -> 0.01, layer2Size -> 9, layer1Size -> 6"
 [41] "average validation RMSE is 0.032552"
 [42] "INFOFor params: initialLearningRate -> 0.1, expDecayConst -> 0.01, layer2Size -> 10, layer1Size -> 6"
 [43] "average validation RMSE is 0.031444"
 [44] "INFOFor params: initialLearningRate -> 0.1, expDecayConst -> 0.01, layer2Size -> 4, layer1Size -> 7"
 [45] "average validation RMSE is 0.031256"
 [46] "INFOFor params: initialLearningRate -> 0.1, expDecayConst -> 0.01, layer2Size -> 5, layer1Size -> 7"
 [47] "average validation RMSE is 0.033391"
 [48] "INFOFor params: initialLearningRate -> 0.1, expDecayConst -> 0.01, layer2Size -> 6, layer1Size -> 7"
 [49] "average validation RMSE is 0.039463"
 [50] "INFOFor params: initialLearningRate -> 0.1, expDecayConst -> 0.01, layer2Size -> 7, layer1Size -> 7"
 [51] "average validation RMSE is 0.027513"
 [52] "INFOFor params: initialLearningRate -> 0.1, expDecayConst -> 0.01, layer2Size -> 8, layer1Size -> 7"
 [53] "average validation RMSE is 0.031067"
 [54] "INFOFor params: initialLearningRate -> 0.1, expDecayConst -> 0.01, layer2Size -> 9, layer1Size -> 7"
 [55] "average validation RMSE is 0.031296"
 [56] "INFOFor params: initialLearningRate -> 0.1, expDecayConst -> 0.01, layer2Size -> 10, layer1Size -> 7"
 [57] "average validation RMSE is 0.031319"
 [58] "INFOFor params: initialLearningRate -> 0.1, expDecayConst -> 0.01, layer2Size -> 4, layer1Size -> 8"
 [59] "average validation RMSE is 0.044248"
 [60] "INFOFor params: initialLearningRate -> 0.1, expDecayConst -> 0.01, layer2Size -> 5, layer1Size -> 8"
 [61] "average validation RMSE is 0.027667"
 [62] "INFOFor params: initialLearningRate -> 0.1, expDecayConst -> 0.01, layer2Size -> 6, layer1Size -> 8"
 [63] "average validation RMSE is 0.030008"
 [64] "INFOFor params: initialLearningRate -> 0.1, expDecayConst -> 0.01, layer2Size -> 7, layer1Size -> 8"
 [65] "average validation RMSE is 0.029659"
 [66] "INFOFor params: initialLearningRate -> 0.1, expDecayConst -> 0.01, layer2Size -> 8, layer1Size -> 8"
 [67] "average validation RMSE is 0.034612"
 [68] "INFOFor params: initialLearningRate -> 0.1, expDecayConst -> 0.01, layer2Size -> 9, layer1Size -> 8"
 [69] "average validation RMSE is 0.038140"
 [70] "INFOFor params: initialLearningRate -> 0.1, expDecayConst -> 0.01, layer2Size -> 10, layer1Size -> 8"
 [71] "average validation RMSE is 0.033341"
 [72] "INFOFor params: initialLearningRate -> 0.1, expDecayConst -> 0.01, layer2Size -> 4, layer1Size -> 9"
 [73] "average validation RMSE is 0.031654"
 [74] "INFOFor params: initialLearningRate -> 0.1, expDecayConst -> 0.01, layer2Size -> 5, layer1Size -> 9"
 [75] "average validation RMSE is 0.025667"
 [76] "INFOFor params: initialLearningRate -> 0.1, expDecayConst -> 0.01, layer2Size -> 6, layer1Size -> 9"
 [77] "average validation RMSE is 0.032754"
 [78] "INFOFor params: initialLearningRate -> 0.1, expDecayConst -> 0.01, layer2Size -> 7, layer1Size -> 9"
 [79] "average validation RMSE is 0.032767"
 [80] "INFOFor params: initialLearningRate -> 0.1, expDecayConst -> 0.01, layer2Size -> 8, layer1Size -> 9"
 [81] "average validation RMSE is 0.029940"
 [82] "INFOFor params: initialLearningRate -> 0.1, expDecayConst -> 0.01, layer2Size -> 9, layer1Size -> 9"
 [83] "average validation RMSE is 0.038518"
 [84] "INFOFor params: initialLearningRate -> 0.1, expDecayConst -> 0.01, layer2Size -> 10, layer1Size -> 9"
 [85] "average validation RMSE is 0.027394"
 [86] "INFOFor params: initialLearningRate -> 0.1, expDecayConst -> 0.01, layer2Size -> 4, layer1Size -> 10"
 [87] "average validation RMSE is 0.032912"
 [88] "INFOFor params: initialLearningRate -> 0.1, expDecayConst -> 0.01, layer2Size -> 5, layer1Size -> 10"
 [89] "average validation RMSE is 0.029584"
 [90] "INFOFor params: initialLearningRate -> 0.1, expDecayConst -> 0.01, layer2Size -> 6, layer1Size -> 10"
 [91] "average validation RMSE is 0.021918"
