

ECGR 4106 Real-time Machine Learning

Homework 2

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Github link: <https://github.com/nguyjd/ecgr-4106-homeworks/tree/main/homework%202>

Problem 1

The goal of the problem is to build a fully connected neural network for same housing data we used in homework 1. The data will now be split with 80% training and 20% validation data.

For **problem 1 part 1**, I first define the normalized data function and the training loop in cell IN[2]. The normalized data function takes the mean and the standard deviation of the input data. Using $(\text{tensor} - \text{mean}) / \text{std}$ normalizes the data. The Training loop is standard with a few modification. The modification records and store the losses from training. The data will be used to graph the loss.

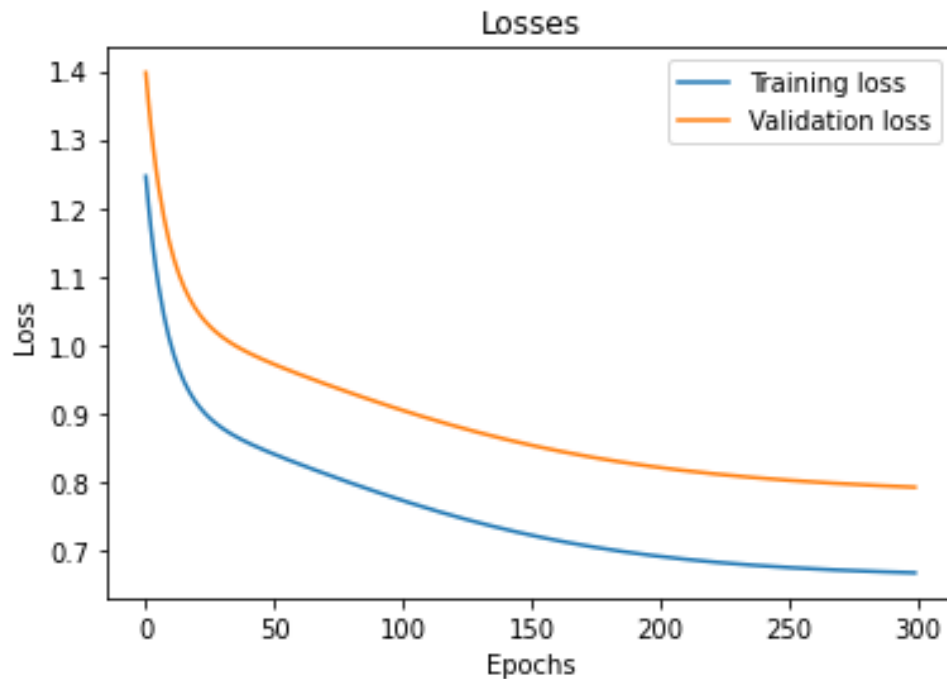
In cell IN[3] I defined the number of epochs and read in the data from the csv file. Then the data was split according the percentage split. Both of the input and output data was normalized.

In cell IN[4], I defined the neural network with a input of 5 node, a hidden layer of 8 nodes and a output of 1 to predict the price. In cell[5] I start the first training loop for 300 epochs and the training loop prints every 10 epochs.

