



Alexandria University- Faculty of Engineering
Computer and Systems Engineering Department

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Pattern Recognition

Lab 4

Modulation Classification

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[Colab link](#)

CNN

1. Raw + Derivative

a. Hyperparameter tuning

i. Learning Rate : 0.1

```
624/624 [=====] - 4s 5ms/step - loss: 3.3241 - accuracy: 0.0992 - val_loss: 2.3130 - val_accuracy: 0.1010
Epoch 2/20
624/624 [=====] - 3s 5ms/step - loss: 2.3122 - accuracy: 0.0977 - val_loss: 2.3135 - val_accuracy: 0.1010
Epoch 3/20
624/624 [=====] - 3s 5ms/step - loss: 2.3123 - accuracy: 0.0980 - val_loss: 2.3136 - val_accuracy: 0.1010
Epoch 4/20
624/624 [=====] - 3s 5ms/step - loss: 2.3123 - accuracy: 0.0981 - val_loss: 2.3137 - val_accuracy: 0.1010
Epoch 5/20
624/624 [=====] - 3s 5ms/step - loss: 2.3124 - accuracy: 0.0980 - val_loss: 2.3137 - val_accuracy: 0.1010
Epoch 6/20
624/624 [=====] - 3s 5ms/step - loss: 2.3124 - accuracy: 0.0980 - val_loss: 2.3137 - val_accuracy: 0.1010
Epoch 7/20
624/624 [=====] - 3s 5ms/step - loss: 2.3124 - accuracy: 0.0980 - val_loss: 2.3137 - val_accuracy: 0.1010
Epoch 8/20
624/624 [=====] - 3s 5ms/step - loss: 2.3124 - accuracy: 0.0980 - val_loss: 2.3137 - val_accuracy: 0.1010
Epoch 9/20
624/624 [=====] - 3s 5ms/step - loss: 2.3124 - accuracy: 0.0980 - val_loss: 2.3137 - val_accuracy: 0.1010
Epoch 10/20
624/624 [=====] - 3s 5ms/step - loss: 2.3124 - accuracy: 0.0980 - val_loss: 2.3137 - val_accuracy: 0.1010
Epoch 11/20
624/624 [=====] - 3s 5ms/step - loss: 2.3124 - accuracy: 0.0980 - val_loss: 2.3137 - val_accuracy: 0.1010
Epoch 12/20
624/624 [=====] - 3s 5ms/step - loss: 2.3124 - accuracy: 0.0980 - val_loss: 2.3137 - val_accuracy: 0.1010
Epoch 13/20
624/624 [=====] - 3s 5ms/step - loss: 2.3124 - accuracy: 0.0980 - val_loss: 2.3137 - val_accuracy: 0.1010
Epoch 14/20
624/624 [=====] - 3s 7ms/step - loss: 2.3124 - accuracy: 0.0980 - val_loss: 2.3137 - val_accuracy: 0.1010
Epoch 15/20
624/624 [=====] - 3s 5ms/step - loss: 2.3124 - accuracy: 0.0980 - val_loss: 2.3137 - val_accuracy: 0.1010
Epoch 16/20
624/624 [=====] - 3s 5ms/step - loss: 2.3124 - accuracy: 0.0980 - val_loss: 2.3137 - val_accuracy: 0.1010
Epoch 17/20
624/624 [=====] - 3s 5ms/step - loss: 2.3124 - accuracy: 0.0980 - val_loss: 2.3137 - val_accuracy: 0.1010
Epoch 18/20
624/624 [=====] - 3s 5ms/step - loss: 2.3124 - accuracy: 0.0980 - val_loss: 2.3137 - val_accuracy: 0.1010
Epoch 19/20
624/624 [=====] - 3s 5ms/step - loss: 2.3124 - accuracy: 0.0980 - val_loss: 2.3137 - val_accuracy: 0.1010
Epoch 20/20
624/624 [=====] - 3s 5ms/step - loss: 2.3124 - accuracy: 0.0980 - val_loss: 2.3137 - val_accuracy: 0.1010
```

ii. Learning Rate : 0.01

```
624/624 [=====] - 5s 7ms/step - loss: 2.0649 - accuracy: 0.2059 - val_loss: 1.8336 - val_accuracy: 0.2619
Epoch 2/20
624/624 [=====] - 4s 6ms/step - loss: 1.9153 - accuracy: 0.2410 - val_loss: 1.7906 - val_accuracy: 0.2819
Epoch 3/20
624/624 [=====] - 3s 5ms/step - loss: 1.8978 - accuracy: 0.2433 - val_loss: 1.7527 - val_accuracy: 0.2805
Epoch 4/20
624/624 [=====] - 3s 6ms/step - loss: 1.8952 - accuracy: 0.2453 - val_loss: 1.7604 - val_accuracy: 0.2857
Epoch 5/20
624/624 [=====] - 3s 5ms/step - loss: 1.8876 - accuracy: 0.2470 - val_loss: 1.7607 - val_accuracy: 0.2833
Epoch 6/20
624/624 [=====] - 3s 5ms/step - loss: 1.8793 - accuracy: 0.2494 - val_loss: 1.7774 - val_accuracy: 0.2786
Epoch 7/20
624/624 [=====] - 4s 6ms/step - loss: 1.8801 - accuracy: 0.2492 - val_loss: 1.7940 - val_accuracy: 0.2886
Epoch 8/20
624/624 [=====] - 4s 6ms/step - loss: 1.8863 - accuracy: 0.2487 - val_loss: 1.7745 - val_accuracy: 0.2814
Epoch 9/20
624/624 [=====] - 3s 5ms/step - loss: 1.8859 - accuracy: 0.2464 - val_loss: 1.7422 - val_accuracy: 0.2852
Epoch 10/20
624/624 [=====] - 3s 5ms/step - loss: 1.9691 - accuracy: 0.2291 - val_loss: 1.8225 - val_accuracy: 0.2676
Epoch 11/20
624/624 [=====] - 4s 6ms/step - loss: 1.9329 - accuracy: 0.2323 - val_loss: 1.7977 - val_accuracy: 0.2686
Epoch 12/20
624/624 [=====] - 4s 6ms/step - loss: 1.9010 - accuracy: 0.2415 - val_loss: 1.8054 - val_accuracy: 0.2695
Epoch 13/20
624/624 [=====] - 3s 6ms/step - loss: 1.8957 - accuracy: 0.2467 - val_loss: 1.7710 - val_accuracy: 0.2771
Epoch 14/20
624/624 [=====] - 3s 5ms/step - loss: 1.8739 - accuracy: 0.2509 - val_loss: 1.7646 - val_accuracy: 0.2805
Epoch 15/20
624/624 [=====] - 3s 5ms/step - loss: 1.9194 - accuracy: 0.2396 - val_loss: 1.7633 - val_accuracy: 0.2871
Epoch 16/20
624/624 [=====] - 3s 5ms/step - loss: 1.9866 - accuracy: 0.2140 - val_loss: 1.8044 - val_accuracy: 0.2652
Epoch 17/20
624/624 [=====] - 3s 5ms/step - loss: 1.9449 - accuracy: 0.2287 - val_loss: 1.8193 - val_accuracy: 0.2738
Epoch 18/20
624/624 [=====] - 3s 5ms/step - loss: 1.9008 - accuracy: 0.2421 - val_loss: 1.8582 - val_accuracy: 0.2552
Epoch 19/20
624/624 [=====] - 3s 5ms/step - loss: 1.8817 - accuracy: 0.2469 - val_loss: 1.7876 - val_accuracy: 0.2686
Epoch 20/20
624/624 [=====] - 3s 5ms/step - loss: 1.9903 - accuracy: 0.2133 - val_loss: 1.8472 - val_accuracy: 0.2381
```

iii. Learning Rate : 0.001

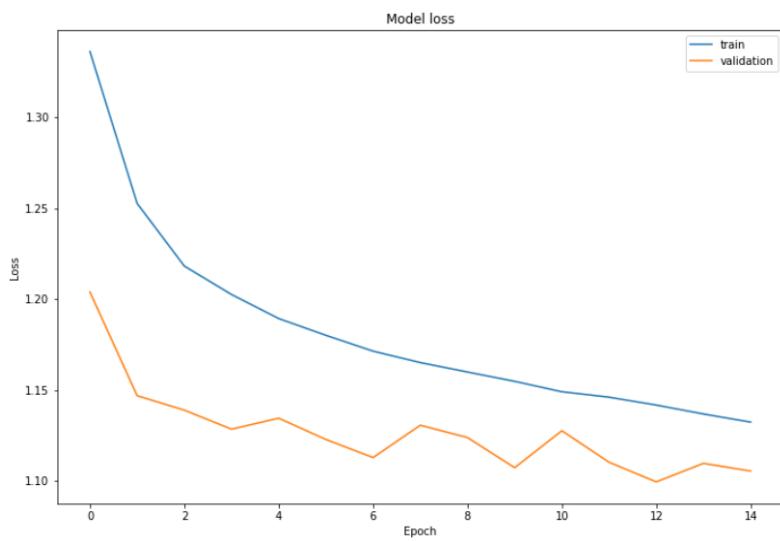
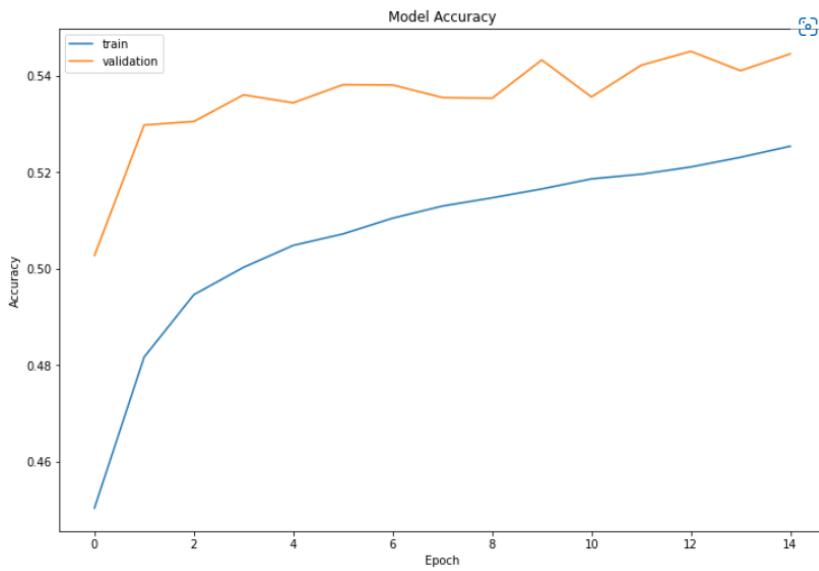
```
624/624 [=====] - 4s 6ms/step - loss: 1.8935 - accuracy: 0.2588 - val_loss: 1.6363 - val_accuracy: 0.3419
Epoch 2/20
624/624 [=====] - 3s 5ms/step - loss: 1.6099 - accuracy: 0.3410 - val_loss: 1.5044 - val_accuracy: 0.3714
Epoch 3/20
624/624 [=====] - 3s 5ms/step - loss: 1.5217 - accuracy: 0.3691 - val_loss: 1.5120 - val_accuracy: 0.3705
Epoch 4/20
624/624 [=====] - 3s 5ms/step - loss: 1.4631 - accuracy: 0.3900 - val_loss: 1.4778 - val_accuracy: 0.3843
Epoch 5/20
624/624 [=====] - 3s 5ms/step - loss: 1.4030 - accuracy: 0.4146 - val_loss: 1.4707 - val_accuracy: 0.3948
Epoch 6/20
624/624 [=====] - 3s 5ms/step - loss: 1.3419 - accuracy: 0.4377 - val_loss: 1.4664 - val_accuracy: 0.4062
Epoch 7/20
624/624 [=====] - 3s 5ms/step - loss: 1.2913 - accuracy: 0.4587 - val_loss: 1.4856 - val_accuracy: 0.4238
Epoch 8/20
624/624 [=====] - 3s 5ms/step - loss: 1.2417 - accuracy: 0.4798 - val_loss: 1.4486 - val_accuracy: 0.4224
Epoch 9/20
624/624 [=====] - 3s 5ms/step - loss: 1.1991 - accuracy: 0.4946 - val_loss: 1.5451 - val_accuracy: 0.4186
Epoch 10/20
624/624 [=====] - 3s 5ms/step - loss: 1.1643 - accuracy: 0.5094 - val_loss: 1.4833 - val_accuracy: 0.4319
Epoch 11/20
624/624 [=====] - 3s 5ms/step - loss: 1.1287 - accuracy: 0.5231 - val_loss: 1.5327 - val_accuracy: 0.4286
Epoch 12/20
624/624 [=====] - 3s 5ms/step - loss: 1.0975 - accuracy: 0.5340 - val_loss: 1.6018 - val_accuracy: 0.4281
Epoch 13/20
624/624 [=====] - 3s 5ms/step - loss: 1.0654 - accuracy: 0.5465 - val_loss: 1.7489 - val_accuracy: 0.4229
Epoch 14/20
624/624 [=====] - 3s 5ms/step - loss: 1.0397 - accuracy: 0.5548 - val_loss: 1.7735 - val_accuracy: 0.4386
Epoch 15/20
624/624 [=====] - 3s 5ms/step - loss: 1.0129 - accuracy: 0.5644 - val_loss: 1.7058 - val_accuracy: 0.4224
Epoch 16/20
624/624 [=====] - 3s 5ms/step - loss: 1.0006 - accuracy: 0.5717 - val_loss: 1.8333 - val_accuracy: 0.4329
Epoch 17/20
624/624 [=====] - 3s 5ms/step - loss: 0.9782 - accuracy: 0.5791 - val_loss: 1.8887 - val_accuracy: 0.4329
Epoch 18/20
624/624 [=====] - 4s 6ms/step - loss: 0.9566 - accuracy: 0.5902 - val_loss: 1.9643 - val_accuracy: 0.4233
Epoch 19/20
624/624 [=====] - 3s 5ms/step - loss: 0.9415 - accuracy: 0.5929 - val_loss: 1.8134 - val_accuracy: 0.4319
Epoch 20/20
624/624 [=====] - 3s 5ms/step - loss: 0.9289 - accuracy: 0.6001 - val_loss: 1.9950 - val_accuracy: 0.4405
```

