

Samuel Lee

CS5330

Project 5

4/7/2024

Project Overview

This project explores the potential of recognition using deep networks. To achieve recognition via deep networks, there are three main parts that are essential: the network model definition, retrieving the datasets, and training and testing the datasets.

The first part of the project focuses on training the model on the MNIST digit dataset. First, I create a network model class and train the model based on the train dataset. When training, many factors play an important part, such as the loss function, optimizer, learning rate, number of epochs, batch size, and more. Once I finished training the model, I confirm the accuracy of the model by using the test dataset. Eventually, I use my own images of digits to test whether my network model is working as expected.

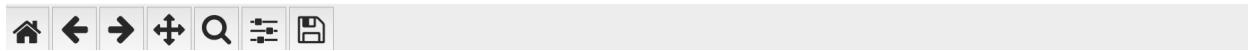
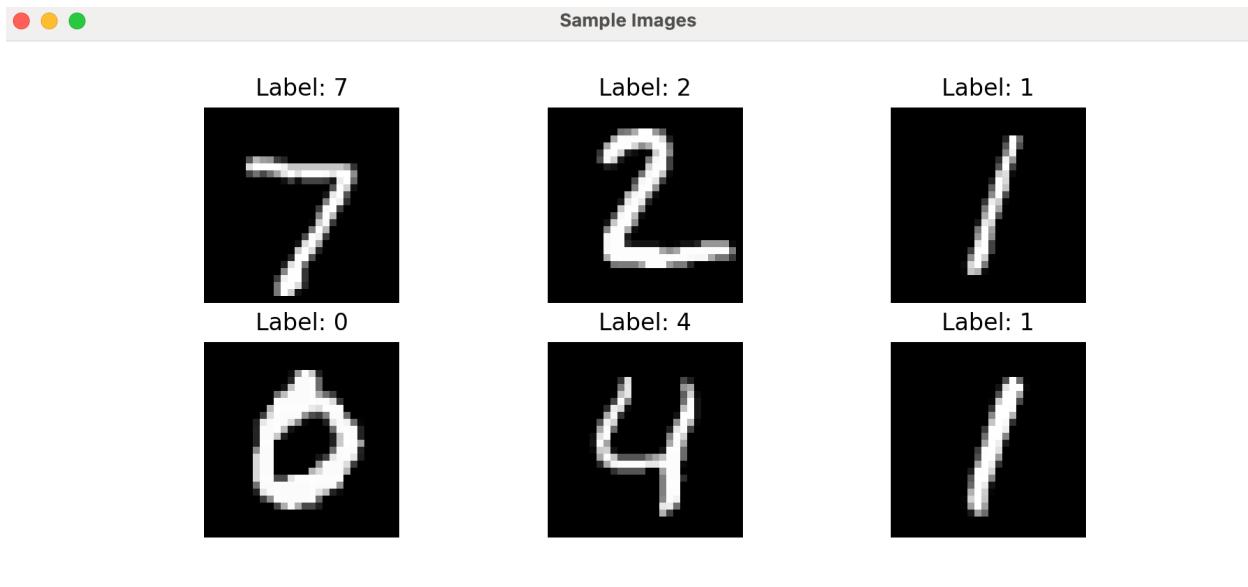
Next, I incorporate the same methodology to recognizing Greek letters, with an addition of transferred learning. Instead of starting from scratch, I use the same model weights from my trained model from MNIST digit dataset but just replace the final layer since the classification is different at the last layer.

Finally, my project evaluates how changing dimensions in the network model itself, such as dropout rate and filter size, affects the performance of training in terms of time and accuracy.

