Cooper Tush

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Machine Learning Assignment 3 Question 1

I tried each design, designs 1 through 3, with different optimizers for a total of 9 CNNs.

3 CNNs designs with the adam optimizer, 3 designs with SGD, and 3 with RMSProp. They were all given at similar 10 convolutional layers as follows (When running the code the loss and accuracy may vary):

Design 1 Model (A regular CNN where the number of filters in each layer increases as the depth of the network grows i.e., the Lth layer will have more filters than the (L-1)th layer):

Model: "sequential\_2"

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Layer (type) Output Shape Param #

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conv2d\_6 (Conv2D) (None, 28, 28, 16) 32

max\_pooling2d\_6 (MaxPooling (None, 14, 14, 16) 0

2D)

conv2d\_7 (Conv2D) (None, 12, 12, 32) 4640

max\_pooling2d\_7 (MaxPooling (None, 6, 6, 32) 0

2D)

conv2d\_8 (Conv2D) (None, 4, 4, 64) 18496

max\_pooling2d\_8 (MaxPooling (None, 2, 2, 64) 0

2D)

flatten\_2 (Flatten) (None, 256) 0

dense\_6 (Dense) (None, 512) 131584

dense\_7 (Dense) (None, 32) 16416

dense\_8 (Dense) (None, 10) 330

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Total params: 171,498

Trainable params: 171,498

Non-trainable params: 0

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Design 2 Model (An inverted CNN where the number of filters in each layer decreases as the depth of the network grows i.e., the Lth layer will have less filters than the (L-1)th layer):

Model: "sequential\_2"

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Layer (type) Output Shape Param #

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conv2d\_6 (Conv2D) (None, 28, 28, 64) 128

max\_pooling2d\_6 (MaxPooling (None, 14, 14, 64) 0

2D)

conv2d\_7 (Conv2D) (None, 12, 12, 32) 18464

max\_pooling2d\_7 (MaxPooling (None, 6, 6, 32) 0

2D)

conv2d\_8 (Conv2D) (None, 4, 4, 16) 4624

max\_pooling2d\_8 (MaxPooling (None, 2, 2, 16) 0

2D)

flatten\_2 (Flatten) (None, 64) 0

dense\_6 (Dense) (None, 512) 33280

dense\_7 (Dense) (None, 64) 32832

dense\_8 (Dense) (None, 10) 650

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Total params: 89,978

Trainable params: 89,978

Non-trainable params: 0

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SGD Design 3 Model (An hour-glass shaped CNN where the number of filters will increase till the Lth layer and

reduce afterwards):

Model: "sequential\_2"

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Layer (type) Output Shape Param #

=================================================================

conv2d\_6 (Conv2D) (None, 28, 28, 36) 72

max\_pooling2d\_6 (MaxPooling (None, 14, 14, 36) 0

2D)

conv2d\_7 (Conv2D) (None, 12, 12, 16) 5200

max\_pooling2d\_7 (MaxPooling (None, 6, 6, 16) 0

2D)

conv2d\_8 (Conv2D) (None, 4, 4, 36) 5220

max\_pooling2d\_8 (MaxPooling (None, 2, 2, 36) 0

2D)

flatten\_2 (Flatten) (None, 144) 0

dense\_6 (Dense) (None, 512) 74240

dense\_7 (Dense) (None, 64) 32832

dense\_8 (Dense) (None, 10) 650

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Total params: 118,214

Trainable params: 118,214

Non-trainable params: 0

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SGD Design 1 Results: Learning Rate is 0.0001 and Batch Size is 16

Epoch 1/10

3000/3000 [==============================] - 46s 15ms/step - loss: 2.3240 - accuracy: 0.1114 - val\_loss: 2.3011 - val\_accuracy: 0.1149

Epoch 2/10

3000/3000 [==============================] - 41s 14ms/step - loss: 2.3014 - accuracy: 0.1117 - val\_loss: 2.3008 - val\_accuracy: 0.1149