iv. Learning Rate : 0.0001

```
624/624 [=====] - 4s 5ms/step - loss: 2.1469 - accuracy: 0.1926 - val_loss: 1.9952 - val_accuracy: 0.2571
Epoch 2/20
624/624 [=====] - 3s 5ms/step - loss: 1.9607 - accuracy: 0.2522 - val_loss: 1.8188 - val_accuracy: 0.3010
Epoch 3/20
624/624 [=====] - 3s 5ms/step - loss: 1.8407 - accuracy: 0.2933 - val_loss: 1.7035 - val_accuracy: 0.3357
Epoch 4/20
624/624 [=====] - 3s 5ms/step - loss: 1.7348 - accuracy: 0.3259 - val_loss: 1.6102 - val_accuracy: 0.3662
Epoch 5/20
624/624 [=====] - 3s 5ms/step - loss: 1.6487 - accuracy: 0.3615 - val_loss: 1.5458 - val_accuracy: 0.3848
Epoch 6/20
624/624 [=====] - 3s 5ms/step - loss: 1.5715 - accuracy: 0.3883 - val_loss: 1.4950 - val_accuracy: 0.4152
Epoch 7/20
624/624 [=====] - 3s 5ms/step - loss: 1.5025 - accuracy: 0.4170 - val_loss: 1.4548 - val_accuracy: 0.4143
Epoch 8/20
624/624 [=====] - 3s 5ms/step - loss: 1.4404 - accuracy: 0.4402 - val_loss: 1.4249 - val_accuracy: 0.4462
Epoch 9/20
624/624 [=====] - 3s 5ms/step - loss: 1.3866 - accuracy: 0.4617 - val_loss: 1.4010 - val_accuracy: 0.4495
Epoch 10/20
624/624 [=====] - 3s 5ms/step - loss: 1.3373 - accuracy: 0.4809 - val_loss: 1.3770 - val_accuracy: 0.4600
Epoch 11/20
624/624 [=====] - 3s 5ms/step - loss: 1.2965 - accuracy: 0.4929 - val_loss: 1.3667 - val_accuracy: 0.4676
Epoch 12/20
624/624 [=====] - 3s 5ms/step - loss: 1.2511 - accuracy: 0.5138 - val_loss: 1.3720 - val_accuracy: 0.4681
Epoch 13/20
624/624 [=====] - 3s 5ms/step - loss: 1.2155 - accuracy: 0.5253 - val_loss: 1.3610 - val_accuracy: 0.4690
Epoch 14/20
624/624 [=====] - 3s 5ms/step - loss: 1.1756 - accuracy: 0.5389 - val_loss: 1.3540 - val_accuracy: 0.4757
Epoch 15/20
624/624 [=====] - 3s 5ms/step - loss: 1.1415 - accuracy: 0.5533 - val_loss: 1.3567 - val_accuracy: 0.4800
Epoch 16/20
624/624 [=====] - 3s 5ms/step - loss: 1.1063 - accuracy: 0.5666 - val_loss: 1.3518 - val_accuracy: 0.4829
Epoch 17/20
624/624 [=====] - 3s 5ms/step - loss: 1.0721 - accuracy: 0.5784 - val_loss: 1.3591 - val_accuracy: 0.4800
Epoch 18/20
624/624 [=====] - 3s 5ms/step - loss: 1.0379 - accuracy: 0.5964 - val_loss: 1.3561 - val_accuracy: 0.4876
Epoch 19/20
624/624 [=====] - 3s 5ms/step - loss: 1.0136 - accuracy: 0.6013 - val_loss: 1.3781 - val_accuracy: 0.4729
Epoch 20/20
624/624 [=====] - 3s 5ms/step - loss: 0.9835 - accuracy: 0.6146 - val_loss: 1.3731 - val_accuracy: 0.4829
```

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- b. Training on best Learning Rate (I chose 0.0001 LR as it has highest val_accuracy above all other LR's)

```
Epoch 1/20
12469/12469 [=====] - 72s 5ms/step - loss: 1.5396 - accuracy: 0.3808 - val_loss: 1.2467 - val_accuracy: 0.4941
Epoch 2/20
12469/12469 [=====] - 62s 5ms/step - loss: 1.2775 - accuracy: 0.4746 - val_loss: 1.1809 - val_accuracy: 0.5159
Epoch 3/20
12469/12469 [=====] - 60s 5ms/step - loss: 1.2296 - accuracy: 0.4916 - val_loss: 1.1489 - val_accuracy: 0.5309
Epoch 4/20
12469/12469 [=====] - 62s 5ms/step - loss: 1.2055 - accuracy: 0.5006 - val_loss: 1.1310 - val_accuracy: 0.5355
Epoch 5/20
12469/12469 [=====] - 62s 5ms/step - loss: 1.1911 - accuracy: 0.5054 - val_loss: 1.1232 - val_accuracy: 0.5373
Epoch 6/20
12469/12469 [=====] - 63s 5ms/step - loss: 1.1788 - accuracy: 0.5103 - val_loss: 1.1165 - val_accuracy: 0.5397
Epoch 7/20
12469/12469 [=====] - 64s 5ms/step - loss: 1.1697 - accuracy: 0.5136 - val_loss: 1.1242 - val_accuracy: 0.5385
Epoch 8/20
12469/12469 [=====] - 62s 5ms/step - loss: 1.1615 - accuracy: 0.5158 - val_loss: 1.1224 - val_accuracy: 0.5387
Epoch 9/20
12469/12469 [=====] - 61s 5ms/step - loss: 1.1543 - accuracy: 0.5182 - val_loss: 1.1193 - val_accuracy: 0.5416
Epoch 10/20
12469/12469 [=====] - 62s 5ms/step - loss: 1.1483 - accuracy: 0.5200 - val_loss: 1.1070 - val_accuracy: 0.5423
Epoch 11/20
12469/12469 [=====] - 61s 5ms/step - loss: 1.1416 - accuracy: 0.5224 - val_loss: 1.1215 - val_accuracy: 0.5394
Epoch 12/20
12469/12469 [=====] - 60s 5ms/step - loss: 1.1360 - accuracy: 0.5245 - val_loss: 1.1183 - val_accuracy: 0.5422
Epoch 13/20
12469/12469 [=====] - 64s 5ms/step - loss: 1.1303 - accuracy: 0.5268 - val_loss: 1.1110 - val_accuracy: 0.5417
Epoch 14/20
12469/12469 [=====] - 68s 5ms/step - loss: 1.1245 - accuracy: 0.5292 - val_loss: 1.1146 - val_accuracy: 0.5411
Epoch 15/20
12469/12469 [=====] - 70s 6ms/step - loss: 1.1217 - accuracy: 0.5300 - val_loss: 1.1084 - val_accuracy: 0.5440
```



2. Raw + Integration

a. Hyperparameter tuning

i. Learning Rate : 0.1

```
624/624 [======] - 16s 7ms/step - loss: 2.7381 - accuracy: 0.0993 - val_loss: 2.9447 - val_accuracy: 0.1062
Epoch 2/20
624/624 [======] - 4s 7ms/step - loss: 2.3121 - accuracy: 0.0979 - val_loss: 2.3133 - val_accuracy: 0.1010
Epoch 3/20
624/624 [======] - 4s 7ms/step - loss: 2.3123 - accuracy: 0.0980 - val_loss: 2.3136 - val_accuracy: 0.1010
Epoch 4/20
624/624 [======] - 5s 7ms/step - loss: 2.3123 - accuracy: 0.0981 - val_loss: 2.3136 - val_accuracy: 0.1010
Epoch 5/20
624/624 [======] - 4s 7ms/step - loss: 2.3124 - accuracy: 0.0981 - val_loss: 2.3137 - val_accuracy: 0.1010
Epoch 6/20
624/624 [======] - 4s 6ms/step - loss: 2.3124 - accuracy: 0.0980 - val_loss: 2.3137 - val_accuracy: 0.1010
Epoch 7/20
624/624 [======] - 4s 6ms/step - loss: 2.3124 - accuracy: 0.0980 - val_loss: 2.3137 - val_accuracy: 0.1010
Epoch 8/20
624/624 [======] - 4s 6ms/step - loss: 2.3124 - accuracy: 0.0980 - val_loss: 2.3137 - val_accuracy: 0.1010
Epoch 9/20
624/624 [======] - 4s 6ms/step - loss: 2.3124 - accuracy: 0.0980 - val_loss: 2.3137 - val_accuracy: 0.1010
Epoch 10/20
624/624 [======] - 4s 7ms/step - loss: 2.3124 - accuracy: 0.0980 - val_loss: 2.3137 - val_accuracy: 0.1010
Epoch 11/20
624/624 [======] - 4s 6ms/step - loss: 2.3124 - accuracy: 0.0980 - val_loss: 2.3137 - val_accuracy: 0.1010
Epoch 12/20
624/624 [======] - 4s 6ms/step - loss: 2.3124 - accuracy: 0.0980 - val_loss: 2.3137 - val_accuracy: 0.1010
Epoch 13/20
624/624 [======] - 4s 6ms/step - loss: 2.3124 - accuracy: 0.0980 - val_loss: 2.3137 - val_accuracy: 0.1010
Epoch 14/20
624/624 [======] - 4s 7ms/step - loss: 2.3124 - accuracy: 0.0980 - val_loss: 2.3137 - val_accuracy: 0.1010
Epoch 15/20
624/624 [======] - 6s 10ms/step - loss: 2.3124 - accuracy: 0.0980 - val_loss: 2.3137 - val_accuracy: 0.1010
Epoch 16/20
624/624 [======] - 6s 9ms/step - loss: 2.3124 - accuracy: 0.0980 - val_loss: 2.3137 - val_accuracy: 0.1010
Epoch 17/20
624/624 [======] - 5s 8ms/step - loss: 2.3124 - accuracy: 0.0980 - val_loss: 2.3137 - val_accuracy: 0.1010
Epoch 18/20
624/624 [======] - 5s 8ms/step - loss: 2.3124 - accuracy: 0.0980 - val_loss: 2.3137 - val_accuracy: 0.1010
Epoch 19/20
624/624 [======] - 6s 9ms/step - loss: 2.3124 - accuracy: 0.0980 - val_loss: 2.3137 - val_accuracy: 0.1010
Epoch 20/20
624/624 [======] - 5s 8ms/step - loss: 2.3124 - accuracy: 0.0980 - val_loss: 2.3137 - val_accuracy: 0.1010
```

ii. Learning Rate : 0.01

```
624/624 [======] - 6s 9ms/step - loss: 2.1250 - accuracy: 0.1778 - val_loss: 524.7890 - val_accuracy: 0.1000
Epoch 2/20
624/624 [======] - 5s 8ms/step - loss: 2.1036 - accuracy: 0.1752 - val_loss: 2.3872 - val_accuracy: 0.1286
Epoch 3/20
624/624 [======] - 5s 9ms/step - loss: 2.0877 - accuracy: 0.1769 - val_loss: 73.0051 - val_accuracy: 0.1000
Epoch 4/20
624/624 [======] - 6s 9ms/step - loss: 2.0605 - accuracy: 0.1836 - val_loss: 19.5032 - val_accuracy: 0.1010
Epoch 5/20
624/624 [======] - 6s 9ms/step - loss: 2.0782 - accuracy: 0.1825 - val_loss: 607.5198 - val_accuracy: 0.1000
Epoch 6/20
624/624 [======] - 5s 8ms/step - loss: 2.0712 - accuracy: 0.1804 - val_loss: 1830.0315 - val_accuracy: 0.1000
Epoch 7/20
624/624 [======] - 6s 9ms/step - loss: 2.0661 - accuracy: 0.1864 - val_loss: 2477.4351 - val_accuracy: 0.1000
Epoch 8/20
624/624 [======] - 6s 10ms/step - loss: 2.1348 - accuracy: 0.1607 - val_loss: 2.3034 - val_accuracy: 0.1010
Epoch 9/20
624/624 [======] - 5s 8ms/step - loss: 2.3037 - accuracy: 0.1007 - val_loss: 2.3034 - val_accuracy: 0.1010
Epoch 10/20
624/624 [======] - 5s 8ms/step - loss: 2.3037 - accuracy: 0.1007 - val_loss: 2.3034 - val_accuracy: 0.1010
Epoch 11/20
624/624 [======] - 6s 9ms/step - loss: 2.3036 - accuracy: 0.1007 - val_loss: 2.3034 - val_accuracy: 0.1010
Epoch 12/20
624/624 [======] - 7s 11ms/step - loss: 2.3036 - accuracy: 0.1007 - val_loss: 2.3034 - val_accuracy: 0.1010
Epoch 13/20
624/624 [======] - 7s 11ms/step - loss: 2.3036 - accuracy: 0.1007 - val_loss: 2.3034 - val_accuracy: 0.1010
Epoch 14/20
624/624 [======] - 7s 11ms/step - loss: 2.3036 - accuracy: 0.1007 - val_loss: 2.3034 - val_accuracy: 0.1010
Epoch 15/20
624/624 [======] - 5s 8ms/step - loss: 2.3036 - accuracy: 0.1007 - val_loss: 2.3034 - val_accuracy: 0.1010
Epoch 16/20
624/624 [======] - 5s 8ms/step - loss: 2.3036 - accuracy: 0.1007 - val_loss: 2.3034 - val_accuracy: 0.1010
Epoch 17/20
624/624 [======] - 5s 8ms/step - loss: 2.3036 - accuracy: 0.1007 - val_loss: 2.3033 - val_accuracy: 0.1010
Epoch 18/20
624/624 [======] - 6s 10ms/step - loss: 2.3036 - accuracy: 0.1007 - val_loss: 2.3033 - val_accuracy: 0.1010
Epoch 19/20
624/624 [======] - 5s 8ms/step - loss: 2.3036 - accuracy: 0.1007 - val_loss: 2.3033 - val_accuracy: 0.1010
Epoch 20/20
624/624 [======] - 4s 7ms/step - loss: 2.3036 - accuracy: 0.1007 - val_loss: 2.3033 - val_accuracy: 0.1010
```

iii. Learning Rate : 0.001

```
624/624 [=====] - 5s 7ms/step - loss: 1.9646 - accuracy: 0.2375 - val_loss: 1.8210 - val_accuracy: 0.3010
Epoch 2/20
624/624 [=====] - 5s 8ms/step - loss: 1.6896 - accuracy: 0.3264 - val_loss: 1.6168 - val_accuracy: 0.3586
Epoch 3/20
624/624 [=====] - 4s 6ms/step - loss: 1.5778 - accuracy: 0.3671 - val_loss: 1.5041 - val_accuracy: 0.3952
Epoch 4/20
624/624 [=====] - 4s 7ms/step - loss: 1.5051 - accuracy: 0.3943 - val_loss: 1.9883 - val_accuracy: 0.3395
Epoch 5/20
624/624 [=====] - 5s 8ms/step - loss: 1.4550 - accuracy: 0.4132 - val_loss: 2.0693 - val_accuracy: 0.3552
Epoch 6/20
624/624 [=====] - 4s 7ms/step - loss: 1.4094 - accuracy: 0.4267 - val_loss: 1.7315 - val_accuracy: 0.3767
Epoch 7/20
624/624 [=====] - 4s 6ms/step - loss: 1.3762 - accuracy: 0.4408 - val_loss: 1.4427 - val_accuracy: 0.4138
Epoch 8/20
624/624 [=====] - 4s 6ms/step - loss: 1.3452 - accuracy: 0.4570 - val_loss: 1.8871 - val_accuracy: 0.3648
Epoch 9/20
624/624 [=====] - 4s 6ms/step - loss: 1.3227 - accuracy: 0.4645 - val_loss: 1.6060 - val_accuracy: 0.4038
Epoch 10/20
624/624 [=====] - 6s 9ms/step - loss: 1.2945 - accuracy: 0.4739 - val_loss: 1.7125 - val_accuracy: 0.3876
Epoch 11/20
624/624 [=====] - 6s 9ms/step - loss: 1.2666 - accuracy: 0.4859 - val_loss: 1.6025 - val_accuracy: 0.3971
Epoch 12/20
624/624 [=====] - 6s 9ms/step - loss: 1.2504 - accuracy: 0.4917 - val_loss: 1.8159 - val_accuracy: 0.3838
Epoch 13/20
624/624 [=====] - 4s 7ms/step - loss: 1.2295 - accuracy: 0.4988 - val_loss: 5.6486 - val_accuracy: 0.2457
Epoch 14/20
624/624 [=====] - 6s 9ms/step - loss: 1.2079 - accuracy: 0.5051 - val_loss: 3.2745 - val_accuracy: 0.3343
Epoch 15/20
624/624 [=====] - 5s 8ms/step - loss: 1.1874 - accuracy: 0.5167 - val_loss: 1.6923 - val_accuracy: 0.3605
Epoch 16/20
624/624 [=====] - 6s 9ms/step - loss: 1.1660 - accuracy: 0.5227 - val_loss: 1.6358 - val_accuracy: 0.4448
Epoch 17/20
624/624 [=====] - 5s 7ms/step - loss: 1.1479 - accuracy: 0.5281 - val_loss: 1.7482 - val_accuracy: 0.3857
Epoch 18/20
624/624 [=====] - 6s 9ms/step - loss: 1.1290 - accuracy: 0.5357 - val_loss: 35.3508 - val_accuracy: 0.1300
Epoch 19/20
624/624 [=====] - 5s 7ms/step - loss: 1.1179 - accuracy: 0.5386 - val_loss: 3.6526 - val_accuracy: 0.3238
Epoch 20/20
624/624 [=====] - 5s 8ms/step - loss: 1.1075 - accuracy: 0.5441 - val_loss: 8.2904 - val_accuracy: 0.2171
```