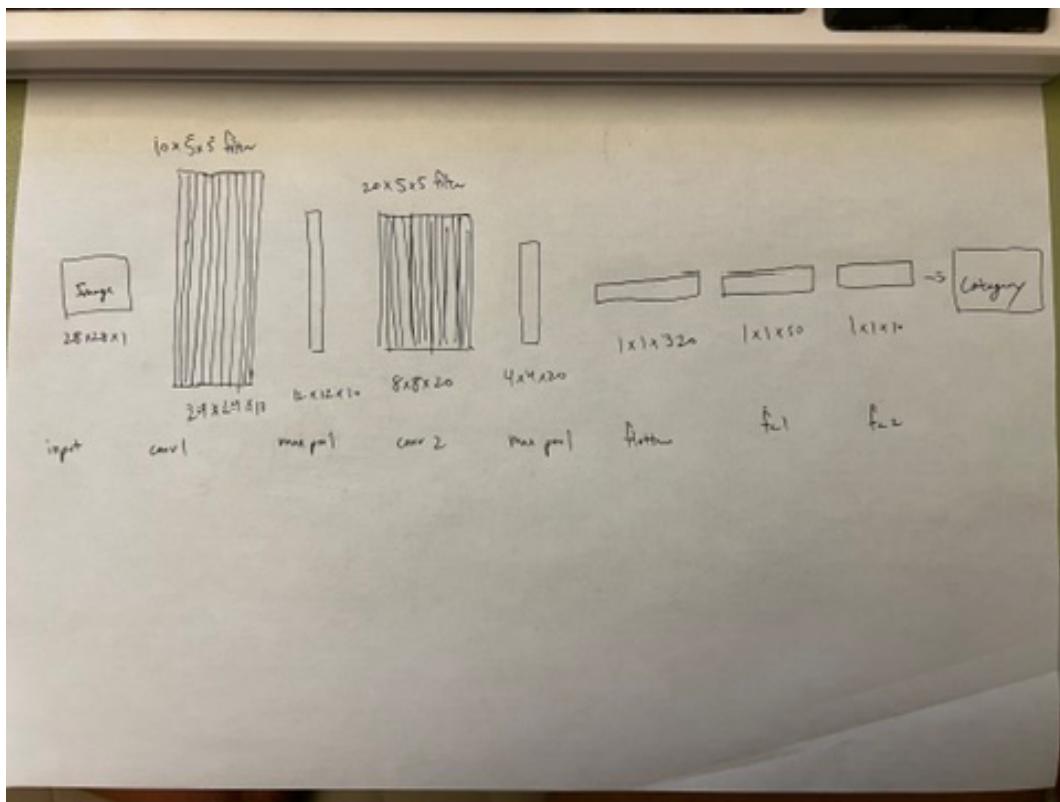
Required Images

Question 1

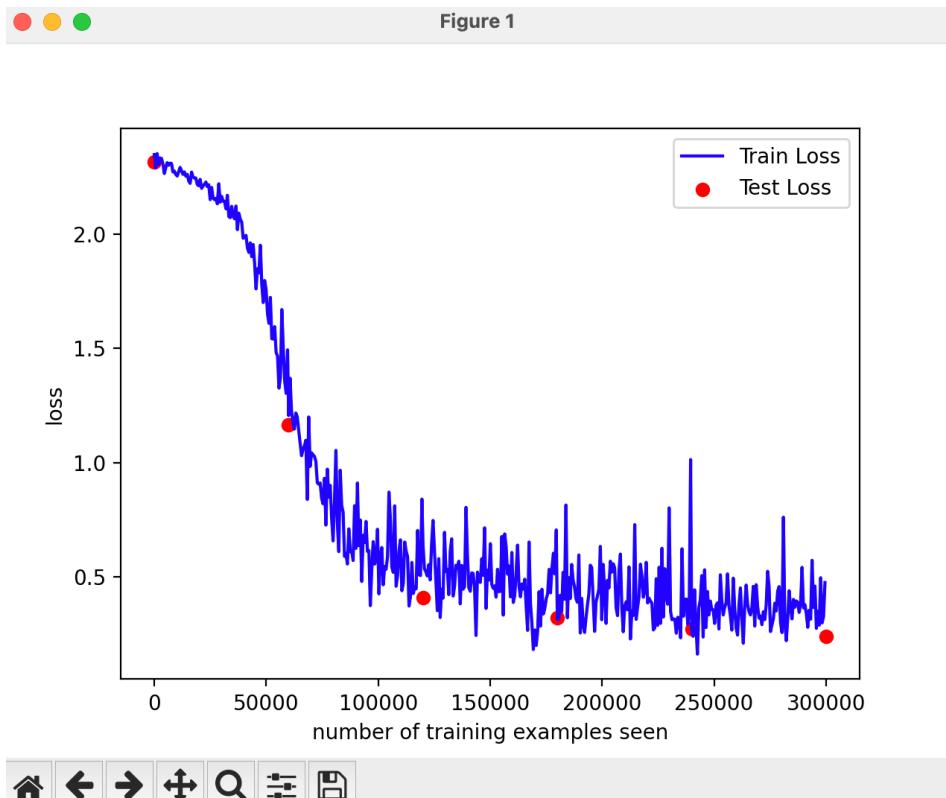
Part A



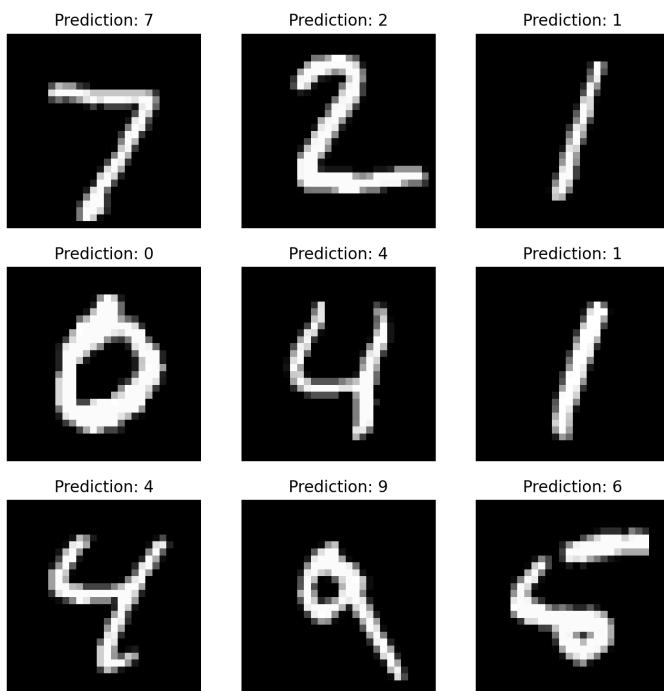
Part B



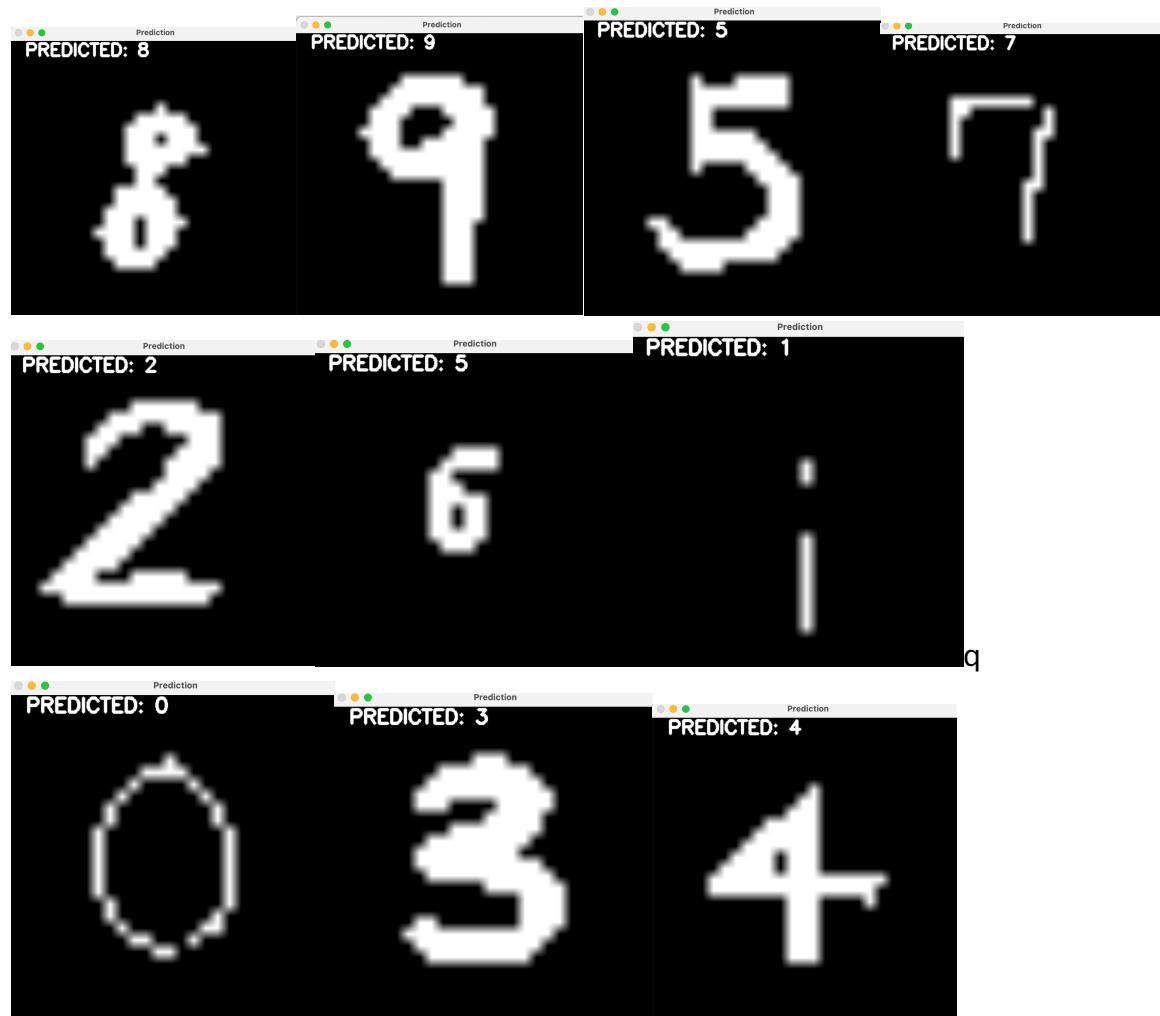
Part C



Part E

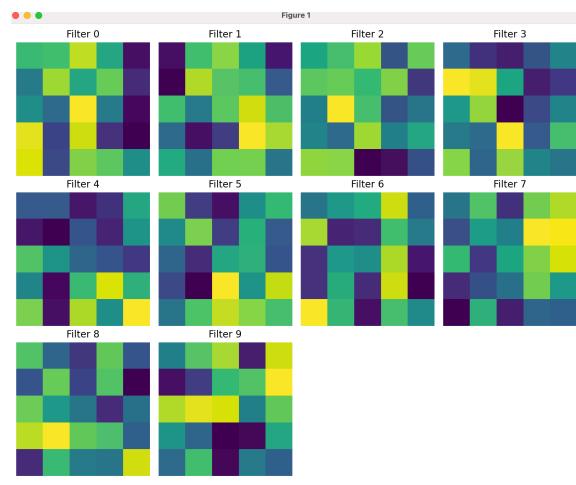


Part F

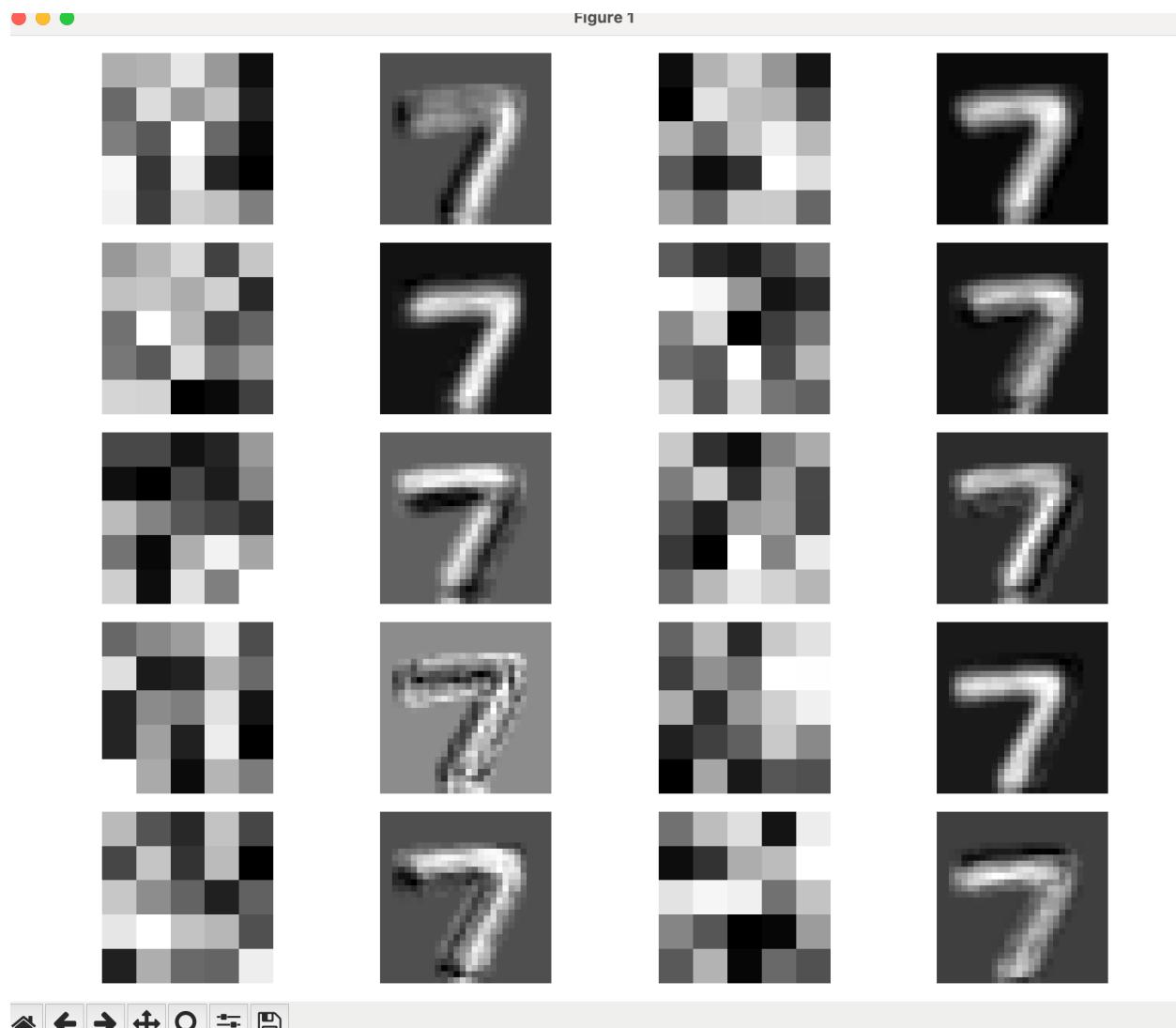


Question 2

Part A



Part B

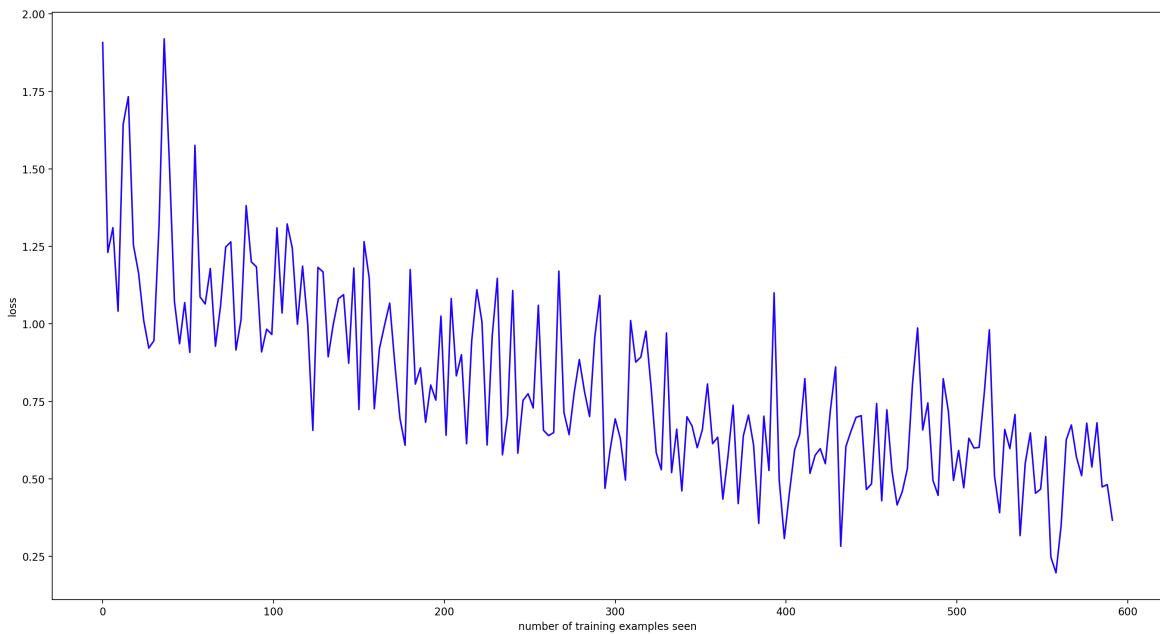


- Each filter is part of the convolution layer and the resulting image is shown next to it.
- The kernel slides across the image to get the weighted sum of each pixel.
- Considering that the original image consists of a white digit and black background, these filters and the resulting images make sense. The more gray and white there are, the more the number is accentuated. The more black there are, the more the color of the number and background are similar.

Question 3

It takes around 20-25 epochs to get nearly 100% accuracy.