 [92] "INFOFor params: initialLearningRate -> 0.1, expDecayConst -> 0.01, layer2Size -> 7, layer1Size -> 10"
 [93] "average validation RMSE is 0.033842"
 [94] "INFOFor params: initialLearningRate -> 0.1, expDecayConst -> 0.01, layer2Size -> 8, layer1Size -> 10"
 [95] "average validation RMSE is 0.033322"
 [96] "INFOFor params: initialLearningRate -> 0.1, expDecayConst -> 0.01, layer2Size -> 9, layer1Size -> 10"
 [97] "average validation RMSE is 0.037018"
 [98] "INFOFor params: initialLearningRate -> 0.1, expDecayConst -> 0.01, layer2Size -> 10, layer1Size -> 10"
 [99] "average validation RMSE is 0.034571"
[100] "INFOFor params: initialLearningRate -> 0.1, expDecayConst -> 0.05, layer2Size -> 4, layer1Size -> 4"
[101] "average validation RMSE is nan"
[102] "INFOFor params: initialLearningRate -> 0.1, expDecayConst -> 0.05, layer2Size -> 5, layer1Size -> 4"
[103] "average validation RMSE is nan"
[104] "INFOFor params: initialLearningRate -> 0.1, expDecayConst -> 0.05, layer2Size -> 6, layer1Size -> 4"
[105] "average validation RMSE is nan"
```

```
[106] "INFOFor params: initialLearningRate -> 0.1, expDecayConst -> 0.05, layer2Size -> 7, layer1Size -> 4"
[107] "average validation RMSE is nan"
[108] "INFOFor params: initialLearningRate -> 0.1, expDecayConst -> 0.05, layer2Size -> 8, layer1Size -> 4"
[109] "average validation RMSE is nan"
[110] "INFOFor params: initialLearningRate -> 0.1, expDecayConst -> 0.05, layer2Size -> 9, layer1Size -> 4"
[111] "average validation RMSE is nan"
[112] "INFOFor params: initialLearningRate -> 0.1, expDecayConst -> 0.05, layer2Size -> 10, layer1Size -> 4"
[113] "average validation RMSE is nan"
[114] "INFOFor params: initialLearningRate -> 0.1, expDecayConst -> 0.05, layer2Size -> 4, layer1Size -> 5"
[115] "average validation RMSE is nan"
[116] "INFOFor params: initialLearningRate -> 0.1, expDecayConst -> 0.05, layer2Size -> 5, layer1Size -> 5"
[117] "average validation RMSE is nan"
[118] "INFOFor params: initialLearningRate -> 0.1, expDecayConst -> 0.05, layer2Size -> 6, layer1Size -> 5"
[119] "average validation RMSE is nan"
[120] "INFOFor params: initialLearningRate -> 0.1, expDecayConst -> 0.05, layer2Size -> 7, layer1Size -> 5"
[121] "average validation RMSE is nan"
[122] "INFOFor params: initialLearningRate -> 0.1, expDecayConst -> 0.05, layer2Size -> 8, layer1Size -> 5"
[123] "average validation RMSE is nan"
[124] "INFOFor params: initialLearningRate -> 0.1, expDecayConst -> 0.05, layer2Size -> 9, layer1Size -> 5"
[125] "average validation RMSE is nan"
[126] "INFOFor params: initialLearningRate -> 0.1, expDecayConst -> 0.05, layer2Size -> 10, layer1Size -> 5"
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[742] "INFOFor params: initialLearningRate -> 0.5, expDecayConst -> 0.05, layer2Size -> 10, layer1Size -> 7"
[743] "average validation RMSE is nan"
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[745] "average validation RMSE is nan"
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[765] "average validation RMSE is nan"
```

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[773] "average validation RMSE is nan"
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[777] "average validation RMSE is nan"
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[779] "average validation RMSE is nan"
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[781] "average validation RMSE is nan"
[782] "INFOFor params: initialLearningRate -> 0.5, expDecayConst -> 0.05, layer2Size -> 9, layer1Size -> 10"
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[830] "INFOFor params: initialLearningRate -> 0.5, expDecayConst -> 0.1, layer2Size -> 5, layer1Size -> 7"
[831] "average validation RMSE is nan"
```

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[832] "INFOFor params: initialLearningRate -> 0.5, expDecayConst -> 0.1, layer2Size -> 6, layer1Size -> 7"
