ELEC-5970

Hardware AI

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Lab 1

Introduction

This Lab was an introduction to Pycharm, a Python IDE, and to train a nural network in Pytorch.

Task 1

In Task 1, we were asked to edit some of the pre-modeled hardware training code and save our tained model with the code. Then we were asked to vary the pruning rate at inference time and generate a bar chart. The chart below in Figure 1 shows the varied pruning rate at 0%, 30%, and 50%. Figures 2 through Figures 4 show the consol output from running this code.

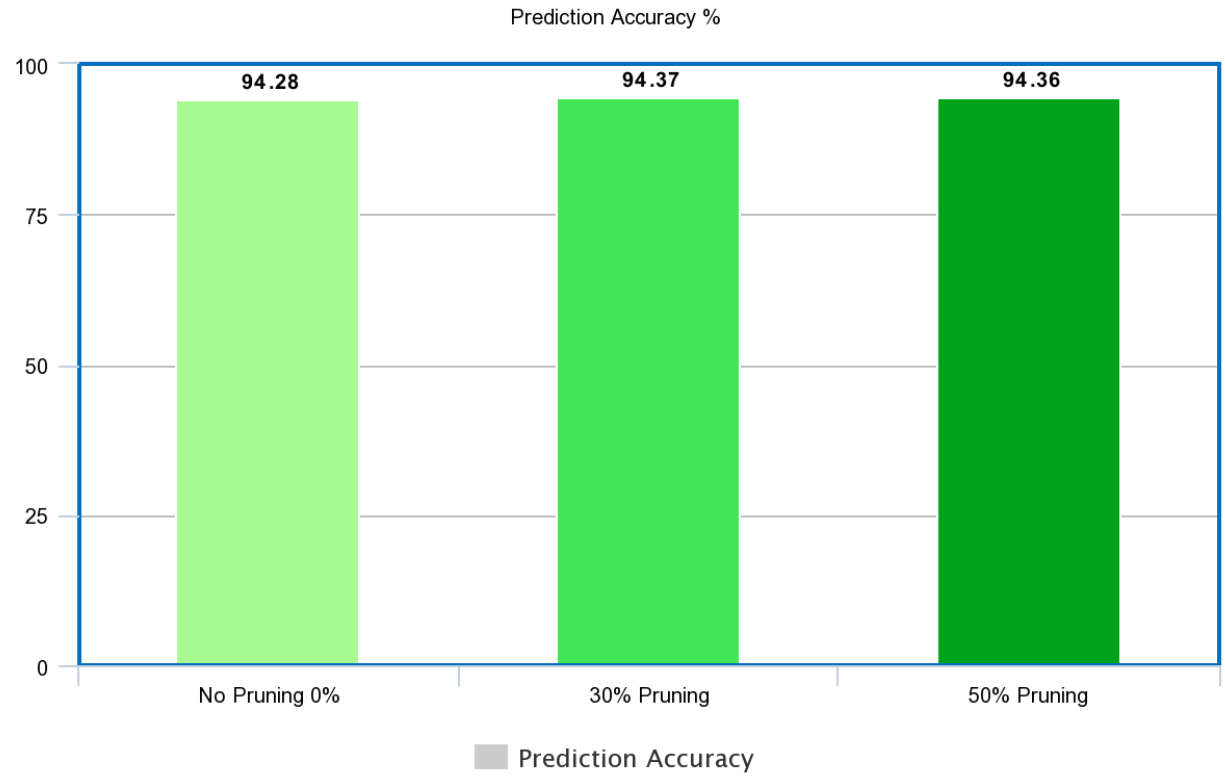

Figure 1

```
Sparsity in Linear Layer 1: 0.00%
Sparsity in Linear Layer 2: 0.00%
Sparsity in Linear Layer 3: 0.00%
Global Sparsity: 0.00%
Predicted Digit = 2
Number Of Images Tested = 10000

Model Accuracy = 94.28 %
```