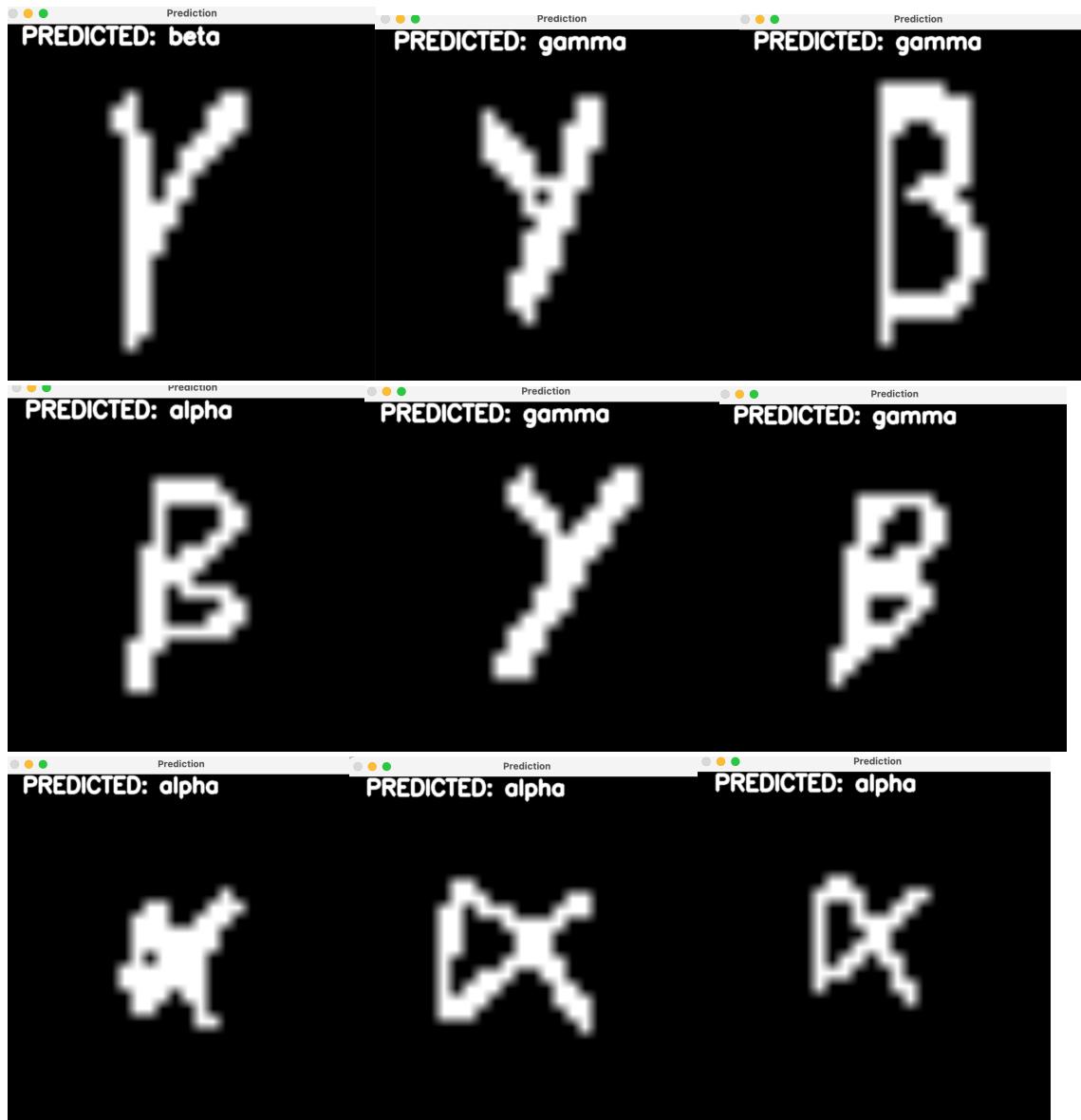
Here is the plot of the training error:



Printout of Modified Network

```
NeuralNetwork(  
    (conv1): Conv2d(1, 10, kernel_size=(5, 5), stride=(1, 1))  
    (conv2): Conv2d(10, 20, kernel_size=(5, 5), stride=(1, 1))  
    (drop50): Dropout2d(p=0.5, inplace=False)  
    (flatten): Flatten(start_dim=1, end_dim=-1)  
    (fc1): Linear(in_features=320, out_features=50, bias=True)  
    (fc2): Linear(in_features=50, out_features=3, bias=True)  
)
```

Results on Additional Data



In README, included a link to a zip file with the additional examples.

Question 4

For this part, I used three dimensions: convolution filter size, convolution filter count, and dropout rate.

```
# set dimensions of model
conv_filter_size = [3, 5, 7, 9]
conv_filter_count = [5, 10, 15]
dropout_rate = [0.3, 0.4, 0.5, 0.6, 0.7]
```

I keep two dimensions constant and change one dimension at a time. This combination evaluates a total of 60 combinations.

Based on each filter size, these are my hypotheses on the time length duration and accuracy of each training model:

- Time Duration
 - An increase in filter size would generally increase the duration of training since more calculations are required per pixel during training.
 - An increase in filter count would generally increase the duration of training since more feature maps are being generated for each convolution layer.
 - Dropout rate generally does not influence the duration of training. However, a higher dropout rate means less data is contributing to training the model, which may increase the number of epochs needed to reach a certain level of accuracy.
- Accuracy
 - A decrease in filter size would generally yield higher accuracy, as smaller filters allow the model to capture more granular details.
 - An increase in the number of filters would generally increase accuracy since more filters allows the model network to learn more diversely and be able to distinguish one feature from another. However, after a certain point, overfitting may cause a problem to the model.
 - A high dropout rate would potentially underfit the data, making the model less favorable for predicting a label for a data point. As a result, high dropout rates could result in lower accuracy. As for a moderate dropout rate, this can prevent a model from overfitting data by randomly disabling data points.

Here are my results after evaluating the model on different parameters for training