[833] "average validation RMSE is nan"
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[852] "INFOFor params: initialLearningRate -> 0.5, expDecayConst -> 0.1, layer2Size -> 9, layer1Size -> 8"
[853] "average validation RMSE is nan"
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[857] "average validation RMSE is nan"
[858] "INFOFor params: initialLearningRate -> 0.5, expDecayConst -> 0.1, layer2Size -> 5, layer1Size -> 9"
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[861] "average validation RMSE is nan"
[862] "INFOFor params: initialLearningRate -> 0.5, expDecayConst -> 0.1, layer2Size -> 7, layer1Size -> 9"
[863] "average validation RMSE is nan"
[864] "INFOFor params: initialLearningRate -> 0.5, expDecayConst -> 0.1, layer2Size -> 8, layer1Size -> 9"
[865] "average validation RMSE is nan"
[866] "INFOFor params: initialLearningRate -> 0.5, expDecayConst -> 0.1, layer2Size -> 9, layer1Size -> 9"
[867] "average validation RMSE is nan"
[868] "INFOFor params: initialLearningRate -> 0.5, expDecayConst -> 0.1, layer2Size -> 10, layer1Size -> 9"
[869] "average validation RMSE is nan"
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[871] "average validation RMSE is nan"
[872] "INFOFor params: initialLearningRate -> 0.5, expDecayConst -> 0.1, layer2Size -> 5, layer1Size -> 10"
[873] "average validation RMSE is nan"
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[875] "average validation RMSE is nan"
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[879] "average validation RMSE is nan"
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[881] "average validation RMSE is nan"
[882] "INFOFor params: initialLearningRate -> 0.5, expDecayConst -> 0.1, layer2Size -> 10, layer1Size -> 10"
[883] "average validation RMSE is nan"
[884] "INFOSelected model with params: initialLearningRate -> 0.1, expDecayConst -> 0.01, layer1Size -> 10, la
[885] "performance: validRmse -> 0.021918454225734, testRmse -> 0.035509418203836"
```

This procedure gave worse results in terms of RMSE test error possibly because of the wrongly selected range of hyperparameters. We see that for some values of hyper parameters the learning procedure experienced numerical overflow. Also the architecture of the network selected is different than the one selected in Exercise 3.

Exercise 5

Exercise 5. Equip the backpropagation method with momentum, and perform comparative analysis of the improvement on the dataset from Ex. 3.

I again perform grid search but now also updating momentum rate with different parameters. The output of the script shows all validated configurations and selected best model and its generalisation error on test data.

Running the script:

```
>          ex5Output <- runLua("module3/ex5.lua")
```

we get following output:

```
>          ex5Output
 [1] "WARNLogger: changing loglevel from DEBUG to INFO"
 [2] "INFOFor params: momentum -> 0.001, layer2Size -> 4, layer1Size -> 4"
 [3] "average validation RMSE is 0.049298"
 [4] "INFOFor params: momentum -> 0.001, layer2Size -> 5, layer1Size -> 4"
 [5] "average validation RMSE is 0.036546"
 [6] "INFOFor params: momentum -> 0.001, layer2Size -> 6, layer1Size -> 4"
 [7] "average validation RMSE is 0.039829"
 [8] "INFOFor params: momentum -> 0.001, layer2Size -> 7, layer1Size -> 4"
 [9] "average validation RMSE is 0.045282"
[10] "INFOFor params: momentum -> 0.001, layer2Size -> 8, layer1Size -> 4"
[11] "average validation RMSE is 0.043558"
[12] "INFOFor params: momentum -> 0.001, layer2Size -> 9, layer1Size -> 4"
[13] "average validation RMSE is 0.044335"
[14] "INFOFor params: momentum -> 0.001, layer2Size -> 10, layer1Size -> 4"
[15] "average validation RMSE is 0.030676"
[16] "INFOFor params: momentum -> 0.001, layer2Size -> 4, layer1Size -> 5"
[17] "average validation RMSE is 0.044713"
[18] "INFOFor params: momentum -> 0.001, layer2Size -> 5, layer1Size -> 5"