Problem 1 part 1 output

```
Epoch 1: Training Loss: 1.2460602521896362, Validation Loss: 1.3977521657943726
Epoch 10: Training Loss: 1.0101455450057983, Validation Loss: 1.151967167854309
Epoch 20: Training Loss: 0.9181671142578125, Validation Loss: 1.054456353187561
Epoch 30: Training Loss: 0.8796026706695557, Validation Loss: 1.0130778551101685
Epoch 40: Training Loss: 0.8576151728630066, Validation Loss: 0.989709198474884
Epoch 50: Training Loss: 0.8409616947174072, Validation Loss: 0.9724629521369934
Epoch 60: Training Loss: 0.8261151313781738, Validation Loss: 0.9574528932571411
Epoch 70: Training Loss: 0.812021791934967, Validation Loss: 0.9434162974357605
Epoch 80: Training Loss: 0.798433780670166, Validation Loss: 0.9299797415733337
Epoch 90: Training Loss: 0.7853594422340393, Validation Loss: 0.917076051235199
Epoch 100: Training Loss: 0.7728792428970337, Validation Loss: 0.904740571975708
Epoch 110: Training Loss: 0.7610804438591003, Validation Loss: 0.8930349946022034
Epoch 120: Training Loss: 0.7500353455543518, Validation Loss: 0.8820186853408813
Epoch 130: Training Loss: 0.739793598651886, Validation Loss: 0.8717361688613892
Epoch 140: Training Loss: 0.7303813695907593, Validation Loss: 0.8622138500213623
Epoch 150: Training Loss: 0.7218034267425537, Validation Loss: 0.8534596562385559
Epoch 160: Training Loss: 0.7140458226203918, Validation Loss: 0.8454656600952148
Epoch 170: Training Loss: 0.7070803642272949, Validation Loss: 0.8382095694541931
Epoch 180: Training Loss: 0.700867235660553, Validation Loss: 0.8316590189933777
Epoch 190: Training Loss: 0.6953589916229248, Validation Loss: 0.8257730603218079
Epoch 200: Training Loss: 0.690502405166626, Validation Loss: 0.8205056190490723
Epoch 210: Training Loss: 0.686242227859497, Validation Loss: 0.8158075213432312
Epoch 220: Training Loss: 0.6825219988822937, Validation Loss: 0.8116279244422913
Epoch 230: Training Loss: 0.6792863011360168, Validation Loss: 0.807917058467865
Epoch 240: Training Loss: 0.6764819025993347, Validation Loss: 0.804625928401947
Epoch 250: Training Loss: 0.6740583777427673, Validation Loss: 0.8017081618309021
Epoch 260: Training Loss: 0.6719690561294556, Validation Loss: 0.7991204261779785
Epoch 270: Training Loss: 0.670170783996582, Validation Loss: 0.7968224883079529
Epoch 280: Training Loss: 0.6686248779296875, Validation Loss: 0.7947779893875122
Epoch 290: Training Loss: 0.667296290397644, Validation Loss: 0.7929537892341614
Epoch 300: Training Loss: 0.6661543250083923, Validation Loss: 0.7913205623626709
```

In cell In[6], I plot the losses.



Training Time: **less than 1 seconds.**

Final Training loss: **0.66615**

Final Validation Loss: **0.79132**

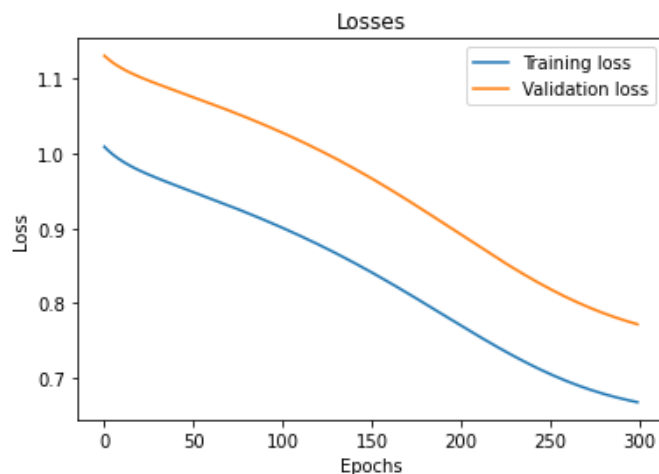
The accuracy of the model is about the same as the linear regression model we did in homework 1. The loss is much less because the prices are normalized this time round. The model is also not over fitting the training data, the validation and the training follow the same trend.

For **problem 1 part 2**, I reuse the training loop and redefined the model. The new model has three hidden layers instead of one. The new hidden layer has 32 nodes and 10 nodes and I ran the training loop of 300 epochs.