		Settings	Duration	Accuracy
0	Filter Size: 3, Number of Filters: 5, Dropout Rate: 0.3	16.367469	78.83	
1	Filter Size: 3, Number of Filters: 5, Dropout Rate: 0.4	16.164374	78.98	
2	Filter Size: 3, Number of Filters: 5, Dropout Rate: 0.5	15.771323	79.95	
3	Filter Size: 3, Number of Filters: 5, Dropout Rate: 0.6	15.245114	78.63	
4	Filter Size: 3, Number of Filters: 5, Dropout Rate: 0.7	16.371680	77.06	
5	Filter Size: 3, Number of Filters: 10, Dropout Rate: 0.3	16.499814	79.52	
6	Filter Size: 3, Number of Filters: 10, Dropout Rate: 0.4	15.894493	80.16	
7	Filter Size: 3, Number of Filters: 10, Dropout Rate: 0.5	15.434924	79.95	
8	Filter Size: 3, Number of Filters: 10, Dropout Rate: 0.6	15.295278	80.01	
9	Filter Size: 3, Number of Filters: 10, Dropout Rate: 0.7	15.357407	79.91	
10	Filter Size: 3, Number of Filters: 15, Dropout Rate: 0.3	16.086077	80.41	
11	Filter Size: 3, Number of Filters: 15, Dropout Rate: 0.4	15.990807	80.78	
12	Filter Size: 3, Number of Filters: 15, Dropout Rate: 0.5	15.912709	79.92	
13	Filter Size: 3, Number of Filters: 15, Dropout Rate: 0.6	16.096369	80.28	
14	Filter Size: 3, Number of Filters: 15, Dropout Rate: 0.7	15.874565	80.53	
15	Filter Size: 5, Number of Filters: 5, Dropout Rate: 0.3	18.342539	78.70	
16	Filter Size: 5, Number of Filters: 5, Dropout Rate: 0.4	16.936033	78.28	
17	Filter Size: 5, Number of Filters: 5, Dropout Rate: 0.5	17.140288	79.54	
18	Filter Size: 5, Number of Filters: 5, Dropout Rate: 0.6	17.513112	78.45	
19	Filter Size: 5, Number of Filters: 5, Dropout Rate: 0.7	17.176407	78.93	
20	Filter Size: 5, Number of Filters: 10, Dropout Rate: 0.3	16.424490	79.91	
21	Filter Size: 5, Number of Filters: 10, Dropout Rate: 0.4	15.978654	79.62	
22	Filter Size: 5, Number of Filters: 10, Dropout Rate: 0.5	16.410081	79.50	
23	Filter Size: 5, Number of Filters: 10, Dropout Rate: 0.6	16.220215	79.67	
24	Filter Size: 5, Number of Filters: 10, Dropout Rate: 0.7	16.584507	80.04	
25	Filter Size: 5, Number of Filters: 15, Dropout Rate: 0.3	16.648384	80.63	
26	Filter Size: 5, Number of Filters: 15, Dropout Rate: 0.4	16.448821	79.38	
27	Filter Size: 5, Number of Filters: 15, Dropout Rate: 0.5	16.501271	79.74	
28	Filter Size: 5, Number of Filters: 15, Dropout Rate: 0.6	16.318207	80.38	
29	Filter Size: 5, Number of Filters: 15, Dropout Rate: 0.7	16.427802	80.15	
30	Filter Size: 7, Number of Filters: 5, Dropout Rate: 0.3	19.784254	77.92	
31	Filter Size: 7, Number of Filters: 5, Dropout Rate: 0.4	18.782432	79.00	
32	Filter Size: 7, Number of Filters: 5, Dropout Rate: 0.5	19.275510	78.22	
33	Filter Size: 7, Number of Filters: 5, Dropout Rate: 0.6	18.330619	78.08	
34	Filter Size: 7, Number of Filters: 5, Dropout Rate: 0.7	18.519318	78.02	
35	Filter Size: 7, Number of Filters: 10, Dropout Rate: 0.3	15.609519	79.09	
36	Filter Size: 7, Number of Filters: 10, Dropout Rate: 0.4	15.971166	78.28	
37	Filter Size: 7, Number of Filters: 10, Dropout Rate: 0.5	15.857738	79.16	
38	Filter Size: 7, Number of Filters: 10, Dropout Rate: 0.6	15.434819	78.50	
39	Filter Size: 7, Number of Filters: 10, Dropout Rate: 0.7	15.895908	78.67	
40	Filter Size: 7, Number of Filters: 15, Dropout Rate: 0.3	17.257570	79.97	
41	Filter Size: 7, Number of Filters: 15, Dropout Rate: 0.4	17.016486	79.82	
42	Filter Size: 7, Number of Filters: 15, Dropout Rate: 0.5	17.103890	78.94	
43	Filter Size: 7, Number of Filters: 15, Dropout Rate: 0.6	15.706972	79.25	
44	Filter Size: 7, Number of Filters: 15, Dropout Rate: 0.7	16.237153	79.66	
45	Filter Size: 9, Number of Filters: 5, Dropout Rate: 0.3	19.567277	77.55	
46	Filter Size: 9, Number of Filters: 5, Dropout Rate: 0.4	19.872694	77.08	
47	Filter Size: 9, Number of Filters: 5, Dropout Rate: 0.5	19.852400	76.39	
48	Filter Size: 9, Number of Filters: 5, Dropout Rate: 0.6	19.944102	75.93	
49	Filter Size: 9, Number of Filters: 5, Dropout Rate: 0.7	19.749137	76.87	
50	Filter Size: 9, Number of Filters: 10, Dropout Rate: 0.3	16.499297	78.38	
51	Filter Size: 9, Number of Filters: 10, Dropout Rate: 0.4	16.300521	77.98	
52	Filter Size: 9, Number of Filters: 10, Dropout Rate: 0.5	16.236265	78.02	
53	Filter Size: 9, Number of Filters: 10, Dropout Rate: 0.6	15.779328	77.90	
54	Filter Size: 9, Number of Filters: 10, Dropout Rate: 0.7	16.068889	78.65	
55	Filter Size: 9, Number of Filters: 15, Dropout Rate: 0.3	16.606317	79.07	
56	Filter Size: 9, Number of Filters: 15, Dropout Rate: 0.4	16.073027	78.62	
57	Filter Size: 9, Number of Filters: 15, Dropout Rate: 0.5	15.940772	78.41	
58	Filter Size: 9, Number of Filters: 15, Dropout Rate: 0.6	15.599353	78.21	
59	Filter Size: 9, Number of Filters: 15, Dropout Rate: 0.7	16.111225	77.76	

Here is my evaluation of my hypotheses:

- Time Duration
 - An increase in filter size would generally increase the duration of training since more calculations are required per pixel during training.
 - Evaluation: based on the results shown above, an increase in filter size increases the average duration of training.
 - An increase in filter count would generally increase the duration of training since more feature maps are being generated for each convolution layer.
 - Evaluation: interestingly enough, holding other parameters constant, an increase in filter count led to a general *decrease* in the duration of training. This was an unexpected result, but after doing some research, I learned that MPS (GPU device for Mac) can process data in parallel, which can lead to more efficient processing. The model and the training are all processed with the device MPS when I checked, so this might explain for this.
 - Dropout rate generally does not influence the duration of training. However, a higher dropout rate means less data is contributing to training the model, which may increase the number of epochs needed to reach a certain level of accuracy.
 - Evaluation: dropout rate as a parameter did not seem to show a consistent trend on increasing/decreasing time duration
- Accuracy
 - A decrease in filter size would generally yield higher accuracy, as smaller filters allow the model to capture more granular details.
 - Evaluation: generally, with other parameters held constant, I can see that increasing the filter size decreases the accuracy
 - An increase in the number of filters would generally increase accuracy since more filters allow the model network to learn more diversely and be able to distinguish one feature from another. However, after a certain point, overfitting may cause a problem to the model.
 - Evaluation: generally, with other parameters held constant, I can see that increasing the number of filters increases accuracy
 - A high dropout rate would potentially underfit the data, making the model less favorable for predicting a label for a data point. As a result, high dropout rates could result in lower accuracy. As for a moderate dropout rate, this can prevent a model from overfitting data by randomly disabling data points.

- Evaluation: in many instances, when dropout rate was the highest with other variables being constant, the accuracy was lower than the model's accuracy with a lower dropout rate. Most of the time, a moderate dropout rate (in the 0.3 – 0.5 range) had the highest accuracy.