Epoch 3/10

3000/3000 [==============================] - 40s 13ms/step - loss: 2.2971 - accuracy: 0.1181 - val\_loss: 2.2802 - val\_accuracy: 0.1828

Epoch 4/10

3000/3000 [==============================] - 43s 14ms/step - loss: 1.1175 - accuracy: 0.6619 - val\_loss: 0.2757 - val\_accuracy: 0.9104

Epoch 5/10

3000/3000 [==============================] - 42s 14ms/step - loss: 0.2223 - accuracy: 0.9298 - val\_loss: 0.1902 - val\_accuracy: 0.9373

Epoch 6/10

3000/3000 [==============================] - 42s 14ms/step - loss: 0.1675 - accuracy: 0.9463 - val\_loss: 0.1655 - val\_accuracy: 0.9467

Epoch 7/10

3000/3000 [==============================] - 41s 14ms/step - loss: 0.1420 - accuracy: 0.9540 - val\_loss: 0.1448 - val\_accuracy: 0.9528

Epoch 8/10

3000/3000 [==============================] - 41s 14ms/step - loss: 0.1257 - accuracy: 0.9582 - val\_loss: 0.1392 - val\_accuracy: 0.9539

Epoch 9/10

3000/3000 [==============================] - 43s 14ms/step - loss: 0.1131 - accuracy: 0.9629 - val\_loss: 0.1327 - val\_accuracy: 0.9584

Epoch 10/10

3000/3000 [==============================] - 42s 14ms/step - loss: 0.1047 - accuracy: 0.9651 - val\_loss: 0.1269 - val\_accuracy: 0.9598

375/375 [==============================] - 3s 7ms/step - loss: 0.1269 - accuracy: 0.9598

Model 1 Test Accuracy: 0.9598333239555359

SGD Design 2 Results: Learning Rate is 0.1 and Batch Size is 16

Epoch 1/10

3000/3000 [==============================] - 46s 15ms/step - loss: 2.3500 - accuracy: 0.1109 - val\_loss: 2.2962 - val\_accuracy: 0.1243

Epoch 2/10

3000/3000 [==============================] - 44s 15ms/step - loss: 1.0779 - accuracy: 0.6354 - val\_loss: 0.4516 - val\_accuracy: 0.8611

Epoch 3/10

3000/3000 [==============================] - 45s 15ms/step - loss: 0.2757 - accuracy: 0.9148 - val\_loss: 0.1841 - val\_accuracy: 0.9419

Epoch 4/10

3000/3000 [==============================] - 44s 15ms/step - loss: 0.1679 - accuracy: 0.9471 - val\_loss: 0.1414 - val\_accuracy: 0.9531

Epoch 5/10

3000/3000 [==============================] - 44s 15ms/step - loss: 0.1297 - accuracy: 0.9596 - val\_loss: 0.1192 - val\_accuracy: 0.9622

Epoch 6/10

3000/3000 [==============================] - 44s 15ms/step - loss: 0.1123 - accuracy: 0.9647 - val\_loss: 0.1087 - val\_accuracy: 0.9671

Epoch 7/10

3000/3000 [==============================] - 45s 15ms/step - loss: 0.0990 - accuracy: 0.9692 - val\_loss: 0.1023 - val\_accuracy: 0.9693

Epoch 8/10

3000/3000 [==============================] - 44s 15ms/step - loss: 0.0913 - accuracy: 0.9706 - val\_loss: 0.0933 - val\_accuracy: 0.9722

Epoch 9/10

3000/3000 [==============================] - 44s 15ms/step - loss: 0.0866 - accuracy: 0.9722 - val\_loss: 0.0989 - val\_accuracy: 0.9699

Epoch 10/10

3000/3000 [==============================] - 44s 15ms/step - loss: 0.0779 - accuracy: 0.9748 - val\_loss: 0.0972 - val\_accuracy: 0.9712

375/375 [==============================] - 3s 6ms/step - loss: 0.0972 - accuracy: 0.9712