[19] "average validation RMSE is 0.038524"
[20] "INFOFor params: momentum -> 0.001, layer2Size -> 6, layer1Size -> 5"
[21] "average validation RMSE is 0.024862"
[22] "INFOFor params: momentum -> 0.001, layer2Size -> 7, layer1Size -> 5"
[23] "average validation RMSE is 0.029635"
[24] "INFOFor params: momentum -> 0.001, layer2Size -> 8, layer1Size -> 5"
[25] "average validation RMSE is 0.031520"
[26] "INFOFor params: momentum -> 0.001, layer2Size -> 9, layer1Size -> 5"
[27] "average validation RMSE is 0.036243"
[28] "INFOFor params: momentum -> 0.001, layer2Size -> 10, layer1Size -> 5"
[29] "average validation RMSE is 0.034007"
[30] "INFOFor params: momentum -> 0.001, layer2Size -> 4, layer1Size -> 6"
[31] "average validation RMSE is 0.031958"
[32] "INFOFor params: momentum -> 0.001, layer2Size -> 5, layer1Size -> 6"
[33] "average validation RMSE is 0.029788"
[34] "INFOFor params: momentum -> 0.001, layer2Size -> 6, layer1Size -> 6"
[35] "average validation RMSE is 0.046071"
[36] "INFOFor params: momentum -> 0.001, layer2Size -> 7, layer1Size -> 6"
[37] "average validation RMSE is 0.029637"
[38] "INFOFor params: momentum -> 0.001, layer2Size -> 8, layer1Size -> 6"
[39] "average validation RMSE is 0.031514"
[40] "INFOFor params: momentum -> 0.001, layer2Size -> 9, layer1Size -> 6"
[41] "average validation RMSE is 0.030669"
[42] "INFOFor params: momentum -> 0.001, layer2Size -> 10, layer1Size -> 6"
[43] "average validation RMSE is 0.030155"
[44] "INFOFor params: momentum -> 0.001, layer2Size -> 4, layer1Size -> 7"
[45] "average validation RMSE is 0.028419"
[46] "INFOFor params: momentum -> 0.001, layer2Size -> 5, layer1Size -> 7"
[47] "average validation RMSE is 0.041866"
[48] "INFOFor params: momentum -> 0.001, layer2Size -> 6, layer1Size -> 7"
[49] "average validation RMSE is 0.032720"
[50] "INFOFor params: momentum -> 0.001, layer2Size -> 7, layer1Size -> 7"
[51] "average validation RMSE is 0.031786"
[52] "INFOFor params: momentum -> 0.001, layer2Size -> 8, layer1Size -> 7"
[53] "average validation RMSE is 0.026708"
[54] "INFOFor params: momentum -> 0.001, layer2Size -> 9, layer1Size -> 7"
[55] "average validation RMSE is 0.030790"
[56] "INFOFor params: momentum -> 0.001, layer2Size -> 10, layer1Size -> 7"
[57] "average validation RMSE is 0.039549"
[58] "INFOFor params: momentum -> 0.001, layer2Size -> 4, layer1Size -> 8"
[59] "average validation RMSE is 0.025701"
[60] "INFOFor params: momentum -> 0.001, layer2Size -> 5, layer1Size -> 8"
[61] "average validation RMSE is 0.019707"
[62] "INFOFor params: momentum -> 0.001, layer2Size -> 6, layer1Size -> 8"
```

```
 [63] "average validation RMSE is 0.038464"
 [64] "INFOFor params: momentum -> 0.001, layer2Size -> 7, layer1Size -> 8"
 [65] "average validation RMSE is 0.030049"
 [66] "INFOFor params: momentum -> 0.001, layer2Size -> 8, layer1Size -> 8"
 [67] "average validation RMSE is 0.035085"
 [68] "INFOFor params: momentum -> 0.001, layer2Size -> 9, layer1Size -> 8"
 [69] "average validation RMSE is 0.031363"
 [70] "INFOFor params: momentum -> 0.001, layer2Size -> 10, layer1Size -> 8"
 [71] "average validation RMSE is 0.025152"
 [72] "INFOFor params: momentum -> 0.001, layer2Size -> 4, layer1Size -> 9"
 [73] "average validation RMSE is 0.023937"
 [74] "INFOFor params: momentum -> 0.001, layer2Size -> 5, layer1Size -> 9"
 [75] "average validation RMSE is 0.021893"
 [76] "INFOFor params: momentum -> 0.001, layer2Size -> 6, layer1Size -> 9"
 [77] "average validation RMSE is 0.036344"
 [78] "INFOFor params: momentum -> 0.001, layer2Size -> 7, layer1Size -> 9"
 [79] "average validation RMSE is 0.033450"
 [80] "INFOFor params: momentum -> 0.001, layer2Size -> 8, layer1Size -> 9"
 [81] "average validation RMSE is 0.036415"
 [82] "INFOFor params: momentum -> 0.001, layer2Size -> 9, layer1Size -> 9"
 [83] "average validation RMSE is 0.030009"