Extensions

Extension #1: Add More Dimensions to Part 4

I wanted to analyze and evaluate further on how changing other dimensions would affect computation duration and accuracy of the model. The two additional dimensions I added to my code fashion_model.py are number of epochs and batch size. Due to computational limits, I had to downsize the dimension sizes for the other 3 dimensions I worked on for Part 4, so the code will reflect the code for the extension, not for Part 4. Here are the results (will have to zoom in to see):

1	Filter Size: 3, Number of Filters: 5, Dropout Rate: 0.3, Epochs: 1, Batch Size: 64	Settings	Duration	Accuracy	58	Filter Size: 5, Number of Filters: 10, Dropout Rate: 0.7, Epochs: 3, Batch Size: 32	24.411185	81.24
2	Filter Size: 3, Number of Filters: 5, Dropout Rate: 0.3, Epochs: 1, Batch Size: 64	6.678223	72.55	60	Filter Size: 5, Number of Filters: 15, Dropout Rate: 0.3, Epochs: 1, Batch Size: 32	8.482541	78.12	
3	Filter Size: 3, Number of Filters: 5, Dropout Rate: 0.3, Epochs: 1, Batch Size: 64	6.678223	72.55	61	Filter Size: 5, Number of Filters: 15, Dropout Rate: 0.3, Epochs: 1, Batch Size: 64	6.033393	74.74	
4	Filter Size: 3, Number of Filters: 5, Dropout Rate: 0.3, Epochs: 1, Batch Size: 64	6.678223	72.55	62	Filter Size: 5, Number of Filters: 15, Dropout Rate: 0.3, Epochs: 3, Batch Size: 32	24.348949	82.43	
5	Filter Size: 3, Number of Filters: 5, Dropout Rate: 0.3, Epochs: 1, Batch Size: 64	6.678223	72.55	63	Filter Size: 5, Number of Filters: 15, Dropout Rate: 0.3, Epochs: 3, Batch Size: 32	16.956130	80.50	
6	Filter Size: 3, Number of Filters: 5, Dropout Rate: 0.3, Epochs: 1, Batch Size: 64	6.678223	72.55	64	Filter Size: 5, Number of Filters: 15, Dropout Rate: 0.3, Epochs: 3, Batch Size: 32	16.653194	78.45	
7	Filter Size: 3, Number of Filters: 5, Dropout Rate: 0.3, Epochs: 1, Batch Size: 64	6.678223	72.55	65	Filter Size: 5, Number of Filters: 15, Dropout Rate: 0.3, Epochs: 1, Batch Size: 64	6.024752	75.05	
8	Filter Size: 3, Number of Filters: 5, Dropout Rate: 0.3, Epochs: 1, Batch Size: 64	6.678223	72.55	66	Filter Size: 5, Number of Filters: 15, Dropout Rate: 0.3, Epochs: 3, Batch Size: 32	24.477753	82.65	
9	Filter Size: 3, Number of Filters: 5, Dropout Rate: 0.3, Epochs: 1, Batch Size: 64	6.678223	72.55	67	Filter Size: 5, Number of Filters: 15, Dropout Rate: 0.3, Epochs: 3, Batch Size: 64	16.799755	80.21	
10	Filter Size: 3, Number of Filters: 5, Dropout Rate: 0.3, Epochs: 1, Batch Size: 64	6.678223	72.55	68	Filter Size: 5, Number of Filters: 15, Dropout Rate: 0.3, Epochs: 3, Batch Size: 64	8.476132	78.02	
11	Filter Size: 3, Number of Filters: 5, Dropout Rate: 0.3, Epochs: 1, Batch Size: 64	6.678223	72.55	69	Filter Size: 5, Number of Filters: 15, Dropout Rate: 0.3, Epochs: 1, Batch Size: 64	1.121981	75.31	
12	Filter Size: 3, Number of Filters: 10, Dropout Rate: 0.3, Epochs: 1, Batch Size: 32	8.529468	78.87	70	Filter Size: 5, Number of Filters: 15, Dropout Rate: 0.3, Epochs: 3, Batch Size: 32	23.888359	81.60	
13	Filter Size: 3, Number of Filters: 10, Dropout Rate: 0.3, Epochs: 1, Batch Size: 32	8.529468	78.87	71	Filter Size: 5, Number of Filters: 15, Dropout Rate: 0.3, Epochs: 3, Batch Size: 64	16.537563	79.68	
14	Filter Size: 3, Number of Filters: 10, Dropout Rate: 0.3, Epochs: 1, Batch Size: 32	24.213747	81.75	72	Filter Size: 5, Number of Filters: 15, Dropout Rate: 0.3, Epochs: 3, Batch Size: 32	8.286717	76.18	
15	Filter Size: 3, Number of Filters: 10, Dropout Rate: 0.3, Epochs: 1, Batch Size: 64	16.535628	79.56	73	Filter Size: 7, Number of Filters: 5, Dropout Rate: 0.3, Epochs: 1, Batch Size: 32	6.665353	77.40	
16	Filter Size: 3, Number of Filters: 10, Dropout Rate: 0.3, Epochs: 1, Batch Size: 64	16.535628	79.56	74	Filter Size: 7, Number of Filters: 5, Dropout Rate: 0.3, Epochs: 3, Batch Size: 32	23.823440	81.17	
17	Filter Size: 3, Number of Filters: 10, Dropout Rate: 0.3, Epochs: 1, Batch Size: 64	5.965315	74.87	75	Filter Size: 7, Number of Filters: 5, Dropout Rate: 0.3, Epochs: 3, Batch Size: 64	19.090951	77.70	
18	Filter Size: 3, Number of Filters: 10, Dropout Rate: 0.3, Epochs: 1, Batch Size: 64	24.474113	82.47	76	Filter Size: 7, Number of Filters: 5, Dropout Rate: 0.3, Epochs: 1, Batch Size: 32	7.856745	75.93	
19	Filter Size: 3, Number of Filters: 10, Dropout Rate: 0.3, Epochs: 1, Batch Size: 64	16.535628	79.56	77	Filter Size: 7, Number of Filters: 5, Dropout Rate: 0.3, Epochs: 1, Batch Size: 64	6.678736	72.95	
20	Filter Size: 3, Number of Filters: 10, Dropout Rate: 0.3, Epochs: 1, Batch Size: 64	8.388399	78.61	78	Filter Size: 7, Number of Filters: 5, Dropout Rate: 0.3, Epochs: 1, Batch Size: 32	22.668555	79.45	
21	Filter Size: 3, Number of Filters: 10, Dropout Rate: 0.3, Epochs: 1, Batch Size: 64	5.938813	75.53	77	Filter Size: 7, Number of Filters: 5, Dropout Rate: 0.3, Epochs: 1, Batch Size: 64	16.653194	78.45	
22	Filter Size: 3, Number of Filters: 10, Dropout Rate: 0.3, Epochs: 1, Batch Size: 64	24.474113	82.47	78	Filter Size: 7, Number of Filters: 5, Dropout Rate: 0.3, Epochs: 1, Batch Size: 64	16.653194	78.45	
23	Filter Size: 3, Number of Filters: 10, Dropout Rate: 0.3, Epochs: 1, Batch Size: 64	17.292964	88.37	79	Filter Size: 7, Number of Filters: 5, Dropout Rate: 0.3, Epochs: 1, Batch Size: 64	7.679988	75.64	
24	Filter Size: 3, Number of Filters: 15, Dropout Rate: 0.3, Epochs: 1, Batch Size: 32	8.644582	79.29	80	Filter Size: 7, Number of Filters: 5, Dropout Rate: 0.3, Epochs: 1, Batch Size: 32	7.646479	74.99	
25	Filter Size: 3, Number of Filters: 15, Dropout Rate: 0.3, Epochs: 1, Batch Size: 32	10.524558	79.29	81	Filter Size: 7, Number of Filters: 5, Dropout Rate: 0.3, Epochs: 1, Batch Size: 64	6.451807	72.55	
26	Filter Size: 3, Number of Filters: 15, Dropout Rate: 0.3, Epochs: 1, Batch Size: 32	23.967908	83.42	81	Filter Size: 7, Number of Filters: 5, Dropout Rate: 0.3, Epochs: 1, Batch Size: 64	16.653194	78.45	
27	Filter Size: 3, Number of Filters: 15, Dropout Rate: 0.3, Epochs: 1, Batch Size: 64	16.732563	81.28	82	Filter Size: 7, Number of Filters: 5, Dropout Rate: 0.3, Epochs: 1, Batch Size: 32	23.253244	79.85	