Model 2 Test Accuracy: 0.9712499976158142

SGD Design 3 Results: Learning Rate is 0.0001 and Batch Size is 16

Epoch 1/10

3000/3000 [==============================] - 54s 18ms/step - loss: 0.2575 - accuracy: 0.9228 - val\_loss: 0.1001 - val\_accuracy: 0.9670

Epoch 2/10

3000/3000 [==============================] - 55s 18ms/step - loss: 0.1006 - accuracy: 0.9685 - val\_loss: 0.0811 - val\_accuracy: 0.9730

Epoch 3/10

3000/3000 [==============================] - 51s 17ms/step - loss: 0.0796 - accuracy: 0.9748 - val\_loss: 0.0728 - val\_accuracy: 0.9771

Epoch 4/10

3000/3000 [==============================] - 52s 17ms/step - loss: 0.0647 - accuracy: 0.9792 - val\_loss: 0.0704 - val\_accuracy: 0.9762

Epoch 5/10

3000/3000 [==============================] - 51s 17ms/step - loss: 0.0555 - accuracy: 0.9817 - val\_loss: 0.0735 - val\_accuracy: 0.9783

Epoch 6/10

3000/3000 [==============================] - 51s 17ms/step - loss: 0.0484 - accuracy: 0.9839 - val\_loss: 0.0660 - val\_accuracy: 0.9812

Epoch 7/10

3000/3000 [==============================] - 51s 17ms/step - loss: 0.0406 - accuracy: 0.9867 - val\_loss: 0.0633 - val\_accuracy: 0.9812

Epoch 8/10

3000/3000 [==============================] - 53s 18ms/step - loss: 0.0363 - accuracy: 0.9880 - val\_loss: 0.0841 - val\_accuracy: 0.9766

Epoch 9/10

3000/3000 [==============================] - 50s 17ms/step - loss: 0.0317 - accuracy: 0.9894 - val\_loss: 0.0626 - val\_accuracy: 0.9822

Epoch 10/10

3000/3000 [==============================] - 51s 17ms/step - loss: 0.0276 - accuracy: 0.9907 - val\_loss: 0.0688 - val\_accuracy: 0.9812

375/375 [==============================] - 3s 7ms/step - loss: 0.0688 - accuracy: 0.9812

Model 3 Test Accuracy: 0.981249988079071

adam Design 1 Results: Learning Rate is 0.1 and Batch Size is 32

Epoch 1/10

1500/1500 [==============================] - 36s 23ms/step - loss: 0.3367 - accuracy: 0.9107 - val\_loss: 0.1705 - val\_accuracy: 0.9482

Epoch 2/10

1500/1500 [==============================] - 34s 23ms/step - loss: 0.1049 - accuracy: 0.9679 - val\_loss: 0.0877 - val\_accuracy: 0.9733

Epoch 3/10

1500/1500 [==============================] - 36s 24ms/step - loss: 0.0805 - accuracy: 0.9754 - val\_loss: 0.0850 - val\_accuracy: 0.9739

Epoch 4/10

1500/1500 [==============================] - 36s 24ms/step - loss: 0.0650 - accuracy: 0.9801 - val\_loss: 0.0752 - val\_accuracy: 0.9772

Epoch 5/10

1500/1500 [==============================] - 35s 23ms/step - loss: 0.0533 - accuracy: 0.9834 - val\_loss: 0.0758 - val\_accuracy: 0.9778

Epoch 6/10

1500/1500 [==============================] - 34s 23ms/step - loss: 0.0449 - accuracy: 0.9855 - val\_loss: 0.0738 - val\_accuracy: 0.9792

Epoch 7/10

1500/1500 [==============================] - 34s 23ms/step - loss: 0.0400 - accuracy: 0.9873 - val\_loss: 0.0829 - val\_accuracy: 0.9778

Epoch 8/10

1500/1500 [==============================] - 34s 23ms/step - loss: 0.0336 - accuracy: 0.9890 - val\_loss: 0.0676 - val\_accuracy: 0.9805