 [84] "INFOFor params: momentum -> 0.001, layer2Size -> 10, layer1Size -> 9"
 [85] "average validation RMSE is 0.026136"
 [86] "INFOFor params: momentum -> 0.001, layer2Size -> 4, layer1Size -> 10"
 [87] "average validation RMSE is 0.027254"
 [88] "INFOFor params: momentum -> 0.001, layer2Size -> 5, layer1Size -> 10"
 [89] "average validation RMSE is 0.028695"
 [90] "INFOFor params: momentum -> 0.001, layer2Size -> 6, layer1Size -> 10"
 [91] "average validation RMSE is 0.022385"
 [92] "INFOFor params: momentum -> 0.001, layer2Size -> 7, layer1Size -> 10"
 [93] "average validation RMSE is 0.026634"
 [94] "INFOFor params: momentum -> 0.001, layer2Size -> 8, layer1Size -> 10"
 [95] "average validation RMSE is 0.026481"
 [96] "INFOFor params: momentum -> 0.001, layer2Size -> 9, layer1Size -> 10"
 [97] "average validation RMSE is 0.028087"
 [98] "INFOFor params: momentum -> 0.001, layer2Size -> 10, layer1Size -> 10"
 [99] "average validation RMSE is 0.030410"
[100] "INFOFor params: momentum -> 0.01, layer2Size -> 4, layer1Size -> 4"
[101] "average validation RMSE is 0.049213"
[102] "INFOFor params: momentum -> 0.01, layer2Size -> 5, layer1Size -> 4"
[103] "average validation RMSE is 0.036591"
[104] "INFOFor params: momentum -> 0.01, layer2Size -> 6, layer1Size -> 4"
[105] "average validation RMSE is 0.039748"
[106] "INFOFor params: momentum -> 0.01, layer2Size -> 7, layer1Size -> 4"
[107] "average validation RMSE is 0.045337"
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[109] "average validation RMSE is 0.043644"
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[111] "average validation RMSE is 0.044302"
[112] "INFOFor params: momentum -> 0.01, layer2Size -> 10, layer1Size -> 4"
[113] "average validation RMSE is 0.030510"
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[115] "average validation RMSE is 0.044610"
[116] "INFOFor params: momentum -> 0.01, layer2Size -> 5, layer1Size -> 5"
[117] "average validation RMSE is 0.038583"
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[119] "average validation RMSE is 0.024777"
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[123] "average validation RMSE is 0.031507"
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[125] "average validation RMSE is 0.036126"
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[127] "average validation RMSE is 0.034020"
[128] "INFOFor params: momentum -> 0.01, layer2Size -> 4, layer1Size -> 6"
```

```
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[169] "average validation RMSE is 0.025071"
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[184] "INFOFor params: momentum -> 0.01, layer2Size -> 4, layer1Size -> 10"
[185] "average validation RMSE is 0.027080"
[186] "INFOFor params: momentum -> 0.01, layer2Size -> 5, layer1Size -> 10"
[187] "average validation RMSE is 0.028669"
[188] "INFOFor params: momentum -> 0.01, layer2Size -> 6, layer1Size -> 10"
[189] "average validation RMSE is 0.022301"
[190] "INFOFor params: momentum -> 0.01, layer2Size -> 7, layer1Size -> 10"
[191] "average validation RMSE is 0.026666"
[192] "INFOFor params: momentum -> 0.01, layer2Size -> 8, layer1Size -> 10"
[193] "average validation RMSE is 0.026463"
[194] "INFOFor params: momentum -> 0.01, layer2Size -> 9, layer1Size -> 10"
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[195] "average validation RMSE is 0.028971"
[196] "INFOFor params: momentum -> 0.01, layer2Size -> 10, layer1Size -> 10"
[197] "average validation RMSE is 0.030102"
[198] "INFOFor params: momentum -> 0.1, layer2Size -> 4, layer1Size -> 4"
[199] "average validation RMSE is 0.049596"
[200] "INFOFor params: momentum -> 0.1, layer2Size -> 5, layer1Size -> 4"
[201] "average validation RMSE is 0.037649"
[202] "INFOFor params: momentum -> 0.1, layer2Size -> 6, layer1Size -> 4"
[203] "average validation RMSE is 0.038885"
[204] "INFOFor params: momentum -> 0.1, layer2Size -> 7, layer1Size -> 4"