28	Filter Size: 3, Number of Filters: 15, Dropout Rate: 0.3, Epochs: 1, Batch Size: 64	16.732563	81.28	83	Filter Size: 7, Number of Filters: 5, Dropout Rate: 0.3, Epochs: 1, Batch Size: 64	18.991761	76.41	
29	Filter Size: 3, Number of Filters: 15, Dropout Rate: 0.3, Epochs: 1, Batch Size: 64	5.952929	76.84	84	Filter Size: 7, Number of Filters: 5, Dropout Rate: 0.3, Epochs: 1, Batch Size: 32	16.895447	76.41	
30	Filter Size: 3, Number of Filters: 15, Dropout Rate: 0.3, Epochs: 1, Batch Size: 64	24.463413	82.23	85	Filter Size: 7, Number of Filters: 5, Dropout Rate: 0.3, Epochs: 1, Batch Size: 64	6.025568	74.06	
31	Filter Size: 3, Number of Filters: 15, Dropout Rate: 0.3, Epochs: 1, Batch Size: 64	16.535628	79.56	86	Filter Size: 7, Number of Filters: 5, Dropout Rate: 0.3, Epochs: 1, Batch Size: 32	29.664735	81.36	
32	Filter Size: 3, Number of Filters: 15, Dropout Rate: 0.3, Epochs: 1, Batch Size: 64	8.329063	77.54	86	Filter Size: 7, Number of Filters: 5, Dropout Rate: 0.3, Epochs: 1, Batch Size: 64	16.874181	78.47	
33	Filter Size: 3, Number of Filters: 15, Dropout Rate: 0.3, Epochs: 1, Batch Size: 64	6.612871	75.97	87	Filter Size: 7, Number of Filters: 5, Dropout Rate: 0.3, Epochs: 1, Batch Size: 32	10.281384	77.17	
34	Filter Size: 3, Number of Filters: 15, Dropout Rate: 0.3, Epochs: 1, Batch Size: 64	23.686382	88.97	88	Filter Size: 7, Number of Filters: 5, Dropout Rate: 0.3, Epochs: 1, Batch Size: 64	16.653194	78.45	
35	Filter Size: 3, Number of Filters: 15, Dropout Rate: 0.3, Epochs: 1, Batch Size: 64	10.653564	88.89	89	Filter Size: 7, Number of Filters: 5, Dropout Rate: 0.3, Epochs: 1, Batch Size: 32	16.653194	78.45	
36	Filter Size: 3, Number of Filters: 5, Dropout Rate: 0.3, Epochs: 1, Batch Size: 32	9.216060	75.49	90	Filter Size: 7, Number of Filters: 5, Dropout Rate: 0.3, Epochs: 1, Batch Size: 32	29.752232	81.61	
37	Filter Size: 3, Number of Filters: 5, Dropout Rate: 0.3, Epochs: 1, Batch Size: 32	20.495333	81.37	91	Filter Size: 7, Number of Filters: 5, Dropout Rate: 0.3, Epochs: 1, Batch Size: 64	16.663343	78.27	
38	Filter Size: 3, Number of Filters: 5, Dropout Rate: 0.3, Epochs: 1, Batch Size: 32	10.249533	81.37	91	Filter Size: 7, Number of Filters: 5, Dropout Rate: 0.3, Epochs: 1, Batch Size: 32	10.377435	76.38	
39	Filter Size: 3, Number of Filters: 5, Dropout Rate: 0.3, Epochs: 1, Batch Size: 64	10.316886	78.51	92	Filter Size: 7, Number of Filters: 5, Dropout Rate: 0.3, Epochs: 1, Batch Size: 64	6.041350	74.69	
40	Filter Size: 3, Number of Filters: 5, Dropout Rate: 0.3, Epochs: 1, Batch Size: 64	9.118442	77.13	93	Filter Size: 7, Number of Filters: 5, Dropout Rate: 0.3, Epochs: 1, Batch Size: 64	16.653194	78.45	
41	Filter Size: 3, Number of Filters: 5, Dropout Rate: 0.3, Epochs: 1, Batch Size: 64	10.316886	77.13	94	Filter Size: 7, Number of Filters: 5, Dropout Rate: 0.3, Epochs: 1, Batch Size: 64	16.653194	78.45	
42	Filter Size: 3, Number of Filters: 5, Dropout Rate: 0.3, Epochs: 1, Batch Size: 64	26.896647	79.69	95	Filter Size: 7, Number of Filters: 5, Dropout Rate: 0.3, Epochs: 1, Batch Size: 64	16.878241	78.74	
43	Filter Size: 3, Number of Filters: 5, Dropout Rate: 0.3, Epochs: 1, Batch Size: 64	17.871299	78.41	96	Filter Size: 7, Number of Filters: 5, Dropout Rate: 0.3, Epochs: 1, Batch Size: 32	8.640200	77.20	
44	Filter Size: 3, Number of Filters: 5, Dropout Rate: 0.3, Epochs: 1, Batch Size: 64	10.316886	79.04	97	Filter Size: 7, Number of Filters: 5, Dropout Rate: 0.3, Epochs: 1, Batch Size: 64	5.962444	74.74	
45	Filter Size: 3, Number of Filters: 5, Dropout Rate: 0.3, Epochs: 1, Batch Size: 64	5.325997	71.52	97	Filter Size: 7, Number of Filters: 5, Dropout Rate: 0.3, Epochs: 1, Batch Size: 32	23.959854	84.45	
46	Filter Size: 3, Number of Filters: 5, Dropout Rate: 0.3, Epochs: 1, Batch Size: 64	26.245789	88.19	98	Filter Size: 7, Number of Filters: 5, Dropout Rate: 0.3, Epochs: 1, Batch Size: 64	16.653194	78.45	
47	Filter Size: 3, Number of Filters: 5, Dropout Rate: 0.3, Epochs: 1, Batch Size: 64	10.316886	79.04	99	Filter Size: 7, Number of Filters: 5, Dropout Rate: 0.3, Epochs: 1, Batch Size: 32	16.653194	78.45	
48	Filter Size: 3, Number of Filters: 10, Dropout Rate: 0.3, Epochs: 1, Batch Size: 32	8.388985	77.63	100	Filter Size: 7, Number of Filters: 5, Dropout Rate: 0.3, Epochs: 1, Batch Size: 32	8.458826	78.35	
49	Filter Size: 3, Number of Filters: 10, Dropout Rate: 0.3, Epochs: 1, Batch Size: 64	5.681630	75.13	101	Filter Size: 7, Number of Filters: 5, Dropout Rate: 0.3, Epochs: 1, Batch Size: 64	5.991185	74.91	
50	Filter Size: 3, Number of Filters: 10, Dropout Rate: 0.3, Epochs: 1, Batch Size: 64	24.474113	82.47	102	Filter Size: 7, Number of Filters: 5, Dropout Rate: 0.3, Epochs: 1, Batch Size: 32	24.396683	80.81	
51	Filter Size: 3, Number of Filters: 10, Dropout Rate: 0.3, Epochs: 1, Batch Size: 64	10.316886	79.12	102	Filter Size: 7, Number of Filters: 5, Dropout Rate: 0.3, Epochs: 1, Batch Size: 64	16.855269	79.42	
52	Filter Size: 3, Number of Filters: 10, Dropout Rate: 0.3, Epochs: 1, Batch Size: 64	8.159136	77.19	103	Filter Size: 7, Number of Filters: 5, Dropout Rate: 0.3, Epochs: 1, Batch Size: 32	8.451016	77.04	
53	Filter Size: 3, Number of Filters: 10, Dropout Rate: 0.3, Epochs: 1, Batch Size: 64	10.316886	77.19	104	Filter Size: 7, Number of Filters: 5, Dropout Rate: 0.3, Epochs: 1, Batch Size: 64	16.653194	78.45	
54	Filter Size: 3, Number of Filters: 10, Dropout Rate: 0.3, Epochs: 1, Batch Size: 64	24.396683	88.38	105	Filter Size: 7, Number of Filters: 5, Dropout Rate: 0.3, Epochs: 1, Batch Size: 64	8.458826	74.14	
55	Filter Size: 3, Number of Filters: 10, Dropout Rate: 0.3, Epochs: 1, Batch Size: 64	10.675744	79.73	106	Filter Size: 7, Number of Filters: 5, Dropout Rate: 0.3, Epochs: 1, Batch Size: 32	24.193662	81.99	
56	Filter Size: 3, Number of Filters: 10, Dropout Rate: 0.3, Epochs: 1, Batch Size: 64	5.681630	75.82	107	Filter Size: 7, Number of Filters: 5, Dropout Rate: 0.3, Epochs: 1, Batch Size: 64	16.615992	78.98	