iv. Learning Rate : 0.0001

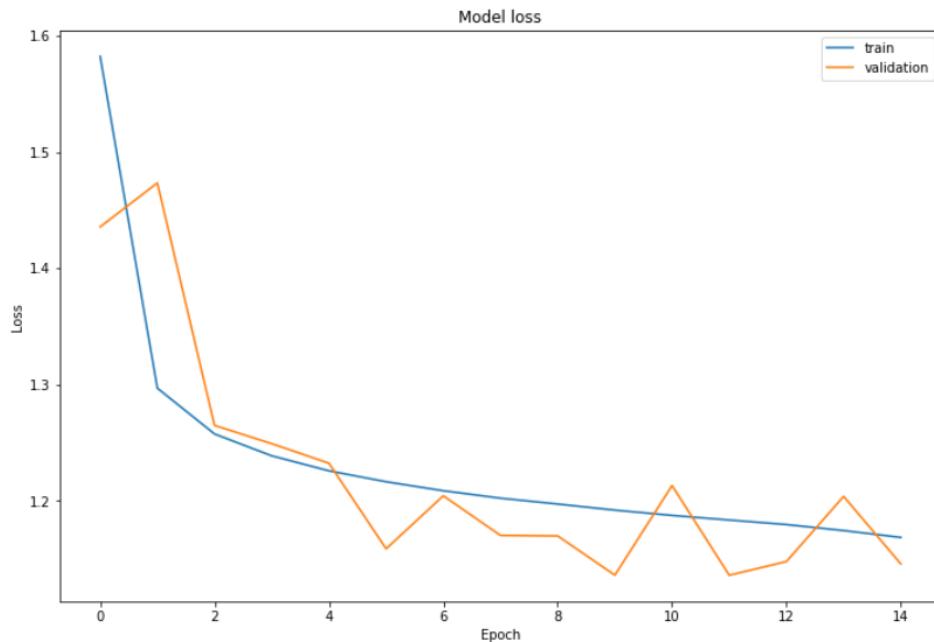
```
624/624 [=====] - 5s 6ms/step - loss: 2.1181 - accuracy: 0.1975 - val_loss: 2.0410 - val_accuracy: 0.2610
Epoch 2/20
624/624 [=====] - 4s 7ms/step - loss: 1.9144 - accuracy: 0.2637 - val_loss: 1.8508 - val_accuracy: 0.2814
Epoch 3/20
624/624 [=====] - 4s 6ms/step - loss: 1.8244 - accuracy: 0.2908 - val_loss: 1.7690 - val_accuracy: 0.2990
Epoch 4/20
624/624 [=====] - 4s 6ms/step - loss: 1.7558 - accuracy: 0.3108 - val_loss: 1.7054 - val_accuracy: 0.3262
Epoch 5/20
624/624 [=====] - 4s 7ms/step - loss: 1.6938 - accuracy: 0.3359 - val_loss: 1.6806 - val_accuracy: 0.3524
Epoch 6/20
624/624 [=====] - 4s 6ms/step - loss: 1.6364 - accuracy: 0.3622 - val_loss: 1.6062 - val_accuracy: 0.3624
Epoch 7/20
624/624 [=====] - 6s 9ms/step - loss: 1.5838 - accuracy: 0.3805 - val_loss: 1.6679 - val_accuracy: 0.3414
Epoch 8/20
624/624 [=====] - 5s 8ms/step - loss: 1.5442 - accuracy: 0.3972 - val_loss: 1.5999 - val_accuracy: 0.3671
Epoch 9/20
624/624 [=====] - 5s 9ms/step - loss: 1.5032 - accuracy: 0.4126 - val_loss: 1.6952 - val_accuracy: 0.3371
Epoch 10/20
624/624 [=====] - 4s 7ms/step - loss: 1.4715 - accuracy: 0.4264 - val_loss: 1.4888 - val_accuracy: 0.4243
Epoch 11/20
624/624 [=====] - 4s 6ms/step - loss: 1.4445 - accuracy: 0.4396 - val_loss: 1.5697 - val_accuracy: 0.3795
Epoch 12/20
624/624 [=====] - 4s 7ms/step - loss: 1.4236 - accuracy: 0.4457 - val_loss: 1.5129 - val_accuracy: 0.4019
Epoch 13/20
624/624 [=====] - 4s 7ms/step - loss: 1.4010 - accuracy: 0.4511 - val_loss: 1.5074 - val_accuracy: 0.3995
Epoch 14/20
624/624 [=====] - 4s 6ms/step - loss: 1.3763 - accuracy: 0.4605 - val_loss: 1.4672 - val_accuracy: 0.4138
Epoch 15/20
624/624 [=====] - 4s 6ms/step - loss: 1.3548 - accuracy: 0.4689 - val_loss: 1.5330 - val_accuracy: 0.3881
Epoch 16/20
624/624 [=====] - 4s 6ms/step - loss: 1.3390 - accuracy: 0.4755 - val_loss: 1.4152 - val_accuracy: 0.4310
Epoch 17/20
624/624 [=====] - 4s 6ms/step - loss: 1.3243 - accuracy: 0.4805 - val_loss: 1.4473 - val_accuracy: 0.4257
Epoch 18/20
624/624 [=====] - 4s 7ms/step - loss: 1.3096 - accuracy: 0.4896 - val_loss: 1.4424 - val_accuracy: 0.4210
Epoch 19/20
624/624 [=====] - 4s 6ms/step - loss: 1.2902 - accuracy: 0.4949 - val_loss: 1.5831 - val_accuracy: 0.3881
Epoch 20/20
624/624 [=====] - 4s 7ms/step - loss: 1.2790 - accuracy: 0.4977 - val_loss: 1.5715 - val_accuracy: 0.3943
```

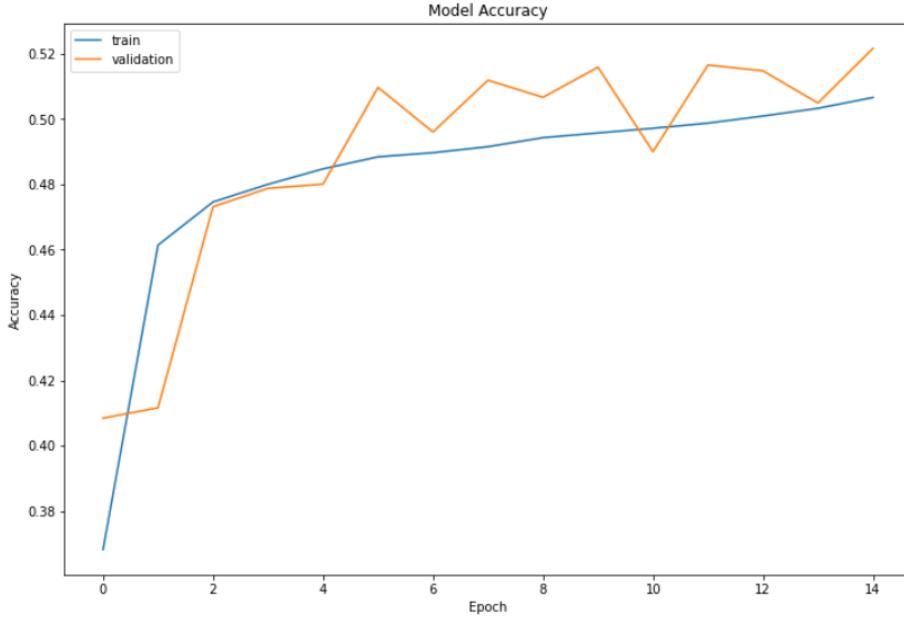
- b. Training on best Learning Rate (I chose 0.0001 LR as it has highest val_accuracy above all other LR's)

```

Epoch 1/15
12469/12469 [=====] - 76s 5ms/step - loss: 1.5823 - accuracy: 0.3682 - val_loss: 1.4357 - val_accuracy: 0.4085
Epoch 2/15
12469/12469 [=====] - 63s 5ms/step - loss: 1.2970 - accuracy: 0.4614 - val_loss: 1.4734 - val_accuracy: 0.4116
Epoch 3/15
12469/12469 [=====] - 62s 5ms/step - loss: 1.2576 - accuracy: 0.4746 - val_loss: 1.2649 - val_accuracy: 0.4732
Epoch 4/15
12469/12469 [=====] - 64s 5ms/step - loss: 1.2388 - accuracy: 0.4800 - val_loss: 1.2493 - val_accuracy: 0.4788
Epoch 5/15
12469/12469 [=====] - 62s 5ms/step - loss: 1.2259 - accuracy: 0.4847 - val_loss: 1.2325 - val_accuracy: 0.4801
Epoch 6/15
12469/12469 [=====] - 62s 5ms/step - loss: 1.2165 - accuracy: 0.4884 - val_loss: 1.1589 - val_accuracy: 0.5097
Epoch 7/15
12469/12469 [=====] - 63s 5ms/step - loss: 1.2088 - accuracy: 0.4897 - val_loss: 1.2044 - val_accuracy: 0.4960
Epoch 8/15
12469/12469 [=====] - 62s 5ms/step - loss: 1.2024 - accuracy: 0.4915 - val_loss: 1.1704 - val_accuracy: 0.5119
Epoch 9/15
12469/12469 [=====] - 62s 5ms/step - loss: 1.1974 - accuracy: 0.4943 - val_loss: 1.1699 - val_accuracy: 0.5066
Epoch 10/15
12469/12469 [=====] - 63s 5ms/step - loss: 1.1921 - accuracy: 0.4957 - val_loss: 1.1362 - val_accuracy: 0.5159
Epoch 11/15
12469/12469 [=====] - 62s 5ms/step - loss: 1.1876 - accuracy: 0.4972 - val_loss: 1.2133 - val_accuracy: 0.4900
Epoch 12/15
12469/12469 [=====] - 62s 5ms/step - loss: 1.1836 - accuracy: 0.4987 - val_loss: 1.1361 - val_accuracy: 0.5165
Epoch 13/15
12469/12469 [=====] - 62s 5ms/step - loss: 1.1797 - accuracy: 0.5009 - val_loss: 1.1479 - val_accuracy: 0.5148
Epoch 14/15
12469/12469 [=====] - 63s 5ms/step - loss: 1.1745 - accuracy: 0.5033 - val_loss: 1.2039 - val_accuracy: 0.5049
Epoch 15/15
12469/12469 [=====] - 62s 5ms/step - loss: 1.1686 - accuracy: 0.5066 - val_loss: 1.1458 - val_accuracy: 0.5216

```





3. Derivative + Integration

a. Hyperparameter tuning

i. Learning Rate : 0.1

```

624/624 [=====] - 16s 6ms/step - loss: 4.3210 - accuracy: 0.0980 - val_loss: 2.3135 - val_accuracy: 0.1010
Epoch 2/20
624/624 [=====] - 4s 6ms/step - loss: 2.3121 - accuracy: 0.0981 - val_loss: 2.3136 - val_accuracy: 0.1010
Epoch 3/20
624/624 [=====] - 4s 6ms/step - loss: 2.3123 - accuracy: 0.0981 - val_loss: 2.3137 - val_accuracy: 0.1010
Epoch 4/20
624/624 [=====] - 4s 6ms/step - loss: 2.3123 - accuracy: 0.0980 - val_loss: 2.3137 - val_accuracy: 0.1010
Epoch 5/20
624/624 [=====] - 4s 6ms/step - loss: 2.3124 - accuracy: 0.0980 - val_loss: 2.3137 - val_accuracy: 0.1010
Epoch 6/20
624/624 [=====] - 4s 6ms/step - loss: 2.3124 - accuracy: 0.0980 - val_loss: 2.3137 - val_accuracy: 0.1010
Epoch 7/20
624/624 [=====] - 4s 6ms/step - loss: 2.3124 - accuracy: 0.0980 - val_loss: 2.3137 - val_accuracy: 0.1010
Epoch 8/20
624/624 [=====] - 4s 6ms/step - loss: 2.3124 - accuracy: 0.0980 - val_loss: 2.3137 - val_accuracy: 0.1010
Epoch 9/20
624/624 [=====] - 4s 6ms/step - loss: 2.3124 - accuracy: 0.0980 - val_loss: 2.3137 - val_accuracy: 0.1010
Epoch 10/20
624/624 [=====] - 4s 6ms/step - loss: 2.3124 - accuracy: 0.0980 - val_loss: 2.3137 - val_accuracy: 0.1010
Epoch 11/20
624/624 [=====] - 4s 6ms/step - loss: 2.3124 - accuracy: 0.0980 - val_loss: 2.3137 - val_accuracy: 0.1010
Epoch 12/20
624/624 [=====] - 4s 6ms/step - loss: 2.3124 - accuracy: 0.0980 - val_loss: 2.3137 - val_accuracy: 0.1010
Epoch 13/20
624/624 [=====] - 4s 6ms/step - loss: 2.3124 - accuracy: 0.0980 - val_loss: 2.3137 - val_accuracy: 0.1010
Epoch 14/20
624/624 [=====] - 4s 6ms/step - loss: 2.3124 - accuracy: 0.0980 - val_loss: 2.3137 - val_accuracy: 0.1010
Epoch 15/20
624/624 [=====] - 4s 6ms/step - loss: 2.3124 - accuracy: 0.0980 - val_loss: 2.3137 - val_accuracy: 0.1010
Epoch 16/20
624/624 [=====] - 4s 6ms/step - loss: 2.3124 - accuracy: 0.0980 - val_loss: 2.3137 - val_accuracy: 0.1010
Epoch 17/20
624/624 [=====] - 4s 6ms/step - loss: 2.3124 - accuracy: 0.0980 - val_loss: 2.3137 - val_accuracy: 0.1010
Epoch 18/20
624/624 [=====] - 4s 6ms/step - loss: 2.3124 - accuracy: 0.0980 - val_loss: 2.3137 - val_accuracy: 0.1010
Epoch 19/20
624/624 [=====] - 4s 6ms/step - loss: 2.3124 - accuracy: 0.0980 - val_loss: 2.3137 - val_accuracy: 0.1010
Epoch 20/20
624/624 [=====] - 3s 5ms/step - loss: 2.3124 - accuracy: 0.0980 - val_loss: 2.3137 - val_accuracy: 0.1010