[205] "average validation RMSE is 0.046014"
[206] "INFOFor params: momentum -> 0.1, layer2Size -> 8, layer1Size -> 4"
[207] "average validation RMSE is 0.044652"
[208] "INFOFor params: momentum -> 0.1, layer2Size -> 9, layer1Size -> 4"
[209] "average validation RMSE is 0.043765"
[210] "INFOFor params: momentum -> 0.1, layer2Size -> 10, layer1Size -> 4"
[211] "average validation RMSE is 0.029800"
[212] "INFOFor params: momentum -> 0.1, layer2Size -> 4, layer1Size -> 5"
[213] "average validation RMSE is 0.043603"
[214] "INFOFor params: momentum -> 0.1, layer2Size -> 5, layer1Size -> 5"
[215] "average validation RMSE is 0.039502"
[216] "INFOFor params: momentum -> 0.1, layer2Size -> 6, layer1Size -> 5"
[217] "average validation RMSE is 0.025388"
[218] "INFOFor params: momentum -> 0.1, layer2Size -> 7, layer1Size -> 5"
[219] "average validation RMSE is 0.030848"
[220] "INFOFor params: momentum -> 0.1, layer2Size -> 8, layer1Size -> 5"
[221] "average validation RMSE is 0.032881"
[222] "INFOFor params: momentum -> 0.1, layer2Size -> 9, layer1Size -> 5"
[223] "average validation RMSE is 0.034940"
[224] "INFOFor params: momentum -> 0.1, layer2Size -> 10, layer1Size -> 5"
[225] "average validation RMSE is 0.033997"
[226] "INFOFor params: momentum -> 0.1, layer2Size -> 4, layer1Size -> 6"
[227] "average validation RMSE is 0.031818"
[228] "INFOFor params: momentum -> 0.1, layer2Size -> 5, layer1Size -> 6"
[229] "average validation RMSE is 0.029579"
[230] "INFOFor params: momentum -> 0.1, layer2Size -> 6, layer1Size -> 6"
[231] "average validation RMSE is 0.038213"
[232] "INFOFor params: momentum -> 0.1, layer2Size -> 7, layer1Size -> 6"
[233] "average validation RMSE is 0.029144"
[234] "INFOFor params: momentum -> 0.1, layer2Size -> 8, layer1Size -> 6"
[235] "average validation RMSE is 0.031680"
[236] "INFOFor params: momentum -> 0.1, layer2Size -> 9, layer1Size -> 6"
[237] "average validation RMSE is 0.032893"
[238] "INFOFor params: momentum -> 0.1, layer2Size -> 10, layer1Size -> 6"
[239] "average validation RMSE is 0.031027"
[240] "INFOFor params: momentum -> 0.1, layer2Size -> 4, layer1Size -> 7"
[241] "average validation RMSE is 0.027620"
[242] "INFOFor params: momentum -> 0.1, layer2Size -> 5, layer1Size -> 7"
[243] "average validation RMSE is 0.043764"
[244] "INFOFor params: momentum -> 0.1, layer2Size -> 6, layer1Size -> 7"
[245] "average validation RMSE is 0.032176"
[246] "INFOFor params: momentum -> 0.1, layer2Size -> 7, layer1Size -> 7"
[247] "average validation RMSE is 0.031010"
[248] "INFOFor params: momentum -> 0.1, layer2Size -> 8, layer1Size -> 7"
[249] "average validation RMSE is 0.026674"
[250] "INFOFor params: momentum -> 0.1, layer2Size -> 9, layer1Size -> 7"
[251] "average validation RMSE is 0.032181"
[252] "INFOFor params: momentum -> 0.1, layer2Size -> 10, layer1Size -> 7"
[253] "average validation RMSE is 0.038652"
[254] "INFOFor params: momentum -> 0.1, layer2Size -> 4, layer1Size -> 8"
[255] "average validation RMSE is 0.025450"
[256] "INFOFor params: momentum -> 0.1, layer2Size -> 5, layer1Size -> 8"
[257] "average validation RMSE is 0.022016"
[258] "INFOFor params: momentum -> 0.1, layer2Size -> 6, layer1Size -> 8"
[259] "average validation RMSE is 0.039360"
[260] "INFOFor params: momentum -> 0.1, layer2Size -> 7, layer1Size -> 8"
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[261] "average validation RMSE is 0.028982"
[262] "INFOFor params: momentum -> 0.1, layer2Size -> 8, layer1Size -> 8"
[263] "average validation RMSE is 0.032063"
[264] "INFOFor params: momentum -> 0.1, layer2Size -> 9, layer1Size -> 8"
[265] "average validation RMSE is 0.031110"
[266] "INFOFor params: momentum -> 0.1, layer2Size -> 10, layer1Size -> 8"
[267] "average validation RMSE is 0.024154"
[268] "INFOFor params: momentum -> 0.1, layer2Size -> 4, layer1Size -> 9"
[269] "average validation RMSE is 0.023843"