Problem 1 part 2 output

```
Epoch 1: Training Loss: 1.008755087852478, Validation Loss: 1.1300957202911377
Epoch 10: Training Loss: 0.9911390542984009, Validation Loss: 1.1144399642944336
Epoch 20: Training Loss: 0.9779357314109802, Validation Loss: 1.1026506423950195
Epoch 30: Training Loss: 0.9675033092498779, Validation Loss: 1.0931150913238525
Epoch 40: Training Loss: 0.9581463932991028, Validation Loss: 1.0843251943588257
Epoch 50: Training Loss: 0.9491453766822815, Validation Loss: 1.0756783485412598
Epoch 60: Training Loss: 0.9401654005050659, Validation Loss: 1.0669103860855103
Epoch 70: Training Loss: 0.9310250878334045, Validation Loss: 1.0578820705413818
Epoch 80: Training Loss: 0.9216070175170898, Validation Loss: 1.0485001802444458
Epoch 90: Training Loss: 0.9118227958679199, Validation Loss: 1.0386887788772583
Epoch 100: Training Loss: 0.901601254940033, Validation Loss: 1.028381586074829
Epoch 110: Training Loss: 0.8908839225769043, Validation Loss: 1.0175195932388306
Epoch 120: Training Loss: 0.8796263337135315, Validation Loss: 1.0060539245605469
Epoch 130: Training Loss: 0.8677998185157776, Validation Loss: 0.9939488172531128
Epoch 140: Training Loss: 0.8553949594497681, Validation Loss: 0.9811856150627136
Epoch 150: Training Loss: 0.8424268364906311, Validation Loss: 0.9677679538726807
Epoch 160: Training Loss: 0.8289375901222229, Validation Loss: 0.9537258148193359
Epoch 170: Training Loss: 0.81500244140625, Validation Loss: 0.9391213655471802
Epoch 180: Training Loss: 0.8007311224937439, Validation Loss: 0.9240509867668152
Epoch 190: Training Loss: 0.7862692475318909, Validation Loss: 0.9086489677429199
Epoch 200: Training Loss: 0.7717961072921753, Validation Loss: 0.8930847644805908
Epoch 210: Training Loss: 0.7575180530548096, Validation Loss: 0.8775590062141418
Epoch 220: Training Loss: 0.7436574101448059, Validation Loss: 0.8622939586639404
Epoch 230: Training Loss: 0.730439305305481, Validation Loss: 0.8475205898284912
Epoch 240: Training Loss: 0.7180732488632202, Validation Loss: 0.8334622979164124
Epoch 250: Training Loss: 0.7067372798919678, Validation Loss: 0.820317804813385
Epoch 260: Training Loss: 0.6965621113777161, Validation Loss: 0.808246910572052
Epoch 270: Training Loss: 0.6876233220100403, Validation Loss: 0.7973576784133911
Epoch 280: Training Loss: 0.6799374222755432, Validation Loss: 0.787703275680542
Epoch 290: Training Loss: 0.673466682434082, Validation Loss: 0.7792821526527405
Epoch 300: Training Loss: 0.6681283116340637, Validation Loss: 0.7720456719398499
```

In cell In[8], I plot the losses.



Training Time: **less than 1 seconds.**

Final Training loss: **0.668**

Final Validation Loss: **0.7720**

The accuracy of the model is the same as problem 1 part 1. The model is not overfitting to the training data. Both of the losses are following the same trend.

Found in Cell In[35]

Problem 1 part 1 model size: 57

Problem 1 part 2 model size: 667

The new model is 11 times larger than the baseline.

Problem 2

The goal of the problem is also create a fully connected neural network for the 10 classes in CIFAR-10.

For problem 2 part 1, The model has one hidden layer of 512, input of 3072, and the output of 10.

The problem started in cell IN[9] with defining how to transform the images in the dataset. The code was found from the lectures. The training loop is also defined in cell IN[9].

In cell IN[10] the dataset was downloaded and transformed using the code in IN[9]. In cell IN[11], I set defined the model with the layers explained before. The both the training and the validation data was loaded in using the DataLoader from torch.