```

ii. Learning Rate : 0.01

```
624/624 [=====] - 4s 5ms/step - loss: 2.1174 - accuracy: 0.1840 - val_loss: 1.9585 - val_accuracy: 0.2090
Epoch 2/20
624/624 [=====] - 3s 5ms/step - loss: 1.9903 - accuracy: 0.2121 - val_loss: 1.8737 - val_accuracy: 0.2543
Epoch 3/20
624/624 [=====] - 4s 6ms/step - loss: 1.9644 - accuracy: 0.2188 - val_loss: 1.8642 - val_accuracy: 0.2552
Epoch 4/20
624/624 [=====] - 3s 5ms/step - loss: 1.9586 - accuracy: 0.2250 - val_loss: 1.8815 - val_accuracy: 0.2262
Epoch 5/20
624/624 [=====] - 3s 5ms/step - loss: 1.9496 - accuracy: 0.2262 - val_loss: 1.9029 - val_accuracy: 0.2686
Epoch 6/20
624/624 [=====] - 3s 5ms/step - loss: 1.9778 - accuracy: 0.2238 - val_loss: 2.0171 - val_accuracy: 0.2124
Epoch 7/20
624/624 [=====] - 3s 5ms/step - loss: 2.0353 - accuracy: 0.2004 - val_loss: 1.8440 - val_accuracy: 0.2595
Epoch 8/20
624/624 [=====] - 3s 5ms/step - loss: 1.9448 - accuracy: 0.2291 - val_loss: 1.8381 - val_accuracy: 0.2648
Epoch 9/20
624/624 [=====] - 3s 5ms/step - loss: 1.9441 - accuracy: 0.2321 - val_loss: 1.8332 - val_accuracy: 0.2629
Epoch 10/20
624/624 [=====] - 3s 5ms/step - loss: 1.9024 - accuracy: 0.2452 - val_loss: 1.7837 - val_accuracy: 0.2919
Epoch 11/20
624/624 [=====] - 3s 5ms/step - loss: 1.8940 - accuracy: 0.2488 - val_loss: 1.7944 - val_accuracy: 0.2738
Epoch 12/20
624/624 [=====] - 3s 5ms/step - loss: 1.8551 - accuracy: 0.2600 - val_loss: 1.7296 - val_accuracy: 0.3110
Epoch 13/20
624/624 [=====] - 3s 5ms/step - loss: 1.8549 - accuracy: 0.2650 - val_loss: 1.7662 - val_accuracy: 0.2971
Epoch 14/20
624/624 [=====] - 3s 5ms/step - loss: 1.8465 - accuracy: 0.2648 - val_loss: 1.7245 - val_accuracy: 0.3029
Epoch 15/20
624/624 [=====] - 3s 5ms/step - loss: 1.8478 - accuracy: 0.2639 - val_loss: 1.7375 - val_accuracy: 0.2957
Epoch 16/20
624/624 [=====] - 3s 5ms/step - loss: 1.8338 - accuracy: 0.2674 - val_loss: 1.7055 - val_accuracy: 0.3129
Epoch 17/20
624/624 [=====] - 3s 5ms/step - loss: 1.8723 - accuracy: 0.2571 - val_loss: 1.7783 - val_accuracy: 0.2910
Epoch 18/20
624/624 [=====] - 3s 5ms/step - loss: 1.8497 - accuracy: 0.2653 - val_loss: 1.7152 - val_accuracy: 0.3148
Epoch 19/20
624/624 [=====] - 3s 5ms/step - loss: 1.8233 - accuracy: 0.2716 - val_loss: 1.7078 - val_accuracy: 0.3114
Epoch 20/20
624/624 [=====] - 3s 5ms/step - loss: 2.1983 - accuracy: 0.1419 - val_loss: 2.0957 - val_accuracy: 0.1733
```

iii.

Learning Rate : 0.001

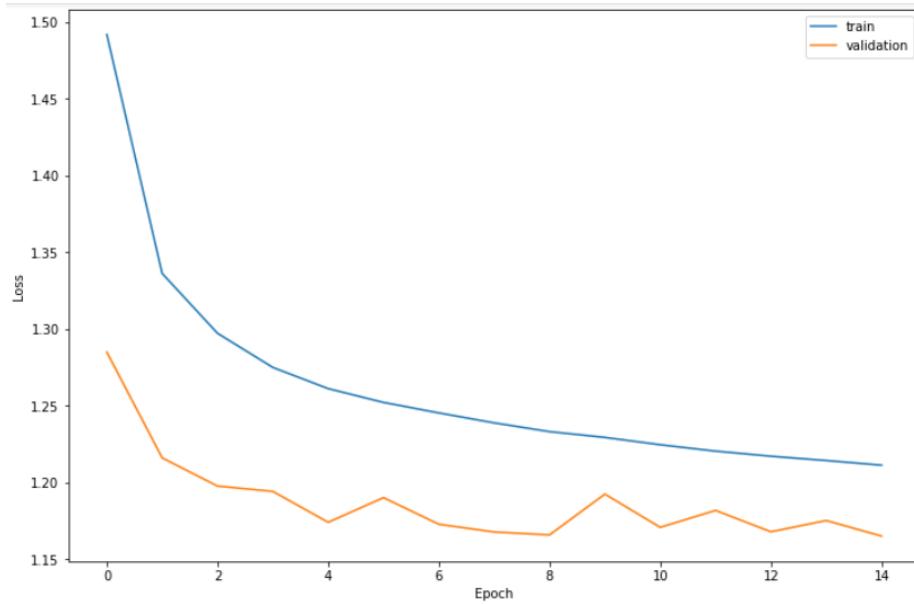
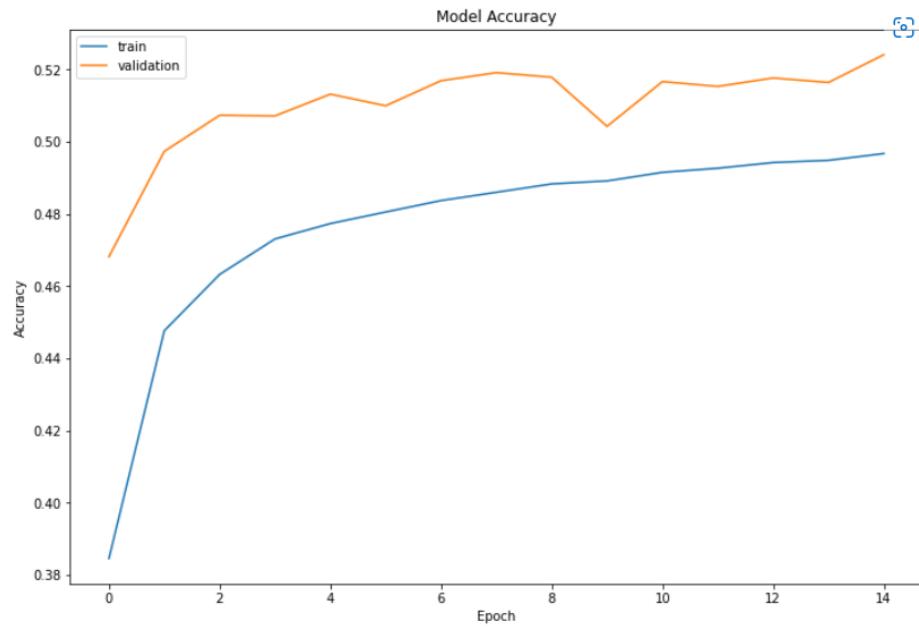
```
624/624 [=====] - 4s 6ms/step - loss: 1.9176 - accuracy: 0.2539 - val_loss: 1.6493 - val_accuracy: 0.3557
Epoch 2/20
624/624 [=====] - 4s 6ms/step - loss: 1.6101 - accuracy: 0.3381 - val_loss: 1.7988 - val_accuracy: 0.3390
Epoch 3/20
624/624 [=====] - 4s 6ms/step - loss: 1.5199 - accuracy: 0.3609 - val_loss: 1.5091 - val_accuracy: 0.3600
Epoch 4/20
624/624 [=====] - 4s 6ms/step - loss: 1.4703 - accuracy: 0.3801 - val_loss: 1.5478 - val_accuracy: 0.3776
Epoch 5/20
624/624 [=====] - 4s 6ms/step - loss: 1.4282 - accuracy: 0.3958 - val_loss: 1.4875 - val_accuracy: 0.3919
Epoch 6/20
624/624 [=====] - 4s 6ms/step - loss: 1.3883 - accuracy: 0.4130 - val_loss: 1.4844 - val_accuracy: 0.3967
Epoch 7/20
624/624 [=====] - 4s 6ms/step - loss: 1.3472 - accuracy: 0.4253 - val_loss: 1.4790 - val_accuracy: 0.4033
Epoch 8/20
624/624 [=====] - 4s 6ms/step - loss: 1.3051 - accuracy: 0.4440 - val_loss: 1.4948 - val_accuracy: 0.4086
Epoch 9/20
624/624 [=====] - 4s 6ms/step - loss: 1.2803 - accuracy: 0.4538 - val_loss: 1.4502 - val_accuracy: 0.4252
Epoch 10/20
624/624 [=====] - 4s 6ms/step - loss: 1.2458 - accuracy: 0.4689 - val_loss: 1.4764 - val_accuracy: 0.4286
Epoch 11/20
624/624 [=====] - 4s 6ms/step - loss: 1.2139 - accuracy: 0.4829 - val_loss: 1.4590 - val_accuracy: 0.4271
Epoch 12/20
624/624 [=====] - 4s 6ms/step - loss: 1.1860 - accuracy: 0.4931 - val_loss: 1.5153 - val_accuracy: 0.4171
Epoch 13/20
624/624 [=====] - 4s 6ms/step - loss: 1.1621 - accuracy: 0.5041 - val_loss: 1.4694 - val_accuracy: 0.4200
Epoch 14/20
624/624 [=====] - 4s 6ms/step - loss: 1.1399 - accuracy: 0.5186 - val_loss: 1.5502 - val_accuracy: 0.4129
Epoch 15/20
624/624 [=====] - 4s 6ms/step - loss: 1.1252 - accuracy: 0.5176 - val_loss: 1.5085 - val_accuracy: 0.4038
Epoch 16/20
624/624 [=====] - 3s 5ms/step - loss: 1.0995 - accuracy: 0.5246 - val_loss: 1.5768 - val_accuracy: 0.4152
Epoch 17/20
624/624 [=====] - 3s 5ms/step - loss: 1.0806 - accuracy: 0.5335 - val_loss: 1.5663 - val_accuracy: 0.4271
Epoch 18/20
624/624 [=====] - 3s 5ms/step - loss: 1.0633 - accuracy: 0.5409 - val_loss: 1.5921 - val_accuracy: 0.4276
Epoch 19/20
624/624 [=====] - 3s 5ms/step - loss: 1.0458 - accuracy: 0.5464 - val_loss: 1.5742 - val_accuracy: 0.4181
Epoch 20/20
624/624 [=====] - 3s 5ms/step - loss: 1.0324 - accuracy: 0.5547 - val_loss: 1.5542 - val_accuracy: 0.4205
```

iv. Learning Rate : 0.0001

```
624/624 [=====] - 4s 6ms/step - loss: 2.1184 - accuracy: 0.2075 - val_loss: 1.9622 - val_accuracy: 0.2624
Epoch 2/20
624/624 [=====] - 4s 6ms/step - loss: 1.9209 - accuracy: 0.2638 - val_loss: 1.7969 - val_accuracy: 0.2871
Epoch 3/20
624/624 [=====] - 3s 6ms/step - loss: 1.8144 - accuracy: 0.2989 - val_loss: 1.6972 - val_accuracy: 0.3219
Epoch 4/20
624/624 [=====] - 4s 6ms/step - loss: 1.7202 - accuracy: 0.3317 - val_loss: 1.6191 - val_accuracy: 0.3410
Epoch 5/20
624/624 [=====] - 3s 5ms/step - loss: 1.6387 - accuracy: 0.3654 - val_loss: 1.5659 - val_accuracy: 0.3657
Epoch 6/20
624/624 [=====] - 4s 6ms/step - loss: 1.5714 - accuracy: 0.3868 - val_loss: 1.5249 - val_accuracy: 0.3781
Epoch 7/20
624/624 [=====] - 4s 6ms/step - loss: 1.5109 - accuracy: 0.4095 - val_loss: 1.4913 - val_accuracy: 0.3962
Epoch 8/20
624/624 [=====] - 4s 6ms/step - loss: 1.4542 - accuracy: 0.4343 - val_loss: 1.4697 - val_accuracy: 0.4276
Epoch 9/20
624/624 [=====] - 3s 6ms/step - loss: 1.4007 - accuracy: 0.4510 - val_loss: 1.4573 - val_accuracy: 0.4167
Epoch 10/20
624/624 [=====] - 4s 6ms/step - loss: 1.3489 - accuracy: 0.4766 - val_loss: 1.4417 - val_accuracy: 0.4310
Epoch 11/20
624/624 [=====] - 3s 5ms/step - loss: 1.3044 - accuracy: 0.4935 - val_loss: 1.4404 - val_accuracy: 0.4386
Epoch 12/20
624/624 [=====] - 3s 5ms/step - loss: 1.2666 - accuracy: 0.5079 - val_loss: 1.4281 - val_accuracy: 0.4467
Epoch 13/20
624/624 [=====] - 4s 6ms/step - loss: 1.2162 - accuracy: 0.5256 - val_loss: 1.4299 - val_accuracy: 0.4438
Epoch 14/20
624/624 [=====] - 3s 5ms/step - loss: 1.1822 - accuracy: 0.5430 - val_loss: 1.4245 - val_accuracy: 0.4557
Epoch 15/20
624/624 [=====] - 3s 5ms/step - loss: 1.1437 - accuracy: 0.5545 - val_loss: 1.4338 - val_accuracy: 0.4605
Epoch 16/20
624/624 [=====] - 3s 5ms/step - loss: 1.1078 - accuracy: 0.5678 - val_loss: 1.4427 - val_accuracy: 0.4543
Epoch 17/20
624/624 [=====] - 3s 5ms/step - loss: 1.0759 - accuracy: 0.5809 - val_loss: 1.4760 - val_accuracy: 0.4419
Epoch 18/20
624/624 [=====] - 3s 5ms/step - loss: 1.0463 - accuracy: 0.5921 - val_loss: 1.4738 - val_accuracy: 0.4505
Epoch 19/20
624/624 [=====] - 3s 5ms/step - loss: 1.0174 - accuracy: 0.6019 - val_loss: 1.4795 - val_accuracy: 0.4548
Epoch 20/20
624/624 [=====] - 3s 5ms/step - loss: 0.9837 - accuracy: 0.6184 - val_loss: 1.4871 - val_accuracy: 0.4514
```