Figure 2

```
Sparsity in Linear Layer 1: 31.92%
Sparsity in Linear Layer 2: 10.01%
Sparsity in Linear Layer 3: 7.34%
Global Sparsity: 30.00%
Predicted Digit = 4
Number Of Images Tested = 10000

Model Accuracy = 94.37 %
```

Figure 3

```
Sparsity in Linear Layer 1: 53.16%
Sparsity in Linear Layer 2: 16.97%
Sparsity in Linear Layer 3: 13.91%
Global Sparsity: 50.00%
Predicted Digit = 4
Number Of Images Tested = 10000

Model Accuracy = 94.36 %
```

Figure 4

Task 2

In Task 2, we were asked to train multiple networks by varying the number of hidden layers and number of neurons in hidden layers. The first network was asked to have 2 hidden layers of 128 neurons. The second network was asked to have 2 hidden layers with 512 neurons. The third network was asked to have 3 hidden layers with 256, 128, and 64 neurons respectively.

The fourth network was asked to have 3 hidden layers, each having 64 neurons. All networks were trained for 20 epochs. *Figure 5* below shows the Model Accuracy and *Figure 6* shows the Training Time in minutes. *Figure 7* through *Figure 10* show the consol output of the training.

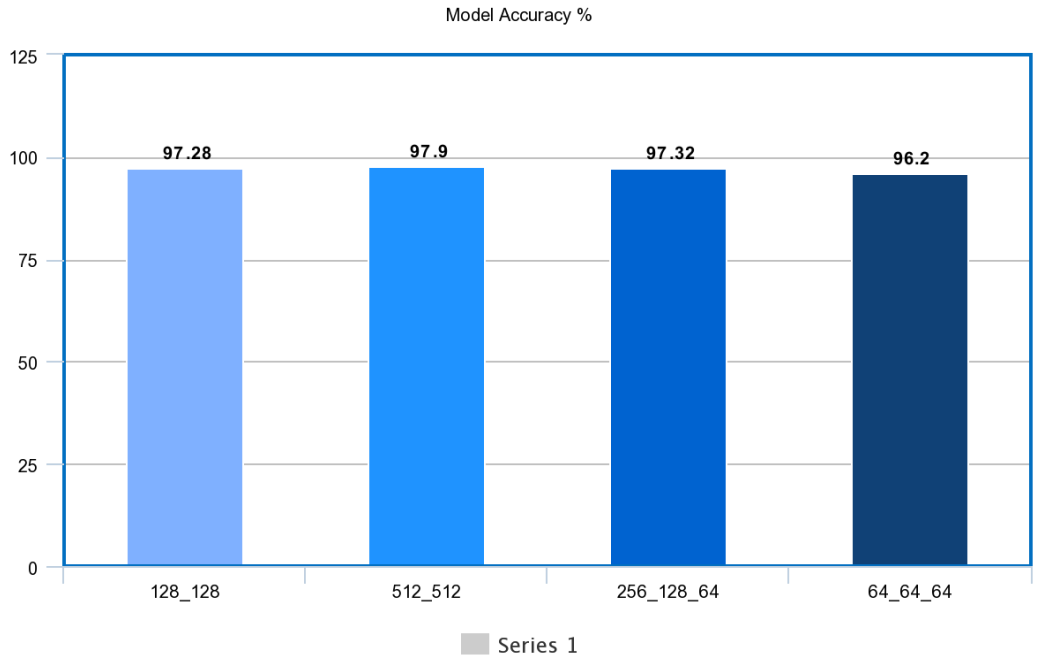

Figure 5

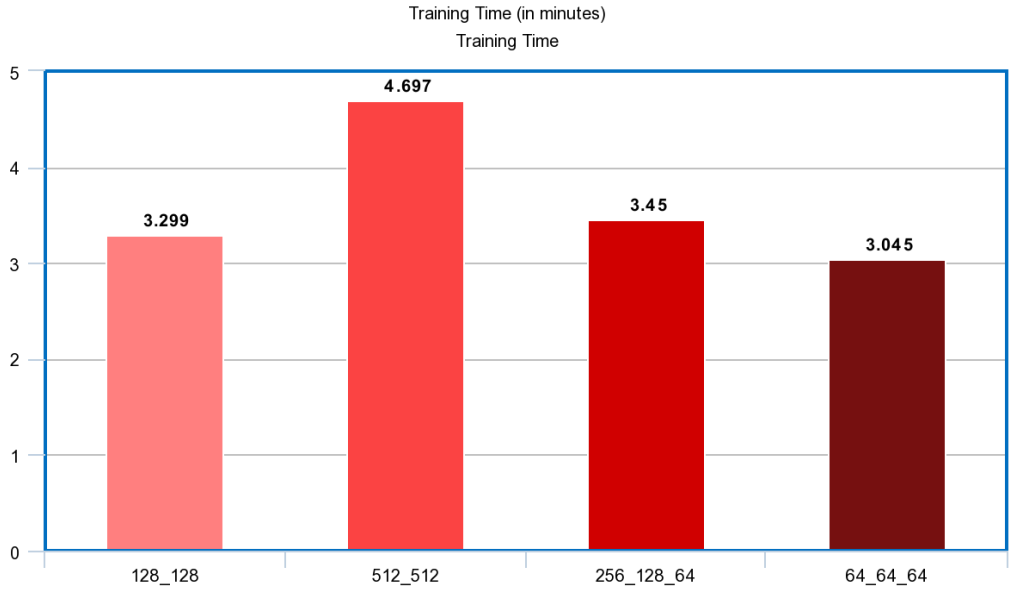

Figure 6

```
Epoch 19 - Training loss: 0.063965961337585 97
Iterations in one Epoch 938

Training Time (in minutes) = 3.2997615456581117
Predicted Digit = 7
Number Of Images Tested = 10000

Model Accuracy = 97.28 %
```

Figure 7

```
Epoch 19 - Training loss: 0.014061156108245395
Iterations in one Epoch 938

Training Time (in minutes) = 4.69712221622467
Predicted Digit = 5
Number Of Images Tested = 10000

Model Accuracy = 97.89999999999999 %
```

Figure 8

```
Epoch 19 - Training loss: 0.0386210049486169
Iterations in one Epoch 938

Training Time (in minutes) = 3.450217306613922
Predicted Digit = 6