The model was trained in Cell IN[12].

```
Epoch: 1, Training Loss: 1.9678707122802734, Validation Loss: 2.2674553394317627, Accuracy: 13.19%
Epoch: 10, Training Loss: 1.680593490600586, Validation Loss: 1.7601591348648071, Accuracy: 39.629999999999995%
Epoch: 20, Training Loss: 1.683751106262207, Validation Loss: 1.7104140520095825, Accuracy: 41.81%
Epoch: 30, Training Loss: 1.6511505842208862, Validation Loss: 1.6814672946929932, Accuracy: 42.76%
Epoch: 40, Training Loss: 1.5423791408538818, Validation Loss: 1.661741018295288, Accuracy: 43.730000000000004%
Epoch: 50, Training Loss: 1.5605401992797852, Validation Loss: 1.6429061889648438, Accuracy: 44.24%
Epoch: 60, Training Loss: 1.4842920303344727, Validation Loss: 1.6270273923873901, Accuracy: 45.07%
Epoch: 70, Training Loss: 1.4811780452728271, Validation Loss: 1.614139199256897, Accuracy: 45.440000000000005%
Epoch: 80, Training Loss: 1.4788289070129395, Validation Loss: 1.5981080532073975, Accuracy: 46.02%
Epoch: 90, Training Loss: 1.4786642789840698, Validation Loss: 1.5835200548171997, Accuracy: 46.6%
Epoch: 100, Training Loss: 1.4138902425765991, Validation Loss: 1.5733616352081299, Accuracy: 47.28%
Epoch: 110, Training Loss: 1.4385255575180054, Validation Loss: 1.561989665031433, Accuracy: 47.44%
Epoch: 120, Training Loss: 1.383408546447754, Validation Loss: 1.5483051538467407, Accuracy: 47.85%
Epoch: 130, Training Loss: 1.3222304582595825, Validation Loss: 1.5401769876480103, Accuracy: 48.14%
Epoch: 140, Training Loss: 1.2957812547683716, Validation Loss: 1.5294804573059082, Accuracy: 48.49%
Epoch: 150, Training Loss: 1.2477396726608276, Validation Loss: 1.5214554071426392, Accuracy: 48.480000000000004%
Epoch: 160, Training Loss: 1.270158052444458, Validation Loss: 1.5157904624938965, Accuracy: 49.02%
Epoch: 170, Training Loss: 1.1731148958206177, Validation Loss: 1.5065337419509888, Accuracy: 49.18%
Epoch: 180, Training Loss: 1.2165769338607788, Validation Loss: 1.502706527709961, Accuracy: 49.36%
Epoch: 190, Training Loss: 1.215359091758728, Validation Loss: 1.497601866722107, Accuracy: 49.45%
Epoch: 200, Training Loss: 1.1286588907241821, Validation Loss: 1.5001407861709595, Accuracy: 49.480000000000004%
Epoch: 210, Training Loss: 1.1143525838851929, Validation Loss: 1.4920920133590698, Accuracy: 49.79%
Epoch: 220, Training Loss: 1.0544027090072632, Validation Loss: 1.4892915487289429, Accuracy: 49.97%
Epoch: 230, Training Loss: 1.06126868724823, Validation Loss: 1.4929190874099731, Accuracy: 49.86%
Epoch: 240, Training Loss: 1.0108919143676758, Validation Loss: 1.4876394271850586, Accuracy: 49.9%
Epoch: 250, Training Loss: 0.9650559425354004, Validation Loss: 1.4945276975631714, Accuracy: 50.1%
Epoch: 260, Training Loss: 0.9646227955818176, Validation Loss: 1.4951883554458618, Accuracy: 49.89%
Epoch: 270, Training Loss: 0.9307659268379211, Validation Loss: 1.4912934303283691, Accuracy: 50.09%
Epoch: 280, Training Loss: 0.9296294450759888, Validation Loss: 1.4971216917037964, Accuracy: 50.080000000000005%
Epoch: 290, Training Loss: 0.9564180970191956, Validation Loss: 1.49622642993927, Accuracy: 50.0%
Epoch: 300, Training Loss: 0.8289459347724915, Validation Loss: 1.4961400032043457, Accuracy: 50.029999999999994%

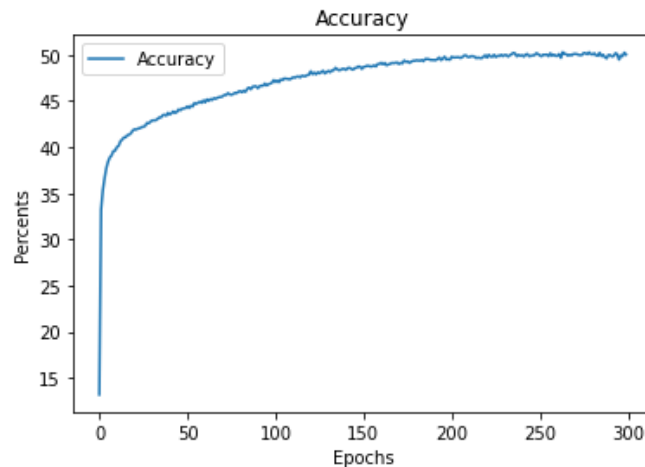
Final Loss: 0.8289459347724915, Final Accuracy: 50.029999999999994%
Training Time: 4272.34 seconds
```