- b. Training on best Learning Rate (I chose 0.001 LR as it has highest val_accuracy above all other LR's)

```
Epoch 1/15
12469/12469 [=====] - 77s 5ms/step - loss: 1.4919 - accuracy: 0.3846 - val_loss: 1.2850 - val_accuracy: 0.4682
Epoch 2/15
12469/12469 [=====] - 64s 5ms/step - loss: 1.3362 - accuracy: 0.4477 - val_loss: 1.2161 - val_accuracy: 0.4974
Epoch 3/15
12469/12469 [=====] - 64s 5ms/step - loss: 1.2973 - accuracy: 0.4633 - val_loss: 1.1978 - val_accuracy: 0.5074
Epoch 4/15
12469/12469 [=====] - 64s 5ms/step - loss: 1.2750 - accuracy: 0.4731 - val_loss: 1.1943 - val_accuracy: 0.5072
Epoch 5/15
12469/12469 [=====] - 64s 5ms/step - loss: 1.2612 - accuracy: 0.4774 - val_loss: 1.1742 - val_accuracy: 0.5132
Epoch 6/15
12469/12469 [=====] - 63s 5ms/step - loss: 1.2523 - accuracy: 0.4806 - val_loss: 1.1902 - val_accuracy: 0.5100
Epoch 7/15
12469/12469 [=====] - 63s 5ms/step - loss: 1.2454 - accuracy: 0.4838 - val_loss: 1.1729 - val_accuracy: 0.5170
Epoch 8/15
12469/12469 [=====] - 64s 5ms/step - loss: 1.2389 - accuracy: 0.4860 - val_loss: 1.1678 - val_accuracy: 0.5192
Epoch 9/15
12469/12469 [=====] - 65s 5ms/step - loss: 1.2332 - accuracy: 0.4884 - val_loss: 1.1659 - val_accuracy: 0.5179
Epoch 10/15
12469/12469 [=====] - 63s 5ms/step - loss: 1.2295 - accuracy: 0.4892 - val_loss: 1.1925 - val_accuracy: 0.5043
Epoch 11/15
12469/12469 [=====] - 63s 5ms/step - loss: 1.2247 - accuracy: 0.4916 - val_loss: 1.1709 - val_accuracy: 0.5167
Epoch 12/15
12469/12469 [=====] - 63s 5ms/step - loss: 1.2205 - accuracy: 0.4927 - val_loss: 1.1819 - val_accuracy: 0.5154
Epoch 13/15
12469/12469 [=====] - 64s 5ms/step - loss: 1.2172 - accuracy: 0.4943 - val_loss: 1.1680 - val_accuracy: 0.5177
Epoch 14/15
12469/12469 [=====] - 63s 5ms/step - loss: 1.2144 - accuracy: 0.4949 - val_loss: 1.1753 - val_accuracy: 0.5165
Epoch 15/15
12469/12469 [=====] - 63s 5ms/step - loss: 1.2114 - accuracy: 0.4968 - val_loss: 1.1652 - val_accuracy: 0.5242
```



Vanilla RNN

4. Raw + Derivative

a. Hyperparameter tuning (5% of validation set)

i. Learning Rate : 0.1

```
Epoch 1/10
624/624 [=====] - 4s 6ms/step - loss: 2.3637 - accuracy: 0.1479 - val_loss: 2.3817 - val_accuracy: 0.1376
Epoch 2/10
624/624 [=====] - 4s 6ms/step - loss: 2.3600 - accuracy: 0.1483 - val_loss: 2.4032 - val_accuracy: 0.1476
Epoch 3/10
624/624 [=====] - 3s 6ms/step - loss: 2.3730 - accuracy: 0.1458 - val_loss: 2.3908 - val_accuracy: 0.1471
Epoch 4/10
624/624 [=====] - 3s 6ms/step - loss: 2.3641 - accuracy: 0.1494 - val_loss: 2.3922 - val_accuracy: 0.1414
Epoch 5/10
624/624 [=====] - 3s 6ms/step - loss: 2.3612 - accuracy: 0.1486 - val_loss: 2.3815 - val_accuracy: 0.1371
Epoch 6/10
624/624 [=====] - 3s 6ms/step - loss: 2.3474 - accuracy: 0.1500 - val_loss: 2.3890 - val_accuracy: 0.1471
Epoch 7/10
624/624 [=====] - 3s 6ms/step - loss: 2.3620 - accuracy: 0.1469 - val_loss: 2.4286 - val_accuracy: 0.1443
Epoch 8/10
624/624 [=====] - 4s 6ms/step - loss: 2.3698 - accuracy: 0.1473 - val_loss: 2.4983 - val_accuracy: 0.1448
Epoch 9/10
624/624 [=====] - 4s 6ms/step - loss: 2.3804 - accuracy: 0.1466 - val_loss: 2.4950 - val_accuracy: 0.1262
Epoch 10/10
624/624 [=====] - 4s 6ms/step - loss: 2.3737 - accuracy: 0.1455 - val_loss: 2.4750 - val_accuracy: 0.1410
```

ii. Learning Rate : 0.01

```
Epoch 1/10
624/624 [=====] - 4s 6ms/step - loss: 2.0895 - accuracy: 0.1881 - val_loss: 2.0064 - val_accuracy: 0.2100
Epoch 2/10
624/624 [=====] - 4s 6ms/step - loss: 1.9744 - accuracy: 0.2146 - val_loss: 1.9746 - val_accuracy: 0.2157
Epoch 3/10
624/624 [=====] - 4s 6ms/step - loss: 1.9358 - accuracy: 0.2273 - val_loss: 1.9450 - val_accuracy: 0.2252
Epoch 4/10
624/624 [=====] - 4s 6ms/step - loss: 1.9143 - accuracy: 0.2338 - val_loss: 1.9403 - val_accuracy: 0.2286
Epoch 5/10
624/624 [=====] - 4s 6ms/step - loss: 1.9027 - accuracy: 0.2371 - val_loss: 1.9297 - val_accuracy: 0.2329
Epoch 6/10
624/624 [=====] - 4s 6ms/step - loss: 1.8904 - accuracy: 0.2418 - val_loss: 1.9349 - val_accuracy: 0.2286
Epoch 7/10
624/624 [=====] - 4s 6ms/step - loss: 1.8833 - accuracy: 0.2453 - val_loss: 1.9339 - val_accuracy: 0.2286
Epoch 8/10
624/624 [=====] - 4s 6ms/step - loss: 1.8746 - accuracy: 0.2472 - val_loss: 1.9441 - val_accuracy: 0.2405
Epoch 9/10
624/624 [=====] - 4s 6ms/step - loss: 1.8714 - accuracy: 0.2510 - val_loss: 1.9384 - val_accuracy: 0.2390
Epoch 10/10
624/624 [=====] - 4s 6ms/step - loss: 1.8663 - accuracy: 0.2487 - val_loss: 1.9629 - val_accuracy: 0.2243
```

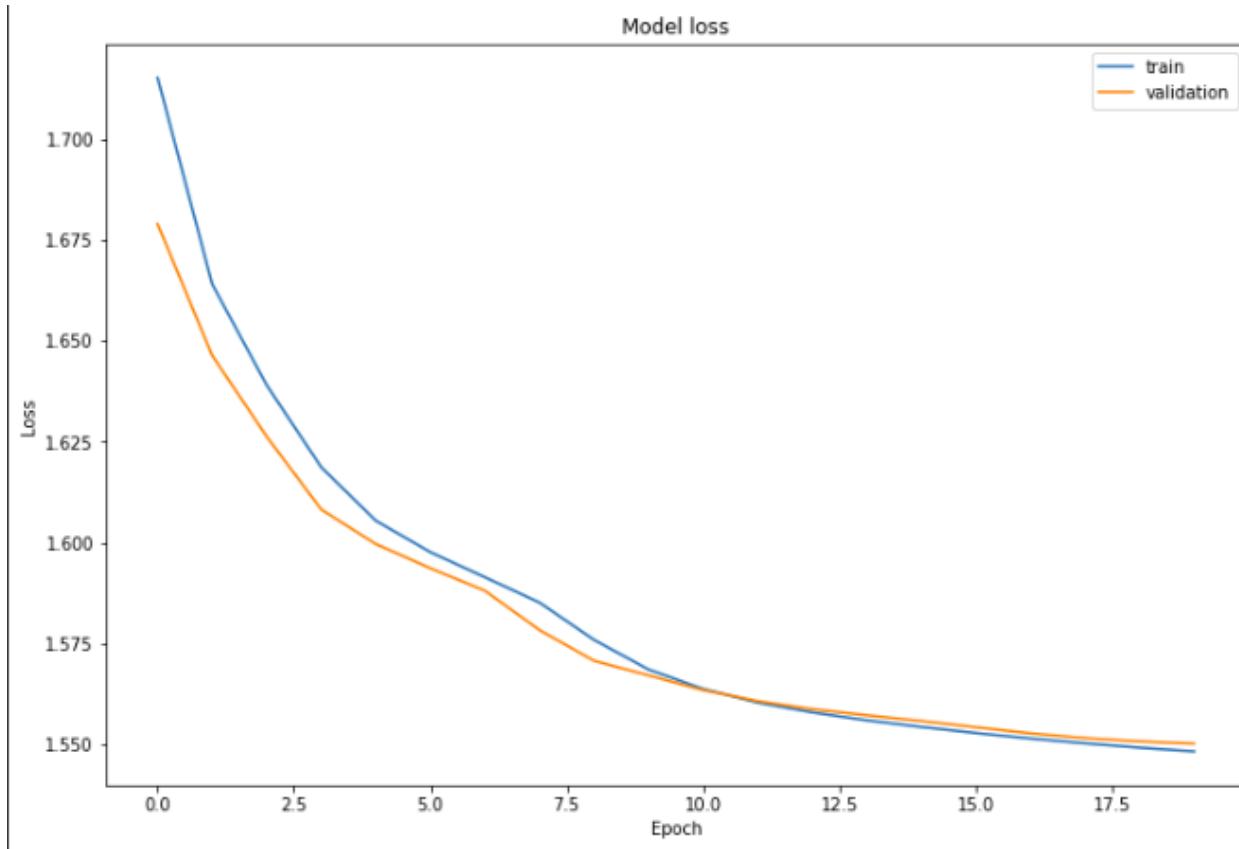
iii. Learning Rate : 0.001

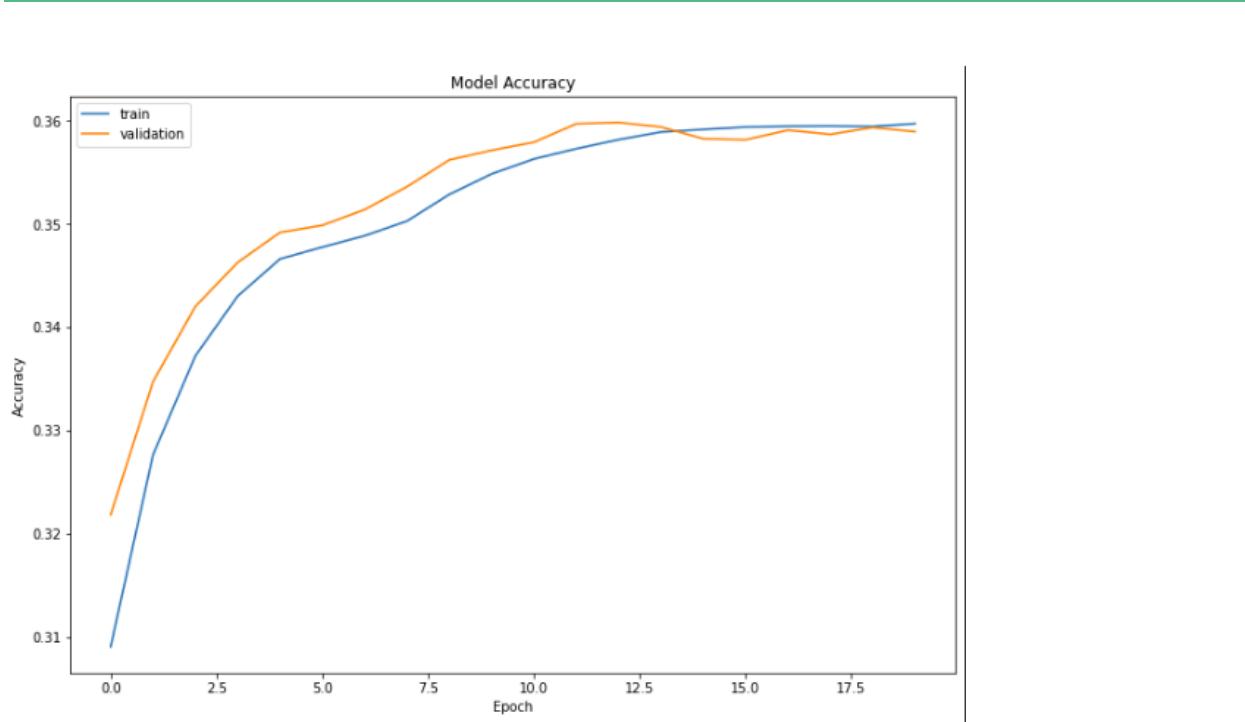
```
Epoch 1/10
624/624 [=====] - 4s 6ms/step - loss: 2.2051 - accuracy: 0.1563 - val_loss: 2.1422 - val_accuracy: 0.1633
Epoch 2/10
624/624 [=====] - 3s 6ms/step - loss: 2.0985 - accuracy: 0.1843 - val_loss: 2.0902 - val_accuracy: 0.1776
Epoch 3/10
624/624 [=====] - 4s 6ms/step - loss: 2.0408 - accuracy: 0.1995 - val_loss: 2.0309 - val_accuracy: 0.1910
Epoch 4/10
624/624 [=====] - 4s 6ms/step - loss: 1.9851 - accuracy: 0.2146 - val_loss: 1.9857 - val_accuracy: 0.2100
Epoch 5/10
624/624 [=====] - 4s 6ms/step - loss: 1.9488 - accuracy: 0.2258 - val_loss: 1.9633 - val_accuracy: 0.2252
Epoch 6/10
624/624 [=====] - 4s 6ms/step - loss: 1.9271 - accuracy: 0.2321 - val_loss: 1.9508 - val_accuracy: 0.2286
Epoch 7/10
624/624 [=====] - 3s 6ms/step - loss: 1.9109 - accuracy: 0.2361 - val_loss: 1.9418 - val_accuracy: 0.2319
Epoch 8/10
624/624 [=====] - 4s 6ms/step - loss: 1.8977 - accuracy: 0.2388 - val_loss: 1.9339 - val_accuracy: 0.2371
Epoch 9/10
624/624 [=====] - 4s 6ms/step - loss: 1.8862 - accuracy: 0.2429 - val_loss: 1.9268 - val_accuracy: 0.2410
Epoch 10/10
624/624 [=====] - 4s 6ms/step - loss: 1.8759 - accuracy: 0.2470 - val_loss: 1.9204 - val_accuracy: 0.2519
```

iv. Learning Rate : 0.0001

```
Epoch 1/10
624/624 [=====] - 4s 6ms/step - loss: 2.3961 - accuracy: 0.1327 - val_loss: 2.3586 - val_accuracy: 0.1329
Epoch 2/10
624/624 [=====] - 3s 6ms/step - loss: 2.3171 - accuracy: 0.1417 - val_loss: 2.3045 - val_accuracy: 0.1390
Epoch 3/10
624/624 [=====] - 4s 6ms/step - loss: 2.2659 - accuracy: 0.1504 - val_loss: 2.2619 - val_accuracy: 0.1414
Epoch 4/10
624/624 [=====] - 4s 6ms/step - loss: 2.2258 - accuracy: 0.1539 - val_loss: 2.2308 - val_accuracy: 0.1467
Epoch 5/10
624/624 [=====] - 3s 6ms/step - loss: 2.1979 - accuracy: 0.1581 - val_loss: 2.2095 - val_accuracy: 0.1500
Epoch 6/10
624/624 [=====] - 3s 6ms/step - loss: 2.1790 - accuracy: 0.1585 - val_loss: 2.1944 - val_accuracy: 0.1571
Epoch 7/10
624/624 [=====] - 4s 6ms/step - loss: 2.1652 - accuracy: 0.1600 - val_loss: 2.1832 - val_accuracy: 0.1581
Epoch 8/10
624/624 [=====] - 4s 6ms/step - loss: 2.1545 - accuracy: 0.1632 - val_loss: 2.1742 - val_accuracy: 0.1590
Epoch 9/10
624/624 [=====] - 4s 6ms/step - loss: 2.1455 - accuracy: 0.1679 - val_loss: 2.1667 - val_accuracy: 0.1629
Epoch 10/10
624/624 [=====] - 4s 6ms/step - loss: 2.1377 - accuracy: 0.1726 - val_loss: 2.1600 - val_accuracy: 0.1667
```