[270] "INFOFor params: momentum -> 0.1, layer2Size -> 5, layer1Size -> 9"
[271] "average validation RMSE is 0.021561"
[272] "INFOFor params: momentum -> 0.1, layer2Size -> 6, layer1Size -> 9"
[273] "average validation RMSE is 0.034738"
[274] "INFOFor params: momentum -> 0.1, layer2Size -> 7, layer1Size -> 9"
[275] "average validation RMSE is 0.032107"
[276] "INFOFor params: momentum -> 0.1, layer2Size -> 8, layer1Size -> 9"
[277] "average validation RMSE is 0.038356"
[278] "INFOFor params: momentum -> 0.1, layer2Size -> 9, layer1Size -> 9"
[279] "average validation RMSE is 0.029613"
[280] "INFOFor params: momentum -> 0.1, layer2Size -> 10, layer1Size -> 9"
[281] "average validation RMSE is 0.025694"
[282] "INFOFor params: momentum -> 0.1, layer2Size -> 4, layer1Size -> 10"
[283] "average validation RMSE is 0.025481"
[284] "INFOFor params: momentum -> 0.1, layer2Size -> 5, layer1Size -> 10"
[285] "average validation RMSE is 0.028568"
[286] "INFOFor params: momentum -> 0.1, layer2Size -> 6, layer1Size -> 10"
[287] "average validation RMSE is 0.021480"
[288] "INFOFor params: momentum -> 0.1, layer2Size -> 7, layer1Size -> 10"
[289] "average validation RMSE is 0.027081"
[290] "INFOFor params: momentum -> 0.1, layer2Size -> 8, layer1Size -> 10"
[291] "average validation RMSE is 0.026183"
[292] "INFOFor params: momentum -> 0.1, layer2Size -> 9, layer1Size -> 10"
[293] "average validation RMSE is 0.027253"
[294] "INFOFor params: momentum -> 0.1, layer2Size -> 10, layer1Size -> 10"
[295] "average validation RMSE is 0.028430"
[296] "INFOFor params: momentum -> 0.2, layer2Size -> 4, layer1Size -> 4"
[297] "average validation RMSE is 0.053664"
[298] "INFOFor params: momentum -> 0.2, layer2Size -> 5, layer1Size -> 4"
[299] "average validation RMSE is 0.036082"
[300] "INFOFor params: momentum -> 0.2, layer2Size -> 6, layer1Size -> 4"
[301] "average validation RMSE is 0.038183"
[302] "INFOFor params: momentum -> 0.2, layer2Size -> 7, layer1Size -> 4"
[303] "average validation RMSE is 0.039263"
[304] "INFOFor params: momentum -> 0.2, layer2Size -> 8, layer1Size -> 4"
[305] "average validation RMSE is 0.046418"
[306] "INFOFor params: momentum -> 0.2, layer2Size -> 9, layer1Size -> 4"
[307] "average validation RMSE is 0.041991"
[308] "INFOFor params: momentum -> 0.2, layer2Size -> 10, layer1Size -> 4"
[309] "average validation RMSE is 0.030775"
[310] "INFOFor params: momentum -> 0.2, layer2Size -> 4, layer1Size -> 5"
[311] "average validation RMSE is 0.042860"
[312] "INFOFor params: momentum -> 0.2, layer2Size -> 5, layer1Size -> 5"
[313] "average validation RMSE is 0.041781"
[314] "INFOFor params: momentum -> 0.2, layer2Size -> 6, layer1Size -> 5"
[315] "average validation RMSE is 0.031132"
[316] "INFOFor params: momentum -> 0.2, layer2Size -> 7, layer1Size -> 5"
[317] "average validation RMSE is 0.031761"
[318] "INFOFor params: momentum -> 0.2, layer2Size -> 8, layer1Size -> 5"
[319] "average validation RMSE is 0.028608"
[320] "INFOFor params: momentum -> 0.2, layer2Size -> 9, layer1Size -> 5"
[321] "average validation RMSE is 0.033680"
[322] "INFOFor params: momentum -> 0.2, layer2Size -> 10, layer1Size -> 5"
[323] "average validation RMSE is 0.034390"
[324] "INFOFor params: momentum -> 0.2, layer2Size -> 4, layer1Size -> 6"
[325] "average validation RMSE is 0.032039"
[326] "INFOFor params: momentum -> 0.2, layer2Size -> 5, layer1Size -> 6"
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[327] "average validation RMSE is 0.029353"
[328] "INFOFor params: momentum -> 0.2, layer2Size -> 6, layer1Size -> 6"
[329] "average validation RMSE is 0.038984"
[330] "INFOFor params: momentum -> 0.2, layer2Size -> 7, layer1Size -> 6"
[331] "average validation RMSE is 0.028613"
[332] "INFOFor params: momentum -> 0.2, layer2Size -> 8, layer1Size -> 6"
[333] "average validation RMSE is 0.030911"