Final Loss: 0.8289

Validation Loss: 1.496

Accuracy: 50.02%

Time: 4272 seconds.



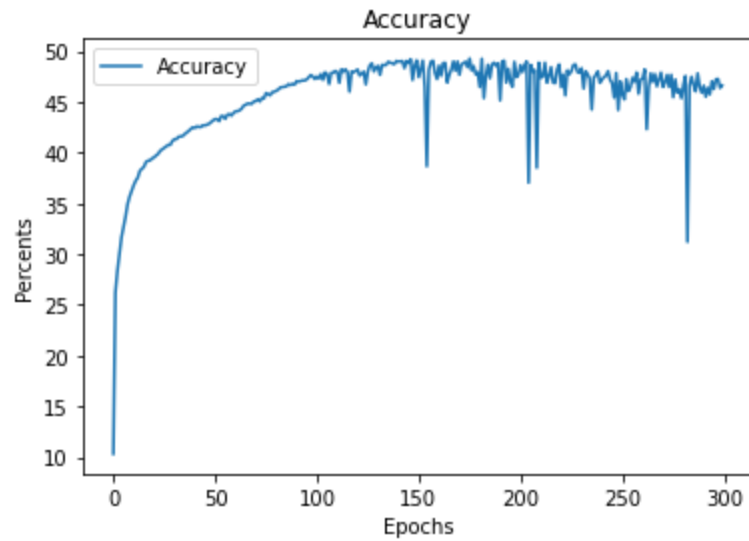
The model predicts the correct label for the picture half the time. Looking at the loss, it seems like it starting to overfit the training data. The validation loss is staying around 1.496 while the training loss is decreasing.