Number Of Images Tested = 10000

Model Accuracy = 97.32 %
```

Figure 9

```
Epoch 19 - Training loss: 0.10963721537311226
Iterations in one Epoch 938

Training Time (in minutes) = 3.045124546686808
Predicted Digit = 3
Number Of Images Tested = 10000

Model Accuracy = 96.2 %
```

Figure 10

Task 3

In Task 3, we were asked pick the best network from task two and plot a Training Loss line graph based on 25 epochs. The Graph is shown below *in Figure 11* and the consol output is shown in *Figure 12*.

Figure 11

```
Epoch 0 - Training loss: 0.49369159321000833
Epoch 1 - Training loss: 0.2346304679221944
Epoch 2 - Training loss: 0.1655988806147756
Epoch 3 - Training loss: 0.12888917631145988
Epoch 4 - Training loss: 0.10295248169924563
Epoch 5 - Training loss: 0.08622285235734747
Epoch 6 - Training loss: 0.0731929958349209
Epoch 7 - Training loss: 0.06358450203975126
Epoch 8 - Training loss: 0.055402651945971
Epoch 9 - Training loss: 0.048118541514359986
Epoch 10 - Training loss: 0.042169919555216456
Epoch 11 - Training loss: 0.03733659500634965
Epoch 12 - Training loss: 0.033517627090936516
Epoch 13 - Training loss: 0.0284981768684281
Epoch 14 - Training loss: 0.024924728495596564
Epoch 15 - Training loss: 0.023632531556653787
Epoch 16 - Training loss: 0.019187115836885572
Epoch 17 - Training loss: 0.018103399605024606
Epoch 18 - Training loss: 0.016804024448810913
Epoch 19 - Training loss: 0.015039416877876794
Epoch 20 - Training loss: 0.0137002984046975
Epoch 21 - Training loss: 0.011690711532058546
Epoch 22 - Training loss: 0.011916202300346455
Epoch 23 - Training loss: 0.010937148237446778
Epoch 24 - Training loss: 0.00729839995778857
Iterations in one Epoch 938

Training Time (in minutes) = 5.390508925914764
Predicted Digit = 9
Number Of Images Tested = 10000

Model Accuracy = 98.08 %
```