Epoch 9/10

1500/1500 [==============================] - 36s 24ms/step - loss: 0.0283 - accuracy: 0.9909 - val\_loss: 0.0646 - val\_accuracy: 0.9833

Epoch 10/10

1500/1500 [==============================] - 35s 23ms/step - loss: 0.0242 - accuracy: 0.9926 - val\_loss: 0.0687 - val\_accuracy: 0.9827

375/375 [==============================] - 3s 7ms/step - loss: 0.0687 - accuracy: 0.9827

Model 1 Test Accuracy: 0.9827499985694885

adam Design 2 Results: Learning Rate is 0.1 and Batch Size is 16

Epoch 1/10

3000/3000 [==============================] - 45s 15ms/step - loss: 0.2930 - accuracy: 0.9119 - val\_loss: 0.1376 - val\_accuracy: 0.9592

Epoch 2/10

3000/3000 [==============================] - 43s 14ms/step - loss: 0.1298 - accuracy: 0.9602 - val\_loss: 0.1251 - val\_accuracy: 0.9626

Epoch 3/10

3000/3000 [==============================] - 44s 15ms/step - loss: 0.0992 - accuracy: 0.9700 - val\_loss: 0.0871 - val\_accuracy: 0.9717

Epoch 4/10

3000/3000 [==============================] - 44s 15ms/step - loss: 0.0837 - accuracy: 0.9745 - val\_loss: 0.0877 - val\_accuracy: 0.9736

Epoch 5/10

3000/3000 [==============================] - 44s 15ms/step - loss: 0.0704 - accuracy: 0.9777 - val\_loss: 0.0784 - val\_accuracy: 0.9770

Epoch 6/10

3000/3000 [==============================] - 43s 14ms/step - loss: 0.0617 - accuracy: 0.9809 - val\_loss: 0.0798 - val\_accuracy: 0.9751

Epoch 7/10

3000/3000 [==============================] - 44s 15ms/step - loss: 0.0558 - accuracy: 0.9823 - val\_loss: 0.0781 - val\_accuracy: 0.9775

Epoch 8/10

3000/3000 [==============================] - 44s 15ms/step - loss: 0.0490 - accuracy: 0.9846 - val\_loss: 0.0640 - val\_accuracy: 0.9801

Epoch 9/10

3000/3000 [==============================] - 44s 15ms/step - loss: 0.0455 - accuracy: 0.9862 - val\_loss: 0.0679 - val\_accuracy: 0.9818

Epoch 10/10

3000/3000 [==============================] - 44s 15ms/step - loss: 0.0428 - accuracy: 0.9870 - val\_loss: 0.0766 - val\_accuracy: 0.9793

375/375 [==============================] - 2s 6ms/step - loss: 0.0766 - accuracy: 0.9793

Model 2 Test Accuracy: 0.9792500138282776

adam Design 3 Results: Learning Rate is 0.0001 and Batch Size is 64

Epoch 1/10

750/750 [==============================] - 37s 48ms/step - loss: 0.3157 - accuracy: 0.9118 - val\_loss: 0.1531 - val\_accuracy: 0.9517

Epoch 2/10

750/750 [==============================] - 37s 49ms/step - loss: 0.1201 - accuracy: 0.9620 - val\_loss: 0.1169 - val\_accuracy: 0.9619

Epoch 3/10

750/750 [==============================] - 36s 47ms/step - loss: 0.0887 - accuracy: 0.9722 - val\_loss: 0.0884 - val\_accuracy: 0.9747

Epoch 4/10

750/750 [==============================] - 35s 47ms/step - loss: 0.0736 - accuracy: 0.9769 - val\_loss: 0.1063 - val\_accuracy: 0.9688

Epoch 5/10

750/750 [==============================] - 36s 49ms/step - loss: 0.0667 - accuracy: 0.9785 - val\_loss: 0.0976 - val\_accuracy: 0.9712