-
- b. Training (70 % of total data) on best Learning Rate (I chose 0.001 LR as it has highest val_accuracy above all other LR's)





```

Epoch 1/20
12469/12469 [=====] - 75s 6ms/step - loss: 1.7153 - accuracy: 0.3091 - val_loss: 1.6790 - val_accuracy: 0.3219
Epoch 2/20
12469/12469 [=====] - 73s 6ms/step - loss: 1.6641 - accuracy: 0.3277 - val_loss: 1.6464 - val_accuracy: 0.3347
Epoch 3/20
12469/12469 [=====] - 72s 6ms/step - loss: 1.6390 - accuracy: 0.3372 - val_loss: 1.6263 - val_accuracy: 0.3420
Epoch 4/20
12469/12469 [=====] - 72s 6ms/step - loss: 1.6187 - accuracy: 0.3430 - val_loss: 1.6082 - val_accuracy: 0.3463
Epoch 5/20
12469/12469 [=====] - 72s 6ms/step - loss: 1.6054 - accuracy: 0.3466 - val_loss: 1.5996 - val_accuracy: 0.3492
Epoch 6/20
12469/12469 [=====] - 72s 6ms/step - loss: 1.5976 - accuracy: 0.3478 - val_loss: 1.5936 - val_accuracy: 0.3499
Epoch 7/20
12469/12469 [=====] - 71s 6ms/step - loss: 1.5914 - accuracy: 0.3489 - val_loss: 1.5881 - val_accuracy: 0.3514
Epoch 8/20
12469/12469 [=====] - 72s 6ms/step - loss: 1.5851 - accuracy: 0.3503 - val_loss: 1.5783 - val_accuracy: 0.3536
Epoch 9/20
12469/12469 [=====] - 72s 6ms/step - loss: 1.5759 - accuracy: 0.3529 - val_loss: 1.5707 - val_accuracy: 0.3562
Epoch 10/20
12469/12469 [=====] - 71s 6ms/step - loss: 1.5685 - accuracy: 0.3549 - val_loss: 1.5671 - val_accuracy: 0.3571
Epoch 11/20
12469/12469 [=====] - 72s 6ms/step - loss: 1.5637 - accuracy: 0.3563 - val_loss: 1.5634 - val_accuracy: 0.3579
Epoch 12/20
12469/12469 [=====] - 73s 6ms/step - loss: 1.5603 - accuracy: 0.3573 - val_loss: 1.5607 - val_accuracy: 0.3597
Epoch 13/20
12469/12469 [=====] - 74s 6ms/step - loss: 1.5579 - accuracy: 0.3582 - val_loss: 1.5587 - val_accuracy: 0.3598
Epoch 14/20
12469/12469 [=====] - 72s 6ms/step - loss: 1.5559 - accuracy: 0.3589 - val_loss: 1.5572 - val_accuracy: 0.3594
Epoch 15/20
12469/12469 [=====] - 72s 6ms/step - loss: 1.5543 - accuracy: 0.3592 - val_loss: 1.5558 - val_accuracy: 0.3583
Epoch 16/20
12469/12469 [=====] - 73s 6ms/step - loss: 1.5528 - accuracy: 0.3594 - val_loss: 1.5542 - val_accuracy: 0.3582
Epoch 17/20
12469/12469 [=====] - 71s 6ms/step - loss: 1.5514 - accuracy: 0.3595 - val_loss: 1.5527 - val_accuracy: 0.3591
Epoch 18/20
12469/12469 [=====] - 72s 6ms/step - loss: 1.5502 - accuracy: 0.3595 - val_loss: 1.5515 - val_accuracy: 0.3587
Epoch 19/20
12469/12469 [=====] - 71s 6ms/step - loss: 1.5492 - accuracy: 0.3595 - val_loss: 1.5507 - val_accuracy: 0.3594
Epoch 20/20
12469/12469 [=====] - 71s 6ms/step - loss: 1.5482 - accuracy: 0.3597 - val_loss: 1.5501 - val_accuracy: 0.3590

```

5. Raw + Integration

a. Hyperparameter tuning (5% of validation set)

i. Learning Rate : 0.1

```
Epoch 1/15
624/624 [=====] - 7s 6ms/step - loss: 2.2672 - accuracy: 0.1494 - val_loss: 2.4009 - val_accuracy: 0.1471
Epoch 2/15
624/624 [=====] - 4s 6ms/step - loss: 2.2991 - accuracy: 0.1451 - val_loss: 2.5291 - val_accuracy: 0.1481
Epoch 3/15
624/624 [=====] - 4s 6ms/step - loss: 2.2698 - accuracy: 0.1454 - val_loss: 2.5255 - val_accuracy: 0.1429
Epoch 4/15
624/624 [=====] - 5s 9ms/step - loss: 2.2695 - accuracy: 0.1442 - val_loss: 2.5302 - val_accuracy: 0.1419
Epoch 5/15
624/624 [=====] - 4s 6ms/step - loss: 2.2685 - accuracy: 0.1446 - val_loss: 2.5293 - val_accuracy: 0.1424
Epoch 6/15
624/624 [=====] - 4s 6ms/step - loss: 2.2674 - accuracy: 0.1435 - val_loss: 2.5345 - val_accuracy: 0.1429
Epoch 7/15
624/624 [=====] - 4s 7ms/step - loss: 2.2674 - accuracy: 0.1442 - val_loss: 2.5358 - val_accuracy: 0.1419
Epoch 8/15
624/624 [=====] - 4s 6ms/step - loss: 2.2690 - accuracy: 0.1442 - val_loss: 2.5186 - val_accuracy: 0.1419
Epoch 9/15
624/624 [=====] - 4s 6ms/step - loss: 2.2715 - accuracy: 0.1438 - val_loss: 2.5317 - val_accuracy: 0.1419
Epoch 10/15
624/624 [=====] - 4s 6ms/step - loss: 2.2716 - accuracy: 0.1445 - val_loss: 2.5527 - val_accuracy: 0.1414
Epoch 11/15
624/624 [=====] - 4s 6ms/step - loss: 2.2668 - accuracy: 0.1442 - val_loss: 2.5600 - val_accuracy: 0.1390
Epoch 12/15
624/624 [=====] - 4s 7ms/step - loss: 2.2690 - accuracy: 0.1435 - val_loss: 2.5579 - val_accuracy: 0.1386
Epoch 13/15
624/624 [=====] - 4s 6ms/step - loss: 2.2711 - accuracy: 0.1448 - val_loss: 2.5248 - val_accuracy: 0.1419
Epoch 14/15
624/624 [=====] - 4s 6ms/step - loss: 2.2704 - accuracy: 0.1431 - val_loss: 2.5374 - val_accuracy: 0.1419
Epoch 15/15
624/624 [=====] - 4s 6ms/step - loss: 2.2718 - accuracy: 0.1446 - val_loss: 2.5501 - val_accuracy: 0.1424
```

ii. Learning Rate : 0.01

```
Epoch 1/15
624/624 [=====] - 5s 7ms/step - loss: 2.1490 - accuracy: 0.1599 - val_loss: 2.1400 - val_accuracy: 0.1662
Epoch 2/15
624/624 [=====] - 4s 7ms/step - loss: 2.0967 - accuracy: 0.1799 - val_loss: 2.1118 - val_accuracy: 0.1695
Epoch 3/15
624/624 [=====] - 4s 7ms/step - loss: 2.0750 - accuracy: 0.1891 - val_loss: 2.0985 - val_accuracy: 0.1824
Epoch 4/15
624/624 [=====] - 4s 7ms/step - loss: 2.0388 - accuracy: 0.2056 - val_loss: 2.0552 - val_accuracy: 0.1971
Epoch 5/15
624/624 [=====] - 4s 7ms/step - loss: 2.0007 - accuracy: 0.2190 - val_loss: 2.0200 - val_accuracy: 0.2181
Epoch 6/15
624/624 [=====] - 4s 7ms/step - loss: 1.9717 - accuracy: 0.2306 - val_loss: 1.9908 - val_accuracy: 0.2281
Epoch 7/15
624/624 [=====] - 4s 6ms/step - loss: 1.9449 - accuracy: 0.2404 - val_loss: 1.9549 - val_accuracy: 0.2414
Epoch 8/15
624/624 [=====] - 4s 6ms/step - loss: 1.9244 - accuracy: 0.2474 - val_loss: 1.9422 - val_accuracy: 0.2538
Epoch 9/15
624/624 [=====] - 4s 6ms/step - loss: 1.9094 - accuracy: 0.2524 - val_loss: 1.9365 - val_accuracy: 0.2590
Epoch 10/15
624/624 [=====] - 4s 6ms/step - loss: 1.8966 - accuracy: 0.2554 - val_loss: 1.9362 - val_accuracy: 0.2590
Epoch 11/15
624/624 [=====] - 4s 6ms/step - loss: 1.8855 - accuracy: 0.2602 - val_loss: 1.9370 - val_accuracy: 0.2576
Epoch 12/15
624/624 [=====] - 4s 6ms/step - loss: 1.8757 - accuracy: 0.2646 - val_loss: 1.9341 - val_accuracy: 0.2562
Epoch 13/15
624/624 [=====] - 4s 6ms/step - loss: 1.8673 - accuracy: 0.2675 - val_loss: 1.9286 - val_accuracy: 0.2567
Epoch 14/15
624/624 [=====] - 4s 6ms/step - loss: 1.8603 - accuracy: 0.2694 - val_loss: 1.9257 - val_accuracy: 0.2590
Epoch 15/15
624/624 [=====] - 4s 6ms/step - loss: 1.8542 - accuracy: 0.2706 - val_loss: 1.9244 - val_accuracy: 0.2614
```