Figure 12

Task 4

In Task 4, we were asked to use Stochastic Gradient Decent with a learning rate of 0.3, 0.03, 0.003, and 0.0003 instead of the Adam optimizer. *Figure 13* through *Figure 16* shows the plots respectively. *Figure 17* through *Figure 20* show the consol outputs respectively.

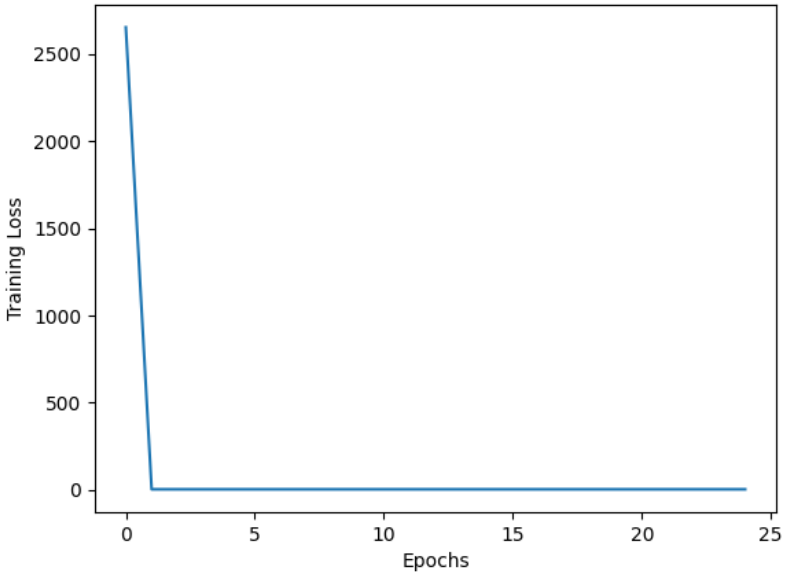

Figure 13

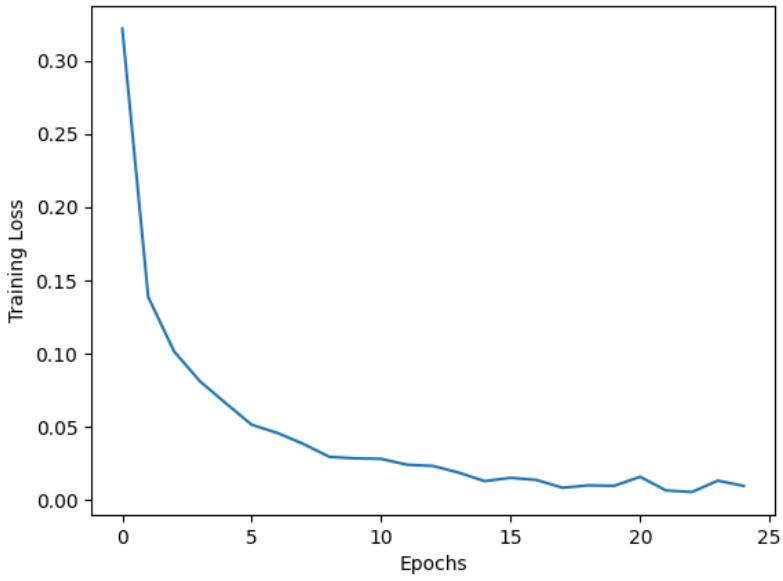

Figure 14

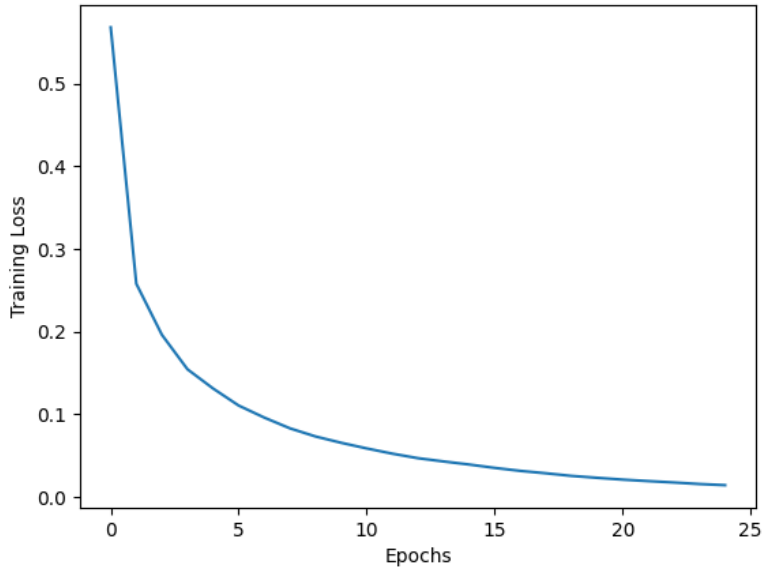

Figure 15

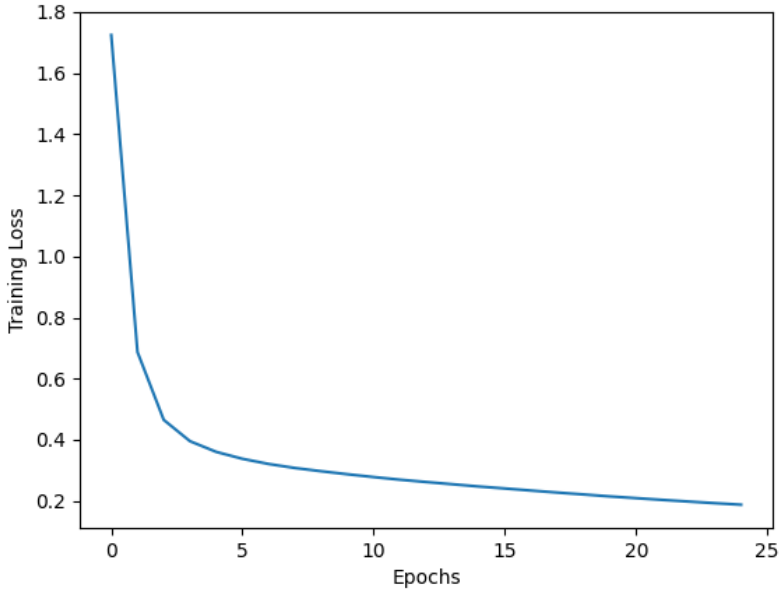

Figure 16

```
Epoch 0 - Training loss: 2654.6753749654235
Epoch 1 - Training loss: 2.3118046267962913
Epoch 2 - Training loss: 2.3123521695513207
Epoch 3 - Training loss: 2.3110103724099424
Epoch 4 - Training loss: 2.3125878506377817
Epoch 5 - Training loss: 2.3118168745976266
Epoch 6 - Training loss: 2.311634652396001
Epoch 7 - Training loss: 2.3114912243031744
Epoch 8 - Training loss: 2.3108505452873866
Epoch 9 - Training loss: 2.3115402986245877
Epoch 10 - Training loss: 2.311458091746007
Epoch 11 - Training loss: 2.311293475663484
Epoch 12 - Training loss: 2.312301385885617
Epoch 13 - Training loss: 2.311683663681372
Epoch 14 - Training loss: 2.311098561358096
Epoch 15 - Training loss: 2.310825493289972
Epoch 16 - Training loss: 2.3103499443037934
Epoch 17 - Training loss: 2.311558850284324
Epoch 18 - Training loss: 2.3120702398357107
Epoch 19 - Training loss: 2.3115937656431056
Epoch 20 - Training loss: 2.3115751349341385
Epoch 21 - Training loss: 2.3122993356891786