Epoch 6/10

750/750 [==============================] - 37s 50ms/step - loss: 0.0577 - accuracy: 0.9810 - val\_loss: 0.0805 - val\_accuracy: 0.9768

Epoch 7/10

750/750 [==============================] - 37s 49ms/step - loss: 0.0480 - accuracy: 0.9845 - val\_loss: 0.0974 - val\_accuracy: 0.9727

Epoch 8/10

750/750 [==============================] - 35s 47ms/step - loss: 0.0455 - accuracy: 0.9850 - val\_loss: 0.0810 - val\_accuracy: 0.9783

Epoch 9/10

750/750 [==============================] - 35s 47ms/step - loss: 0.0394 - accuracy: 0.9865 - val\_loss: 0.0767 - val\_accuracy: 0.9803

Epoch 10/10

750/750 [==============================] - 37s 49ms/step - loss: 0.0327 - accuracy: 0.9892 - val\_loss: 0.0950 - val\_accuracy: 0.9740

375/375 [==============================] - 3s 8ms/step - loss: 0.0950 - accuracy: 0.9740

Model 3 Test Accuracy: 0.9739999771118164

RMSProp Design 1 Results: Learning Rate is 0.1 and batch\_size is 32

Epoch 1/10

1500/1500 [==============================] - 39s 24ms/step - loss: 0.4003 - accuracy: 0.9000 - val\_loss: 0.1086 - val\_accuracy: 0.9690

Epoch 2/10

1500/1500 [==============================] - 36s 24ms/step - loss: 0.1411 - accuracy: 0.9622 - val\_loss: 0.1144 - val\_accuracy: 0.9682

Epoch 3/10

1500/1500 [==============================] - 37s 25ms/step - loss: 0.1226 - accuracy: 0.9681 - val\_loss: 0.1059 - val\_accuracy: 0.9675

Epoch 4/10

1500/1500 [==============================] - 35s 23ms/step - loss: 0.1031 - accuracy: 0.9720 - val\_loss: 0.0728 - val\_accuracy: 0.9799

Epoch 5/10

1500/1500 [==============================] - 37s 25ms/step - loss: 0.0917 - accuracy: 0.9747 - val\_loss: 0.1008 - val\_accuracy: 0.9693

Epoch 6/10

1500/1500 [==============================] - 35s 24ms/step - loss: 0.0859 - accuracy: 0.9756 - val\_loss: 0.0876 - val\_accuracy: 0.9747

Epoch 7/10

1500/1500 [==============================] - 35s 24ms/step - loss: 0.0771 - accuracy: 0.9787 - val\_loss: 0.1616 - val\_accuracy: 0.9679

Epoch 8/10

1500/1500 [==============================] - 35s 24ms/step - loss: 0.0718 - accuracy: 0.9804 - val\_loss: 0.0672 - val\_accuracy: 0.9793

Epoch 9/10

1500/1500 [==============================] - 35s 23ms/step - loss: 0.0690 - accuracy: 0.9812 - val\_loss: 0.0662 - val\_accuracy: 0.9824

Epoch 10/10

1500/1500 [==============================] - 36s 24ms/step - loss: 0.0630 - accuracy: 0.9831 - val\_loss: 0.0802 - val\_accuracy: 0.9751

375/375 [==============================] - 3s 8ms/step - loss: 0.0802 - accuracy: 0.9751

Model 1 Test Accuracy: 0.9750833511352539

RMSProp Design 2 Results: Learning Rate is 0.1 and batch\_size is 16

Epoch 1/10

3000/3000 [==============================] - 85s 28ms/step - loss: 0.3539 - accuracy: 0.9052 - val\_loss: 0.2102 - val\_accuracy: 0.9343

Epoch 2/10

3000/3000 [==============================] - 83s 28ms/step - loss: 0.1427 - accuracy: 0.9585 - val\_loss: 0.1068 - val\_accuracy: 0.9691