For ease of manipulating data, I transferred the data to an Excel sheet named “Extension #1 Data Table.”

Based on the dimensions of epoch count and batch size, the following are my hypotheses:

- Time Duration
 - Epoch Count
 - The relationship between epoch count and time duration is a direct relationship that is linear. In other words, if epoch count is doubled, then we can nearly expect the time duration to double.
 - Batch Size
 - Batch Size

- Since the device my model is using is MPS (Apple's GPU), parallel processing is efficient and requires less overhead for loading data. Therefore, with an increase in batch size, there can actual be a decrease in computation time.
- Accuracy
 - Epoch Count
 - The more epochs there are, the more accurate the data would be. However, there is a point where additional epochs do not provide additional accuracy and learning. Having more epochs than necessary can lead to overfitting, which could decrease accuracy.
 - Batch Size
 - Generally, the larger the batch size, the more accurate the model would calculate the gradients.

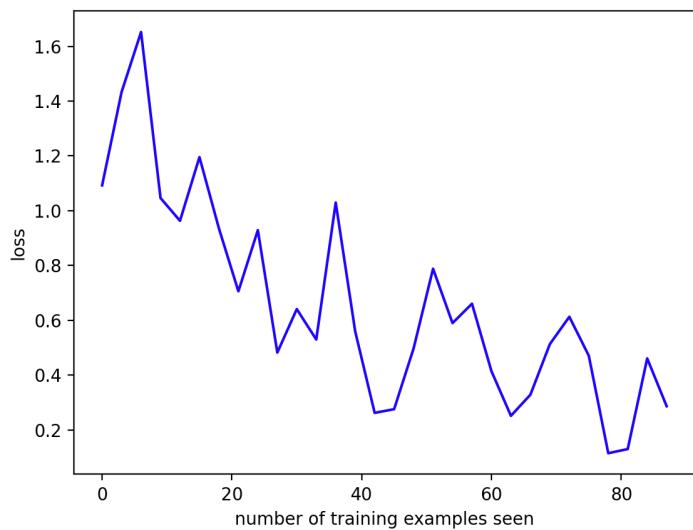
Based on the data provided in the excel sheet, these are the evaluations of my hypotheses:

- Time Duration
 - Epoch Count
 - The relationship between epoch count and time duration is a direct relationship that is linear. In other words, if epoch count is doubled, then we can nearly expect the time duration to double.
 - Evaluation:
 - Batch Size
 - Since the device my model is using is MPS (Apple's GPU), parallel processing is efficient and requires less overhead for loading data. Therefore, with an increase in batch size, there can actual be a decrease in computation time.
 - Evaluation: as batch size increases in the data, there is a decrease in computation time. This can be somewhat counterintuitive, but with GPU/MPS, parallel processing can efficiently handle larger batch sizes. Without GPU/MPS, as batch size increases, computation time would increase.
- Accuracy
 - Epoch Count
 - The more epochs there are, the more accurate the data would be. However, there is a point where additional epochs do not provide additional accuracy and learning. Having more epochs than necessary can lead to overfitting, which could decrease accuracy.
 - Evaluation:

- Batch Size
 - Generally, the larger the batch size, the more accurate the model would calculate the gradients.
 - Evaluation: surprisingly for the most part in the data, as batch size increases, we can see a decrease in accuracy. Based on the possible epoch count values of 1 or 3, I believe there weren't enough epochs to increase the accuracy based on batch size. If the epoch size were maybe 5 or 7, there would potentially be an increase in the model as batch size increases. Another explanation is that a larger batch size results in a more significant minimum value. That means that while the model fit well for the training data, it might not fit well for the test data, especially if there aren't enough epochs.

Extension #2: Transferred Learning Using ResNet18

- Using the ResNet18 trained network from PyTorch, I utilized transferred learning and replaced the final fully connected layer with another one with 3 outputs.
 - The purpose of transferred learning was so that I can adapt the trained network for recognizing social media logos.
 - I used three logos during training: Facebook, Snapchat, Instagram.
 - Then, for testing, I took images not in the training set and ran them through the model.
 - Here is the loss graph
-



- Here are sample images:



Reflection

Through this project, I was able to see the applicability of deep learning and machine learning in the context of image recognition. The idea of “training” a model was very elusive to me prior to this project. I couldn’t really grasp the concept of training something inanimate. This project, however, helped me understand how to train a model and what the outcomes are.

I now know that a model is trained using a dataset with labels to an extent where the model can recognize data at a certain level of confidence. Once trained, we can use the model on new data (not trained data). The trained network model can be transferrable for other datasets by replacing some layers, which is a concept called transferred learning.

Overall, I’m glad that I learned a lot from this project. This project got me more interested in applying this knowledge to my final project and beyond.

Final Project Idea Submission

- I am in a group with Aaron Pan and Abhishek Uddaraju.
- Aaron submitted the final project idea proposal.

Acknowledgement

- Professor Maxwell's lectures – for filling knowledge gaps
- PyTorch Documentation – for tutorials and deep-diving
- Professor Maxwell & TAs – to ask questions to whenever stuck
- NextJournal Tutorial on MNIST Recognition using PyTorch