Epoch 22 - Training loss: 2.3114285105581223
Epoch 23 - Training loss: 2.3112688125577816
Epoch 24 - Training loss: 2.311417553470587
Iterations in one Epoch 938

Training Time (in minutes) = 5.791792360941569
Predicted Digit = 1
Number Of Images Tested = 10000

Model Accuracy = 11.35 %
```

Figure 17

```
Epoch 0 - Training loss: 0.32192656403975384
Epoch 1 - Training loss: 0.13879723937860303
Epoch 2 - Training loss: 0.10164280488455632
Epoch 3 - Training loss: 0.08128521877399553
Epoch 4 - Training loss: 0.0662283753506593
Epoch 5 - Training loss: 0.051608164786986176
Epoch 6 - Training loss: 0.045939062087731346
Epoch 7 - Training loss: 0.0384593147389553
Epoch 8 - Training loss: 0.029698879868302844
```

```
Epoch 9 - Training loss: 0.02866329605410677
Epoch 10 - Training loss: 0.02830264122733389
Epoch 11 - Training loss: 0.02433073219009902
Epoch 12 - Training loss: 0.02347428494368151
Epoch 13 - Training loss: 0.018895332934953487
Epoch 14 - Training loss: 0.01313715974205196
Epoch 15 - Training loss: 0.015404410989310037
Epoch 16 - Training loss: 0.013932780509751696
Epoch 17 - Training loss: 0.008613778010485301
Epoch 18 - Training loss: 0.010239752777346563
Epoch 19 - Training loss: 0.009942862576877981
Epoch 20 - Training loss: 0.016078028021366143
Epoch 21 - Training loss: 0.006765035739267165
Epoch 22 - Training loss: 0.005714427405784231
Epoch 23 - Training loss: 0.013463515612906905
Epoch 24 - Training loss: 0.00986472285497653