[334] "INFOFor params: momentum -> 0.2, layer2Size -> 9, layer1Size -> 6"
[335] "average validation RMSE is 0.027878"
[336] "INFOFor params: momentum -> 0.2, layer2Size -> 10, layer1Size -> 6"
[337] "average validation RMSE is 0.028984"
[338] "INFOFor params: momentum -> 0.2, layer2Size -> 4, layer1Size -> 7"
[339] "average validation RMSE is 0.026840"
[340] "INFOFor params: momentum -> 0.2, layer2Size -> 5, layer1Size -> 7"
[341] "average validation RMSE is 0.045027"
[342] "INFOFor params: momentum -> 0.2, layer2Size -> 6, layer1Size -> 7"
[343] "average validation RMSE is 0.032893"
[344] "INFOFor params: momentum -> 0.2, layer2Size -> 7, layer1Size -> 7"
[345] "average validation RMSE is 0.029954"
[346] "INFOFor params: momentum -> 0.2, layer2Size -> 8, layer1Size -> 7"
[347] "average validation RMSE is 0.026846"
[348] "INFOFor params: momentum -> 0.2, layer2Size -> 9, layer1Size -> 7"
[349] "average validation RMSE is 0.032487"
[350] "INFOFor params: momentum -> 0.2, layer2Size -> 10, layer1Size -> 7"
[351] "average validation RMSE is 0.037482"
[352] "INFOFor params: momentum -> 0.2, layer2Size -> 4, layer1Size -> 8"
[353] "average validation RMSE is 0.025620"
[354] "INFOFor params: momentum -> 0.2, layer2Size -> 5, layer1Size -> 8"
[355] "average validation RMSE is 0.022262"
[356] "INFOFor params: momentum -> 0.2, layer2Size -> 6, layer1Size -> 8"
[357] "average validation RMSE is 0.038290"
[358] "INFOFor params: momentum -> 0.2, layer2Size -> 7, layer1Size -> 8"
[359] "average validation RMSE is 0.027774"
[360] "INFOFor params: momentum -> 0.2, layer2Size -> 8, layer1Size -> 8"
[361] "average validation RMSE is 0.029804"
[362] "INFOFor params: momentum -> 0.2, layer2Size -> 9, layer1Size -> 8"
[363] "average validation RMSE is 0.029380"
[364] "INFOFor params: momentum -> 0.2, layer2Size -> 10, layer1Size -> 8"
[365] "average validation RMSE is 0.023308"
[366] "INFOFor params: momentum -> 0.2, layer2Size -> 4, layer1Size -> 9"
[367] "average validation RMSE is 0.023877"
[368] "INFOFor params: momentum -> 0.2, layer2Size -> 5, layer1Size -> 9"
[369] "average validation RMSE is 0.021290"
[370] "INFOFor params: momentum -> 0.2, layer2Size -> 6, layer1Size -> 9"
[371] "average validation RMSE is 0.029617"
[372] "INFOFor params: momentum -> 0.2, layer2Size -> 7, layer1Size -> 9"
[373] "average validation RMSE is 0.030525"
[374] "INFOFor params: momentum -> 0.2, layer2Size -> 8, layer1Size -> 9"
[375] "average validation RMSE is 0.039928"
[376] "INFOFor params: momentum -> 0.2, layer2Size -> 9, layer1Size -> 9"
[377] "average validation RMSE is 0.029070"
[378] "INFOFor params: momentum -> 0.2, layer2Size -> 10, layer1Size -> 9"
[379] "average validation RMSE is 0.025152"
[380] "INFOFor params: momentum -> 0.2, layer2Size -> 4, layer1Size -> 10"
[381] "average validation RMSE is 0.024075"
[382] "INFOFor params: momentum -> 0.2, layer2Size -> 5, layer1Size -> 10"
[383] "average validation RMSE is 0.028976"
[384] "INFOFor params: momentum -> 0.2, layer2Size -> 6, layer1Size -> 10"
[385] "average validation RMSE is 0.020600"
[386] "INFOFor params: momentum -> 0.2, layer2Size -> 7, layer1Size -> 10"
[387] "average validation RMSE is 0.027274"
[388] "INFOFor params: momentum -> 0.2, layer2Size -> 8, layer1Size -> 10"
[389] "average validation RMSE is 0.025772"
[390] "INFOFor params: momentum -> 0.2, layer2Size -> 9, layer1Size -> 10"
[391] "average validation RMSE is 0.036636"
[392] "INFOFor params: momentum -> 0.2, layer2Size -> 10, layer1Size -> 10"
```

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[393] "average validation RMSE is 0.027896"
[394] "INFOSelected model with params: momentum -> 0.001, layer1Size -> 8, layer2Size -> 5,"
[395] "performance: validRmse -> 0.019706549963553, testRmse -> 0.03310714112449"
```

This procedure again selected different architecture, the build model has better validation error but worse test error.