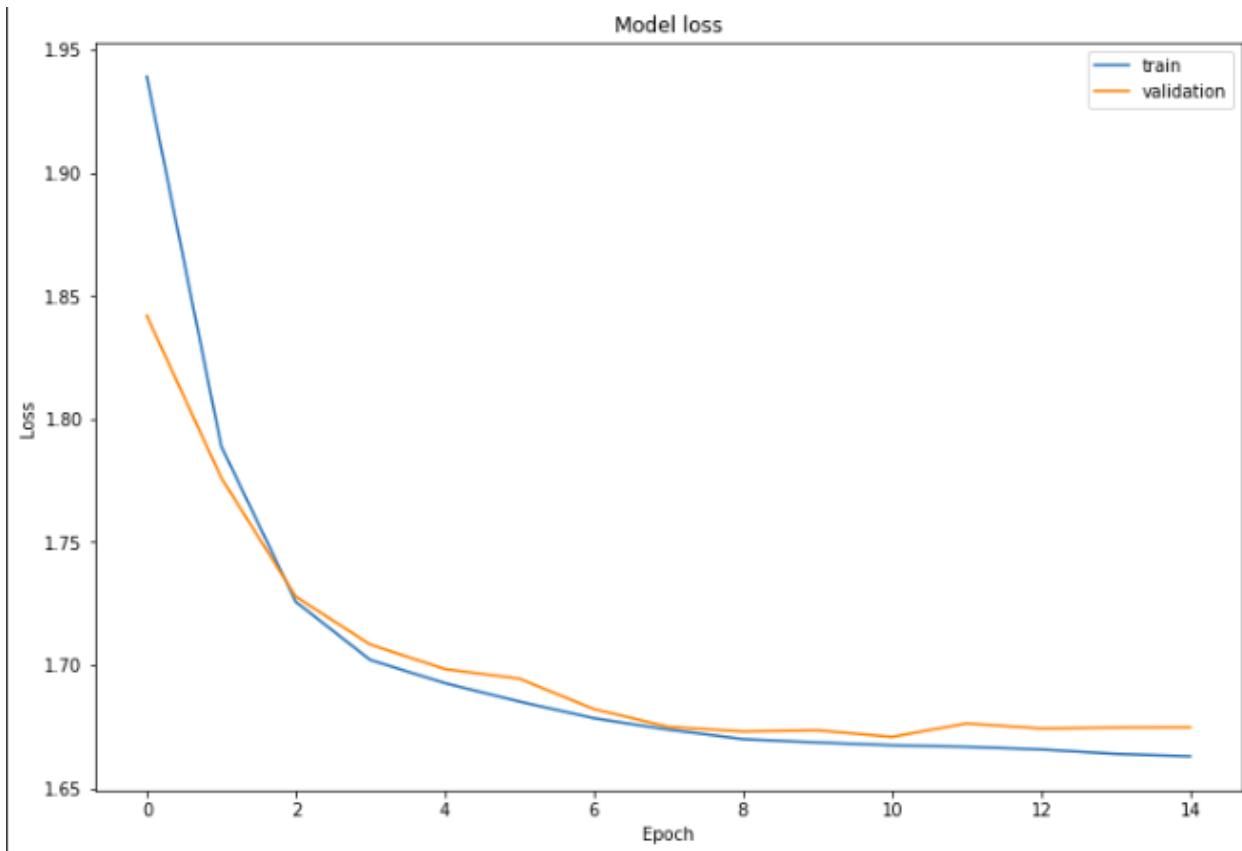
iii. Learning Rate : 0.001

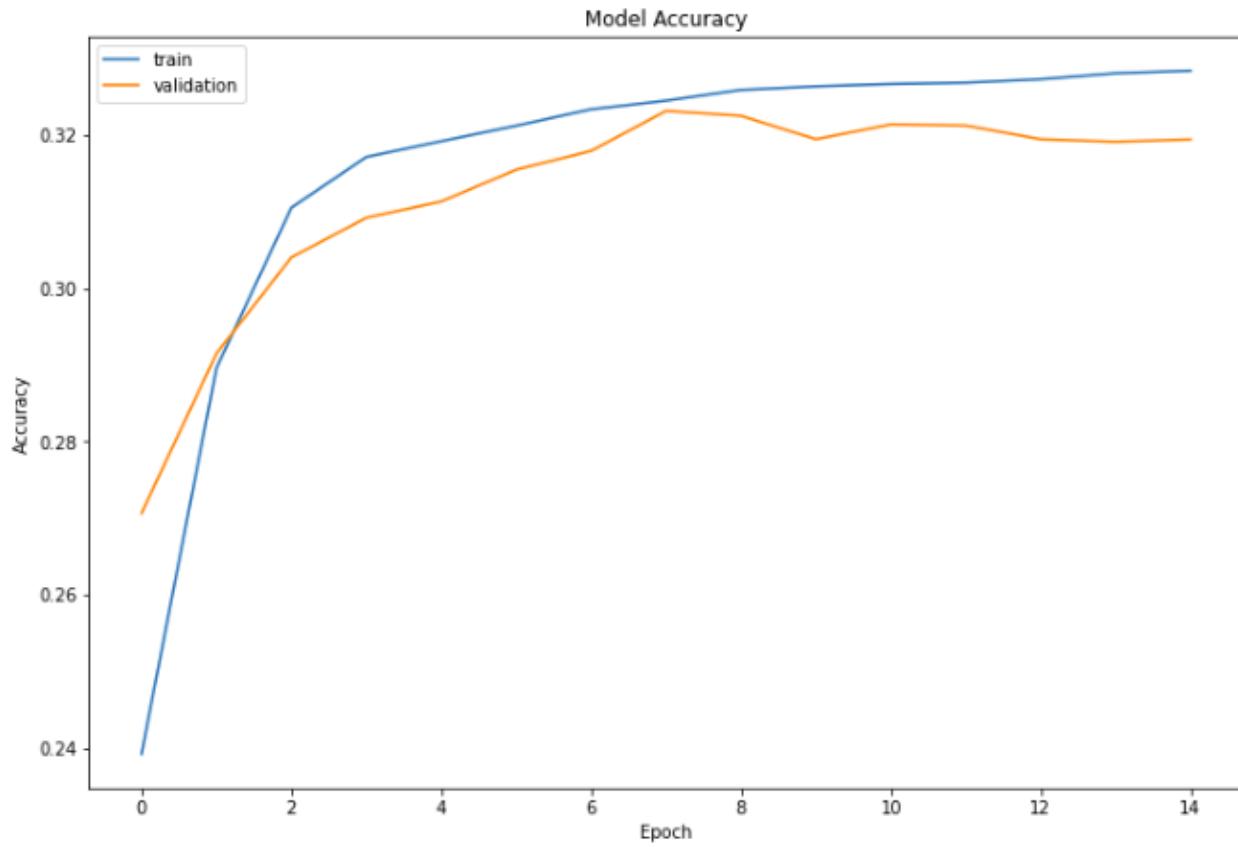
```
Epoch 1/15
624/624 [=====] - 5s 7ms/step - loss: 2.2600 - accuracy: 0.1405 - val_loss: 2.2002 - val_accuracy: 0.1605
Epoch 2/15
624/624 [=====] - 4s 6ms/step - loss: 2.1688 - accuracy: 0.1566 - val_loss: 2.1680 - val_accuracy: 0.1548
Epoch 3/15
624/624 [=====] - 4s 6ms/step - loss: 2.1429 - accuracy: 0.1627 - val_loss: 2.1463 - val_accuracy: 0.1614
Epoch 4/15
624/624 [=====] - 4s 6ms/step - loss: 2.1229 - accuracy: 0.1692 - val_loss: 2.1300 - val_accuracy: 0.1629
Epoch 5/15
624/624 [=====] - 4s 6ms/step - loss: 2.1109 - accuracy: 0.1716 - val_loss: 2.1208 - val_accuracy: 0.1633
Epoch 6/15
624/624 [=====] - 4s 6ms/step - loss: 2.1031 - accuracy: 0.1757 - val_loss: 2.1140 - val_accuracy: 0.1700
Epoch 7/15
624/624 [=====] - 4s 6ms/step - loss: 2.0975 - accuracy: 0.1783 - val_loss: 2.1090 - val_accuracy: 0.1700
Epoch 8/15
624/624 [=====] - 4s 6ms/step - loss: 2.0935 - accuracy: 0.1805 - val_loss: 2.1053 - val_accuracy: 0.1705
Epoch 9/15
624/624 [=====] - 4s 6ms/step - loss: 2.0905 - accuracy: 0.1831 - val_loss: 2.1023 - val_accuracy: 0.1767
Epoch 10/15
624/624 [=====] - 4s 6ms/step - loss: 2.0880 - accuracy: 0.1848 - val_loss: 2.0997 - val_accuracy: 0.1800
Epoch 11/15
624/624 [=====] - 4s 6ms/step - loss: 2.0857 - accuracy: 0.1867 - val_loss: 2.0972 - val_accuracy: 0.1810
Epoch 12/15
624/624 [=====] - 4s 6ms/step - loss: 2.0835 - accuracy: 0.1875 - val_loss: 2.0948 - val_accuracy: 0.1805
Epoch 13/15
624/624 [=====] - 4s 6ms/step - loss: 2.0814 - accuracy: 0.1896 - val_loss: 2.0924 - val_accuracy: 0.1800
Epoch 14/15
624/624 [=====] - 4s 6ms/step - loss: 2.0793 - accuracy: 0.1910 - val_loss: 2.0899 - val_accuracy: 0.1814
Epoch 15/15
624/624 [=====] - 4s 6ms/step - loss: 2.0770 - accuracy: 0.1930 - val_loss: 2.0874 - val_accuracy: 0.1810
```

iv. Learning Rate : 0.0001

```
Epoch 1/15
624/624 [=====] - 5s 7ms/step - loss: 2.3649 - accuracy: 0.0999 - val_loss: 2.3291 - val_accuracy: 0.1014
Epoch 2/15
624/624 [=====] - 4s 6ms/step - loss: 2.3100 - accuracy: 0.1041 - val_loss: 2.2965 - val_accuracy: 0.1371
Epoch 3/15
624/624 [=====] - 4s 6ms/step - loss: 2.2901 - accuracy: 0.1520 - val_loss: 2.2833 - val_accuracy: 0.1519
Epoch 4/15
624/624 [=====] - 4s 6ms/step - loss: 2.2773 - accuracy: 0.1496 - val_loss: 2.2698 - val_accuracy: 0.1543
Epoch 5/15
624/624 [=====] - 4s 6ms/step - loss: 2.2627 - accuracy: 0.1498 - val_loss: 2.2539 - val_accuracy: 0.1581
Epoch 6/15
624/624 [=====] - 4s 6ms/step - loss: 2.2462 - accuracy: 0.1485 - val_loss: 2.2365 - val_accuracy: 0.1557
Epoch 7/15
624/624 [=====] - 4s 6ms/step - loss: 2.2295 - accuracy: 0.1475 - val_loss: 2.2204 - val_accuracy: 0.1481
Epoch 8/15
624/624 [=====] - 5s 9ms/step - loss: 2.2149 - accuracy: 0.1476 - val_loss: 2.2074 - val_accuracy: 0.1471
Epoch 9/15
624/624 [=====] - 4s 6ms/step - loss: 2.2029 - accuracy: 0.1484 - val_loss: 2.1975 - val_accuracy: 0.1519
Epoch 10/15
624/624 [=====] - 4s 6ms/step - loss: 2.1932 - accuracy: 0.1502 - val_loss: 2.1897 - val_accuracy: 0.1529
Epoch 11/15
624/624 [=====] - 4s 6ms/step - loss: 2.1848 - accuracy: 0.1514 - val_loss: 2.1833 - val_accuracy: 0.1519
Epoch 12/15
624/624 [=====] - 4s 6ms/step - loss: 2.1775 - accuracy: 0.1543 - val_loss: 2.1778 - val_accuracy: 0.1552
Epoch 13/15
624/624 [=====] - 4s 7ms/step - loss: 2.1710 - accuracy: 0.1567 - val_loss: 2.1732 - val_accuracy: 0.1500
Epoch 14/15
624/624 [=====] - 4s 6ms/step - loss: 2.1653 - accuracy: 0.1601 - val_loss: 2.1693 - val_accuracy: 0.1529
Epoch 15/15
624/624 [=====] - 4s 6ms/step - loss: 2.1603 - accuracy: 0.1624 - val_loss: 2.1658 - val_accuracy: 0.1543
```

-
- b. Training (70 % of total data) on best Learning Rate (I chose 0.01 LR as it has highest val_accuracy above all other LR's)





```
Epoch 1/15
12469/12469 [=====] - 80s 6ms/step - loss: 1.9391 - accuracy: 0.2393 - val_loss: 1.8419 - val_accuracy: 0.2707
Epoch 2/15
12469/12469 [=====] - 73s 6ms/step - loss: 1.7889 - accuracy: 0.2896 - val_loss: 1.7761 - val_accuracy: 0.2915
Epoch 3/15
12469/12469 [=====] - 74s 6ms/step - loss: 1.7257 - accuracy: 0.3105 - val_loss: 1.7278 - val_accuracy: 0.3040
Epoch 4/15
12469/12469 [=====] - 73s 6ms/step - loss: 1.7021 - accuracy: 0.3171 - val_loss: 1.7083 - val_accuracy: 0.3092
Epoch 5/15
12469/12469 [=====] - 75s 6ms/step - loss: 1.6927 - accuracy: 0.3191 - val_loss: 1.6984 - val_accuracy: 0.3113
Epoch 6/15
12469/12469 [=====] - 71s 6ms/step - loss: 1.6852 - accuracy: 0.3212 - val_loss: 1.6945 - val_accuracy: 0.3154
Epoch 7/15
12469/12469 [=====] - 74s 6ms/step - loss: 1.6784 - accuracy: 0.3233 - val_loss: 1.6821 - val_accuracy: 0.3179
Epoch 8/15
12469/12469 [=====] - 72s 6ms/step - loss: 1.6738 - accuracy: 0.3244 - val_loss: 1.6749 - val_accuracy: 0.3231
Epoch 9/15
12469/12469 [=====] - 71s 6ms/step - loss: 1.6699 - accuracy: 0.3258 - val_loss: 1.6730 - val_accuracy: 0.3225
Epoch 10/15
12469/12469 [=====] - 73s 6ms/step - loss: 1.6686 - accuracy: 0.3263 - val_loss: 1.6735 - val_accuracy: 0.3194
Epoch 11/15
12469/12469 [=====] - 71s 6ms/step - loss: 1.6674 - accuracy: 0.3266 - val_loss: 1.6708 - val_accuracy: 0.3213
Epoch 12/15
12469/12469 [=====] - 71s 6ms/step - loss: 1.6668 - accuracy: 0.3268 - val_loss: 1.6763 - val_accuracy: 0.3212
Epoch 13/15
12469/12469 [=====] - 72s 6ms/step - loss: 1.6657 - accuracy: 0.3272 - val_loss: 1.6743 - val_accuracy: 0.3194
Epoch 14/15
12469/12469 [=====] - 71s 6ms/step - loss: 1.6639 - accuracy: 0.3280 - val_loss: 1.6746 - val_accuracy: 0.3191
Epoch 15/15
12469/12469 [=====] - 73s 6ms/step - loss: 1.6630 - accuracy: 0.3283 - val_loss: 1.6747 - val_accuracy: 0.3194
```

6. Derivative + Integration

a. Hyperparameter tuning (5% of validation set)

i. Learning Rate : 0.1

```
Epoch 1/15
624/624 [=====] - 7s 6ms/step - loss: 2.3003 - accuracy: 0.1573 - val_loss: 2.3636 - val_accuracy: 0.1538
Epoch 2/15
624/624 [=====] - 3s 6ms/step - loss: 2.3171 - accuracy: 0.1556 - val_loss: 2.3735 - val_accuracy: 0.1352
Epoch 3/15
624/624 [=====] - 4s 6ms/step - loss: 2.3366 - accuracy: 0.1483 - val_loss: 2.3519 - val_accuracy: 0.1490
Epoch 4/15
624/624 [=====] - 4s 6ms/step - loss: 2.3442 - accuracy: 0.1477 - val_loss: 2.4220 - val_accuracy: 0.1462
Epoch 5/15
624/624 [=====] - 4s 6ms/step - loss: 2.3436 - accuracy: 0.1501 - val_loss: 2.3461 - val_accuracy: 0.1510
Epoch 6/15
624/624 [=====] - 4s 6ms/step - loss: 2.3378 - accuracy: 0.1489 - val_loss: 2.3470 - val_accuracy: 0.1352
Epoch 7/15
624/624 [=====] - 4s 6ms/step - loss: 2.3576 - accuracy: 0.1445 - val_loss: 2.3875 - val_accuracy: 0.1452
Epoch 8/15
624/624 [=====] - 4s 6ms/step - loss: 2.3616 - accuracy: 0.1482 - val_loss: 2.3474 - val_accuracy: 0.1314
Epoch 9/15
624/624 [=====] - 4s 6ms/step - loss: 2.3608 - accuracy: 0.1430 - val_loss: 2.4495 - val_accuracy: 0.1452
Epoch 10/15
624/624 [=====] - 4s 6ms/step - loss: 2.3904 - accuracy: 0.1434 - val_loss: 2.4491 - val_accuracy: 0.1405
Epoch 11/15
624/624 [=====] - 4s 6ms/step - loss: 2.3838 - accuracy: 0.1466 - val_loss: 2.5079 - val_accuracy: 0.1386
Epoch 12/15
624/624 [=====] - 4s 6ms/step - loss: 2.3754 - accuracy: 0.1482 - val_loss: 2.3940 - val_accuracy: 0.1414
Epoch 13/15
624/624 [=====] - 4s 6ms/step - loss: 2.3744 - accuracy: 0.1479 - val_loss: 2.4114 - val_accuracy: 0.1419
Epoch 14/15
624/624 [=====] - 4s 6ms/step - loss: 2.3743 - accuracy: 0.1455 - val_loss: 2.4218 - val_accuracy: 0.1381
Epoch 15/15
624/624 [=====] - 4s 6ms/step - loss: 2.3722 - accuracy: 0.1435 - val_loss: 2.3977 - val_accuracy: 0.1381
```

ii. Learning Rate : 0.01

```
Epoch 1/15
624/624 [=====] - 4s 6ms/step - loss: 2.0807 - accuracy: 0.1905 - val_loss: 2.0218 - val_accuracy: 0.2067
Epoch 2/15
624/624 [=====] - 4s 6ms/step - loss: 1.9592 - accuracy: 0.2225 - val_loss: 1.9772 - val_accuracy: 0.2271
Epoch 3/15
624/624 [=====] - 4s 6ms/step - loss: 1.9230 - accuracy: 0.2310 - val_loss: 1.9669 - val_accuracy: 0.2290
Epoch 4/15
624/624 [=====] - 4s 6ms/step - loss: 1.9032 - accuracy: 0.2382 - val_loss: 1.9485 - val_accuracy: 0.2262
Epoch 5/15
624/624 [=====] - 4s 6ms/step - loss: 1.8894 - accuracy: 0.2426 - val_loss: 1.9662 - val_accuracy: 0.2238
Epoch 6/15
624/624 [=====] - 4s 6ms/step - loss: 1.8833 - accuracy: 0.2461 - val_loss: 1.9611 - val_accuracy: 0.2290
Epoch 7/15
624/624 [=====] - 4s 6ms/step - loss: 1.8775 - accuracy: 0.2496 - val_loss: 1.9445 - val_accuracy: 0.2229
Epoch 8/15
624/624 [=====] - 4s 6ms/step - loss: 1.8739 - accuracy: 0.2484 - val_loss: 1.9663 - val_accuracy: 0.2295
Epoch 9/15
624/624 [=====] - 4s 6ms/step - loss: 1.8710 - accuracy: 0.2513 - val_loss: 1.9597 - val_accuracy: 0.2376
Epoch 10/15
624/624 [=====] - 4s 6ms/step - loss: 1.8671 - accuracy: 0.2506 - val_loss: 1.9609 - val_accuracy: 0.2419
Epoch 11/15
624/624 [=====] - 4s 6ms/step - loss: 1.8645 - accuracy: 0.2510 - val_loss: 1.9678 - val_accuracy: 0.2348
Epoch 12/15
624/624 [=====] - 4s 6ms/step - loss: 1.8607 - accuracy: 0.2526 - val_loss: 1.9755 - val_accuracy: 0.2419
Epoch 13/15
624/624 [=====] - 4s 6ms/step - loss: 1.8573 - accuracy: 0.2549 - val_loss: 1.9875 - val_accuracy: 0.2362
Epoch 14/15
624/624 [=====] - 4s 6ms/step - loss: 1.8558 - accuracy: 0.2547 - val_loss: 1.9794 - val_accuracy: 0.2367
Epoch 15/15
624/624 [=====] - 4s 6ms/step - loss: 1.8587 - accuracy: 0.2562 - val_loss: 1.9766 - val_accuracy: 0.2319
```