Iterations in one Epoch 938

Training Time (in minutes) = 4.605974356333415
Predicted Digit = 3
Number Of Images Tested = 10000

Model Accuracy = 98.32 %
```

Figure 18

```
Epoch 0 - Training loss: 0.5682428606124575
Epoch 1 - Training loss: 0.2580445544011811
Epoch 2 - Training loss: 0.1962473988791169
Epoch 3 - Training loss: 0.1545096367581694
Epoch 4 - Training loss: 0.13128406789773372
Epoch 5 - Training loss: 0.11065703792485601
Epoch 6 - Training loss: 0.09609965305290878
Epoch 7 - Training loss: 0.08311701673509947
Epoch 8 - Training loss: 0.07327281904649109
Epoch 9 - Training loss: 0.06563289641990447
Epoch 10 - Training loss: 0.05879059531785516
Epoch 11 - Training loss: 0.05247427830408051
Epoch 12 - Training loss: 0.046989414611829323
Epoch 13 - Training loss: 0.043040757642503875
Epoch 14 - Training loss: 0.039335078775395216
Epoch 15 - Training loss: 0.03523481968290874
Epoch 16 - Training loss: 0.031626768687343806
Epoch 17 - Training loss: 0.028722462333194705
```

```
Epoch 18 - Training loss: 0.02555223852696358
Epoch 19 - Training loss: 0.02325209987237861
Epoch 20 - Training loss: 0.021056975276747554
Epoch 21 - Training loss: 0.01925691690571211
Epoch 22 - Training loss: 0.017588125128705584
Epoch 23 - Training loss: 0.015719680366158954
Epoch 24 - Training loss: 0.014336163765065241
Iterations in one Epoch 938

Training Time (in minutes) = 4.575155417124431
Predicted Digit = 6
Number Of Images Tested = 10000

Model Accuracy = 98.04 %
```