Epoch 3/10

3000/3000 [==============================] - 84s 28ms/step - loss: 0.1112 - accuracy: 0.9690 - val\_loss: 0.1384 - val\_accuracy: 0.9567

Epoch 4/10

3000/3000 [==============================] - 83s 28ms/step - loss: 0.1059 - accuracy: 0.9705 - val\_loss: 0.0742 - val\_accuracy: 0.9781

Epoch 5/10

3000/3000 [==============================] - 84s 28ms/step - loss: 0.2897 - accuracy: 0.9078 - val\_loss: 0.2361 - val\_accuracy: 0.9234

Epoch 6/10

3000/3000 [==============================] - 82s 27ms/step - loss: 0.2071 - accuracy: 0.9351 - val\_loss: 0.2520 - val\_accuracy: 0.9183

Epoch 7/10

3000/3000 [==============================] - 83s 28ms/step - loss: 0.1785 - accuracy: 0.9442 - val\_loss: 0.1907 - val\_accuracy: 0.9489

Epoch 8/10

3000/3000 [==============================] - 82s 27ms/step - loss: 0.1714 - accuracy: 0.9477 - val\_loss: 0.1861 - val\_accuracy: 0.9441

Epoch 9/10

3000/3000 [==============================] - 83s 28ms/step - loss: 0.1720 - accuracy: 0.9480 - val\_loss: 0.1799 - val\_accuracy: 0.9433

Epoch 10/10

3000/3000 [==============================] - 85s 28ms/step - loss: 0.1727 - accuracy: 0.9496 - val\_loss: 0.1642 - val\_accuracy: 0.9500

375/375 [==============================] - 5s 12ms/step - loss: 0.1642 - accuracy: 0.9500

Model 2 Test Accuracy: 0.949999988079071

RMSProp Design 3 Results: Learning Rate is 0.0001 and batch\_size is 64

Epoch 1/10

750/750 [==============================] - 44s 57ms/step - loss: 0.3838 - accuracy: 0.9081 - val\_loss: 0.1858 - val\_accuracy: 0.9414

Epoch 2/10

750/750 [==============================] - 40s 53ms/step - loss: 0.1218 - accuracy: 0.9646 - val\_loss: 0.1148 - val\_accuracy: 0.9659

Epoch 3/10

750/750 [==============================] - 40s 54ms/step - loss: 0.0991 - accuracy: 0.9714 - val\_loss: 0.1042 - val\_accuracy: 0.9672

Epoch 4/10

750/750 [==============================] - 41s 55ms/step - loss: 0.0867 - accuracy: 0.9749 - val\_loss: 0.1196 - val\_accuracy: 0.9668

Epoch 5/10

750/750 [==============================] - 40s 54ms/step - loss: 0.0801 - accuracy: 0.9770 - val\_loss: 0.1295 - val\_accuracy: 0.9628

Epoch 6/10

750/750 [==============================] - 40s 54ms/step - loss: 0.0705 - accuracy: 0.9804 - val\_loss: 0.0905 - val\_accuracy: 0.9752

Epoch 7/10

750/750 [==============================] - 42s 55ms/step - loss: 0.0628 - accuracy: 0.9818 - val\_loss: 0.0701 - val\_accuracy: 0.9799

Epoch 8/10

750/750 [==============================] - 43s 58ms/step - loss: 0.0562 - accuracy: 0.9843 - val\_loss: 0.0753 - val\_accuracy: 0.9768

Epoch 9/10

750/750 [==============================] - 42s 56ms/step - loss: 0.0531 - accuracy: 0.9839 - val\_loss: 0.0774 - val\_accuracy: 0.9796

Epoch 10/10

750/750 [==============================] - 42s 55ms/step - loss: 0.0502 - accuracy: 0.9852 - val\_loss: 0.0777 - val\_accuracy: 0.9768

375/375 [==============================] - 3s 9ms/step - loss: 0.0777 - accuracy: 0.9768

Model 3 Test Accuracy: 0.9767500162124634