For problem 2 part 2, The model evolved to have two new hidden layer of 1024 and 256 nodes (cell In[15]). The new model is now retrained on the training loop.

```
Epoch: 1, Training Loss: 2.1452176570892334, Validation Loss: 2.3103466033935547, Accuracy: 10.32%
Epoch: 10, Training Loss: 1.8333007097244263, Validation Loss: 1.8492969274520874, Accuracy: 36.25%
Epoch: 20, Training Loss: 1.7433573007583618, Validation Loss: 1.7603672742843628, Accuracy: 39.42%
Epoch: 30, Training Loss: 1.7012865543365479, Validation Loss: 1.7154326438903809, Accuracy: 41.14%
Epoch: 40, Training Loss: 1.6453821659088135, Validation Loss: 1.6865911483764648, Accuracy: 42.49%
Epoch: 50, Training Loss: 1.6486808061599731, Validation Loss: 1.66253662109375, Accuracy: 43.169999999999995%
Epoch: 60, Training Loss: 1.5862213373184204, Validation Loss: 1.6396384239196777, Accuracy: 43.89%
Epoch: 70, Training Loss: 1.540399193763733, Validation Loss: 1.6203588247299194, Accuracy: 45.04%
Epoch: 80, Training Loss: 1.5035895109176636, Validation Loss: 1.5962070226669312, Accuracy: 45.98%
Epoch: 90, Training Loss: 1.5043388605117798, Validation Loss: 1.5754191875457764, Accuracy: 46.69%
Epoch: 100, Training Loss: 1.3994776010513306, Validation Loss: 1.566023588180542, Accuracy: 47.24%
Epoch: 110, Training Loss: 1.3454256057739258, Validation Loss: 1.5401884317398071, Accuracy: 48.04%
Epoch: 120, Training Loss: 1.262939453125, Validation Loss: 1.551008939743042, Accuracy: 48.03%
Epoch: 130, Training Loss: 1.2566801309585571, Validation Loss: 1.5210061073303223, Accuracy: 48.38%
Epoch: 140, Training Loss: 1.234034538269043, Validation Loss: 1.5160892009735107, Accuracy: 49.02%
Epoch: 150, Training Loss: 1.1209686994552612, Validation Loss: 1.5157856941223145, Accuracy: 49.09%
Epoch: 160, Training Loss: 1.1806663274765015, Validation Loss: 1.5796059370040894, Accuracy: 47.24%
Epoch: 170, Training Loss: 1.1065318584442139, Validation Loss: 1.545309066772461, Accuracy: 48.980000000000004%
Epoch: 180, Training Loss: 1.1540173292160034, Validation Loss: 1.6169922351837158, Accuracy: 47.910000000000004%
Epoch: 190, Training Loss: 1.0791571140289307, Validation Loss: 1.5610172748565674, Accuracy: 48.79%
Epoch: 200, Training Loss: 0.8759352564811707, Validation Loss: 1.6208983659744263, Accuracy: 47.68%
Epoch: 210, Training Loss: 0.9494306445121765, Validation Loss: 1.6281899213790894, Accuracy: 48.86%
Epoch: 220, Training Loss: 1.048671841621399, Validation Loss: 1.6302698850631714, Accuracy: 48.68%
Epoch: 230, Training Loss: 0.7789023518562317, Validation Loss: 1.7281850576400757, Accuracy: 47.870000000000005%
Epoch: 240, Training Loss: 0.7309607863426208, Validation Loss: 1.852726697921753, Accuracy: 46.87%
Epoch: 250, Training Loss: 0.7191540002822876, Validation Loss: 1.8119103908538818, Accuracy: 47.02%
Epoch: 260, Training Loss: 0.6168233752250671, Validation Loss: 1.8419313430786133, Accuracy: 47.17%
Epoch: 270, Training Loss: 0.5479784607887268, Validation Loss: 1.839116096496582, Accuracy: 47.88%
Epoch: 280, Training Loss: 0.5738944411277771, Validation Loss: 2.102342367172241, Accuracy: 45.36%
Epoch: 290, Training Loss: 0.5162743330001831, Validation Loss: 2.0567572116851807, Accuracy: 45.9%
Epoch: 300, Training Loss: 2.5052082538604736, Validation Loss: 2.034482479095459, Accuracy: 46.61%
```

Final Loss: 0.5162, Final Accuracy: 46.61%
Training Time: 4473.68 seconds

Loss: 0.5162
Validation Loss: 2.056
Accuracy: 45.6%
Time: 4473 seconds



The model perform worse than the baseline from problem 2 part 2. The accuracy is worse. The model is overfitting to the training data. The validation loss is increasing while the training loss is decreasing.

Found in Cell In[35]

Problem 1 part 1 model size: 1.58 M

Problem 1 part 2 model size: 2.36 M

The new model is almost 1.5 times larger than the baseline.