Figure 19

```
Epoch 0 - Training loss: 1.724768878935751
Epoch 1 - Training loss: 0.6872422935040012
Epoch 2 - Training loss: 0.4650639512105537
Epoch 3 - Training loss: 0.3953267793252524
Epoch 4 - Training loss: 0.3602595209344618
Epoch 5 - Training loss: 0.33762773232006316
Epoch 6 - Training loss: 0.3206729817349138
Epoch 7 - Training loss: 0.30754143021889585
Epoch 8 - Training loss: 0.2969666250161271
Epoch 9 - Training loss: 0.28710420266874054
Epoch 10 - Training loss: 0.27787661414220133
Epoch 11 - Training loss: 0.26927593007270717
Epoch 12 - Training loss: 0.26170399875592576
Epoch 13 - Training loss: 0.25438102009469893
Epoch 14 - Training loss: 0.24702736487520782
Epoch 15 - Training loss: 0.24051905010761357
Epoch 16 - Training loss: 0.23372087729320343
Epoch 17 - Training loss: 0.22716040165423712
Epoch 18 - Training loss: 0.22095587064446545
Epoch 19 - Training loss: 0.21450781753894363
Epoch 20 - Training loss: 0.20886873728685032
Epoch 21 - Training loss: 0.20315662228555947
Epoch 22 - Training loss: 0.197716179119149
Epoch 23 - Training loss: 0.19243439162638523
Epoch 24 - Training loss: 0.18741381718024516
Iterations in one Epoch 938
```

```
Training Time (in minutes) = 4.556286283334097
Predicted Digit = 0
Number Of Images Tested = 10000

Model Accuracy = 94.66 %
```

Figure 20

Task 5

In Task 5, we were asked to use the best network from Task 4 (learning rate of 0.03) and run with batch sizes of 32, 128, and 512. The recorded test accuracy and training time of all runs is shown in the graph in Figure 21 below. *Figure 22* shows the data collected. I was unsure how to make th graph like the one shown in the example, so this is the best graph I could come up with as of now.

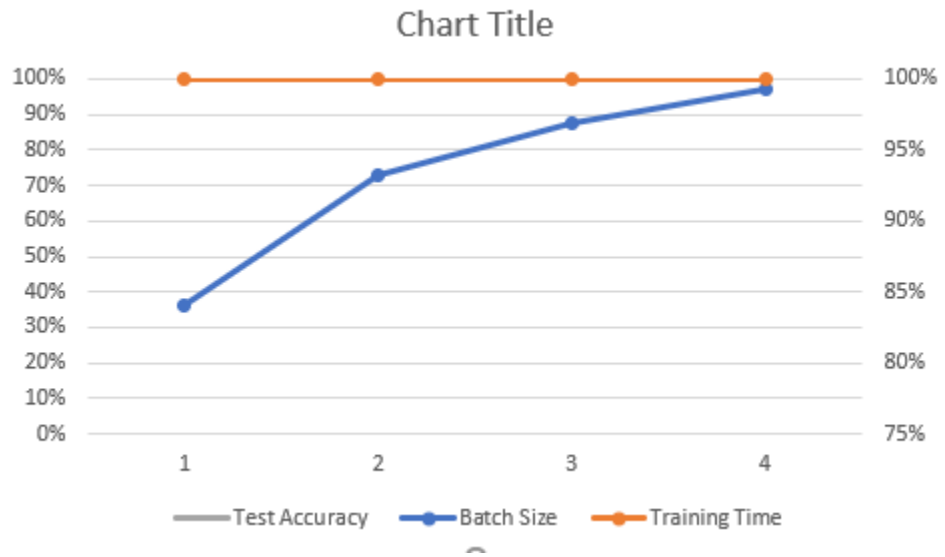

Figure 21

Batch Size	Training Time	Test Accuracy
32	6.053590953	96.24
64	4.64129372	98.4
128	4.1034121	98.57
512	3.603063814	98.23

Figure 22

Task 6

In the last task, we were asked to compare a "256-256-256" size model with and without dropout. The results with dropout are show in *Figure 23* and without dropout in *Figure 24*. From my results, the moddle without dropout is more accurate and takes less time.

```
Epoch 0 - Training loss: 0.9336401552467023
Epoch 1 - Training loss: 0.3769401569487685
Epoch 2 - Training loss: 0.310524363638991
Epoch 3 - Training loss: 0.26428084820508957
Epoch 4 - Training loss: 0.23811339384923547
Epoch 5 - Training loss: 0.22285921555959573
Epoch 6 - Training loss: 0.2100544954508038
Epoch 7 - Training loss: 0.19980675139922208
Epoch 8 - Training loss: 0.1876767169115907
Epoch 9 - Training loss: 0.17409264428888338
Epoch 10 - Training loss: 0.16692218714851445
Epoch 11 - Training loss: 0.16102072154566394
Epoch 12 - Training loss: 0.15233473599714747
Epoch 13 - Training loss: 0.14652521725175743
Epoch 14 - Training loss: 0.14893359173152407
Epoch 15 - Training loss: 0.14263424611950326
Epoch 16 - Training loss: 0.13604173531471672
Epoch 17 - Training loss: 0.13127423355639992
Epoch 18 - Training loss: 0.1303952679795734
Epoch 19 - Training loss: 0.12947619681136083
Epoch 20 - Training loss: 0.12648085732076128
Epoch 21 - Training loss: 0.1176381803796453
Epoch 22 - Training loss: 0.11821403613282462
Epoch 23 - Training loss: 0.11686623206961963
Epoch 24 - Training loss: 0.11586721058366663
```

```
Iterations in one Epoch 118

Training Time (in minutes) = 3.53361029624939
Predicted Digit = 8
Number Of Images Tested = 10000

Model Accuracy = 95.52000000000001 %
```

Figure 23 (with dropout)

```
Epoch 0 - Training loss: 0.7082247626730951
Epoch 1 - Training loss: 0.25757342374930947
Epoch 2 - Training loss: 0.19569621588719094
Epoch 3 - Training loss: 0.15526265764640548
Epoch 4 - Training loss: 0.12731967064536223
Epoch 5 - Training loss: 0.11040241463835966
Epoch 6 - Training loss: 0.09228077208844282
Epoch 7 - Training loss: 0.08188014963673333
Epoch 8 - Training loss: 0.07202267870938374
Epoch 9 - Training loss: 0.06341100927694875
Epoch 10 - Training loss: 0.057322151453818304
Epoch 11 - Training loss: 0.052799303274033434
Epoch 12 - Training loss: 0.0491847801811488
Epoch 13 - Training loss: 0.042748732950096416
Epoch 14 - Training loss: 0.03946076856010546
Epoch 15 - Training loss: 0.03539025171075837
Epoch 16 - Training loss: 0.031468091516802875
Epoch 17 - Training loss: 0.028125225408476288
Epoch 18 - Training loss: 0.02600924901159133
Epoch 19 - Training loss: 0.023128163535147905
Epoch 20 - Training loss: 0.021518777491587957
Epoch 21 - Training loss: 0.021410636832716608
Epoch 22 - Training loss: 0.01829418053424333
Epoch 23 - Training loss: 0.015711224113070105
Epoch 24 - Training loss: 0.015927517652448455
Iterations in one Epoch 118

Training Time (in minutes) = 3.238017749786377
Predicted Digit = 4
Number Of Images Tested = 10000

Model Accuracy = 98.03 %
```

Figure 24 (without dropout)