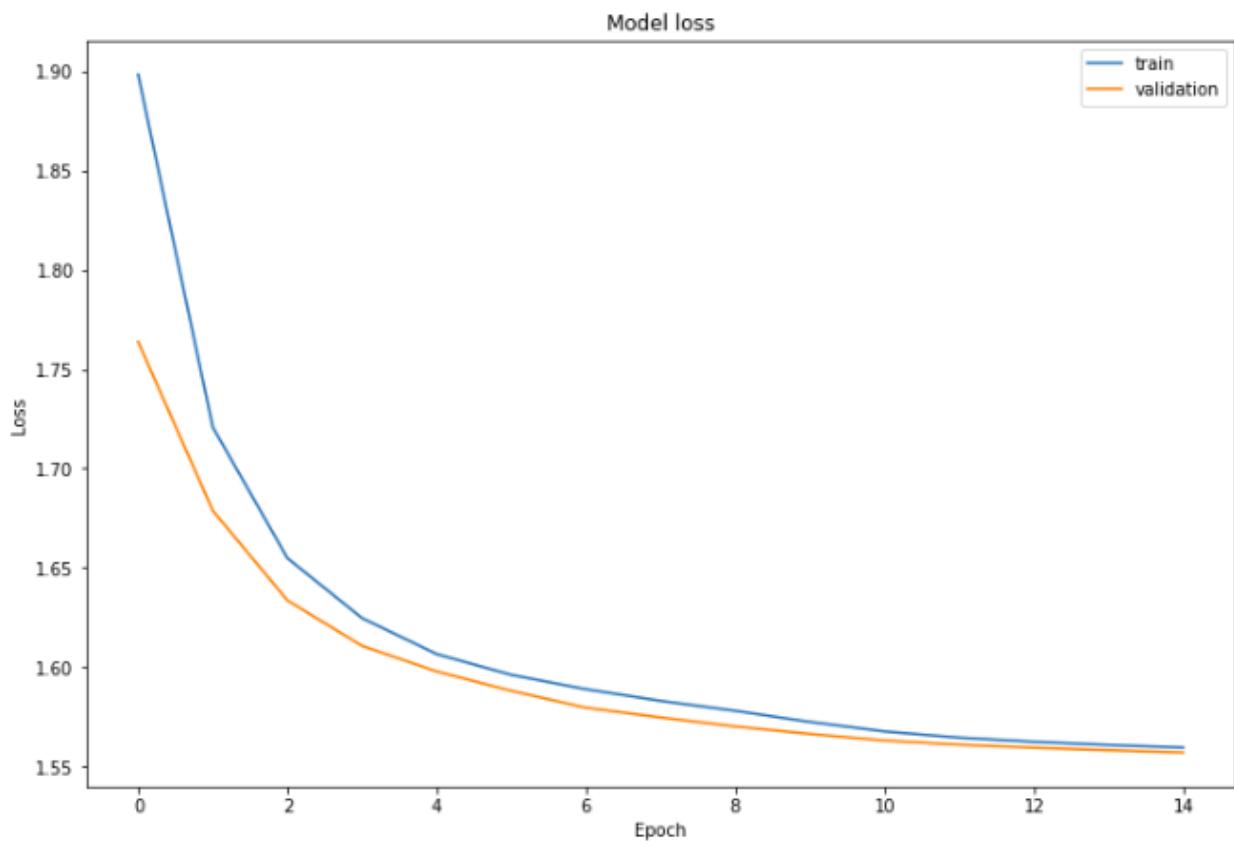
iii. Learning Rate : 0.001

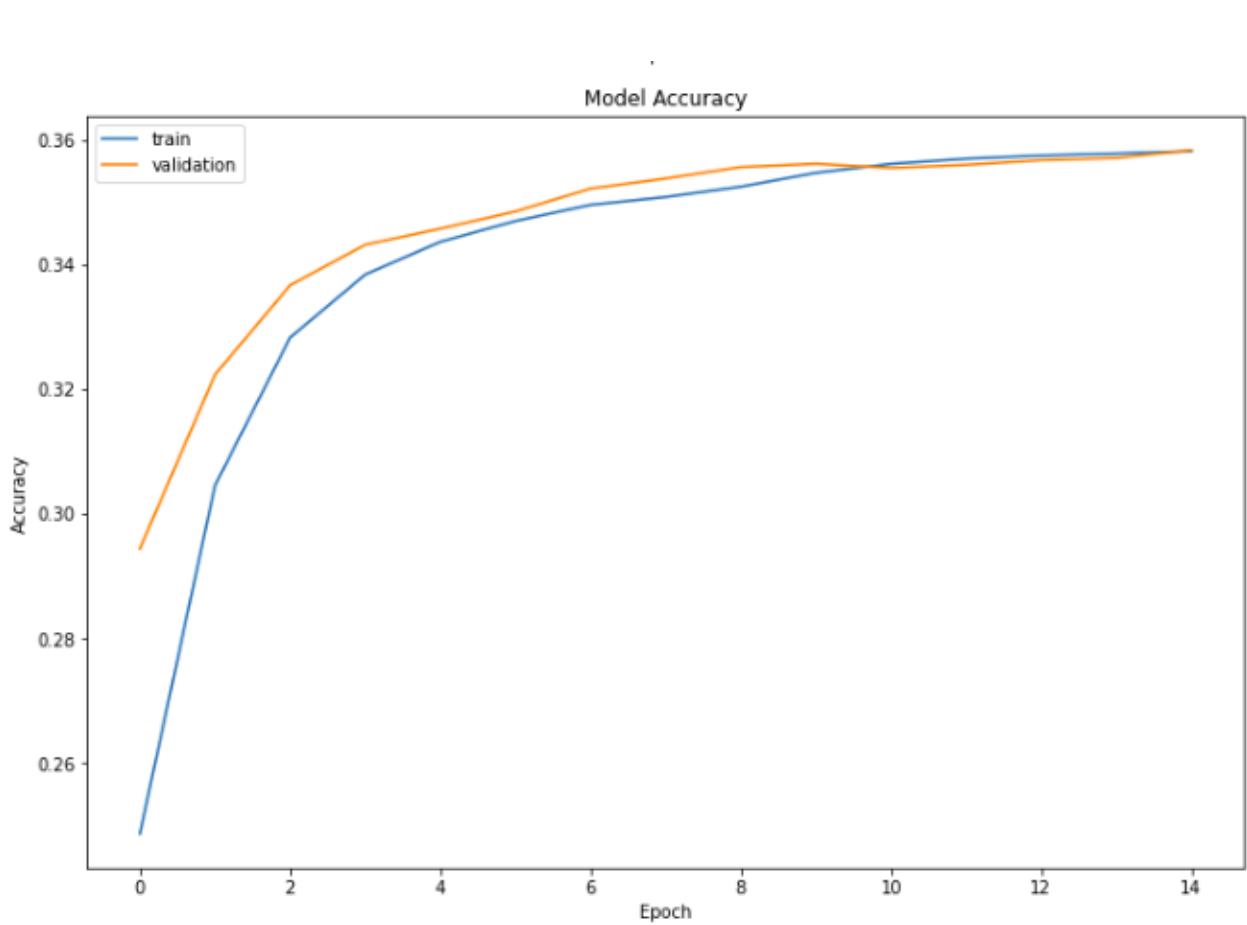
```
Epoch 1/15
624/624 [=====] - 4s 6ms/step - loss: 2.2282 - accuracy: 0.1554 - val_loss: 2.1594 - val_accuracy: 0.1605
Epoch 2/15
624/624 [=====] - 4s 6ms/step - loss: 2.1066 - accuracy: 0.1849 - val_loss: 2.1012 - val_accuracy: 0.1867
Epoch 3/15
624/624 [=====] - 4s 6ms/step - loss: 2.0353 - accuracy: 0.2065 - val_loss: 2.0325 - val_accuracy: 0.2100
Epoch 4/15
624/624 [=====] - 4s 6ms/step - loss: 1.9763 - accuracy: 0.2185 - val_loss: 2.0003 - val_accuracy: 0.2090
Epoch 5/15
624/624 [=====] - 4s 6ms/step - loss: 1.9407 - accuracy: 0.2270 - val_loss: 1.9800 - val_accuracy: 0.2181
Epoch 6/15
624/624 [=====] - 4s 6ms/step - loss: 1.9170 - accuracy: 0.2360 - val_loss: 1.9657 - val_accuracy: 0.2214
Epoch 7/15
624/624 [=====] - 4s 6ms/step - loss: 1.8996 - accuracy: 0.2415 - val_loss: 1.9542 - val_accuracy: 0.2286
Epoch 8/15
624/624 [=====] - 4s 6ms/step - loss: 1.8854 - accuracy: 0.2476 - val_loss: 1.9438 - val_accuracy: 0.2243
Epoch 9/15
624/624 [=====] - 4s 6ms/step - loss: 1.8728 - accuracy: 0.2537 - val_loss: 1.9340 - val_accuracy: 0.2343
Epoch 10/15
624/624 [=====] - 4s 6ms/step - loss: 1.8611 - accuracy: 0.2592 - val_loss: 1.9245 - val_accuracy: 0.2443
Epoch 11/15
624/624 [=====] - 4s 6ms/step - loss: 1.8499 - accuracy: 0.2652 - val_loss: 1.9153 - val_accuracy: 0.2495
Epoch 12/15
624/624 [=====] - 4s 6ms/step - loss: 1.8391 - accuracy: 0.2698 - val_loss: 1.9064 - val_accuracy: 0.2562
Epoch 13/15
624/624 [=====] - 4s 6ms/step - loss: 1.8290 - accuracy: 0.2738 - val_loss: 1.8977 - val_accuracy: 0.2586
Epoch 14/15
624/624 [=====] - 4s 6ms/step - loss: 1.8197 - accuracy: 0.2771 - val_loss: 1.8892 - val_accuracy: 0.2590
Epoch 15/15
624/624 [=====] - 4s 6ms/step - loss: 1.8111 - accuracy: 0.2796 - val_loss: 1.8812 - val_accuracy: 0.2662
```

iv. Learning Rate : 0.0001

```
Epoch 1/15
624/624 [=====] - 4s 6ms/step - loss: 2.3932 - accuracy: 0.1245 - val_loss: 2.3395 - val_accuracy: 0.1419
Epoch 2/15
624/624 [=====] - 4s 6ms/step - loss: 2.3063 - accuracy: 0.1470 - val_loss: 2.2853 - val_accuracy: 0.1514
Epoch 3/15
624/624 [=====] - 4s 6ms/step - loss: 2.2528 - accuracy: 0.1561 - val_loss: 2.2422 - val_accuracy: 0.1538
Epoch 4/15
624/624 [=====] - 4s 6ms/step - loss: 2.2116 - accuracy: 0.1634 - val_loss: 2.2120 - val_accuracy: 0.1595
Epoch 5/15
624/624 [=====] - 4s 6ms/step - loss: 2.1841 - accuracy: 0.1693 - val_loss: 2.1935 - val_accuracy: 0.1590
Epoch 6/15
624/624 [=====] - 4s 6ms/step - loss: 2.1670 - accuracy: 0.1718 - val_loss: 2.1814 - val_accuracy: 0.1610
Epoch 7/15
624/624 [=====] - 4s 6ms/step - loss: 2.1554 - accuracy: 0.1745 - val_loss: 2.1724 - val_accuracy: 0.1629
Epoch 8/15
624/624 [=====] - 4s 6ms/step - loss: 2.1465 - accuracy: 0.1777 - val_loss: 2.1651 - val_accuracy: 0.1648
Epoch 9/15
624/624 [=====] - 4s 6ms/step - loss: 2.1391 - accuracy: 0.1801 - val_loss: 2.1588 - val_accuracy: 0.1648
Epoch 10/15
624/624 [=====] - 4s 6ms/step - loss: 2.1327 - accuracy: 0.1819 - val_loss: 2.1531 - val_accuracy: 0.1686
Epoch 11/15
624/624 [=====] - 4s 6ms/step - loss: 2.1268 - accuracy: 0.1838 - val_loss: 2.1478 - val_accuracy: 0.1710
Epoch 12/15
624/624 [=====] - 4s 6ms/step - loss: 2.1213 - accuracy: 0.1856 - val_loss: 2.1427 - val_accuracy: 0.1733
Epoch 13/15
624/624 [=====] - 4s 6ms/step - loss: 2.1159 - accuracy: 0.1869 - val_loss: 2.1378 - val_accuracy: 0.1719
Epoch 14/15
624/624 [=====] - 4s 6ms/step - loss: 2.1106 - accuracy: 0.1872 - val_loss: 2.1327 - val_accuracy: 0.1719
Epoch 15/15
624/624 [=====] - 4s 6ms/step - loss: 2.1052 - accuracy: 0.1878 - val_loss: 2.1276 - val_accuracy: 0.1729
```

-
- b. Training (70 % of total data) on best Learning Rate (I chose 0.001 LR as it has highest val_accuracy above all other LR's)





```

Epoch 1/15
12469/12469 [=====] - 75s 6ms/step - loss: 1.8982 - accuracy: 0.2487 - val_loss: 1.7638 - val_accuracy: 0.2944
Epoch 2/15
12469/12469 [=====] - 71s 6ms/step - loss: 1.7208 - accuracy: 0.3045 - val_loss: 1.6789 - val_accuracy: 0.3223
Epoch 3/15
12469/12469 [=====] - 71s 6ms/step - loss: 1.6550 - accuracy: 0.3283 - val_loss: 1.6337 - val_accuracy: 0.3366
Epoch 4/15
12469/12469 [=====] - 71s 6ms/step - loss: 1.6248 - accuracy: 0.3384 - val_loss: 1.6108 - val_accuracy: 0.3431
Epoch 5/15
12469/12469 [=====] - 71s 6ms/step - loss: 1.6067 - accuracy: 0.3436 - val_loss: 1.5980 - val_accuracy: 0.3457
Epoch 6/15
12469/12469 [=====] - 71s 6ms/step - loss: 1.5963 - accuracy: 0.3469 - val_loss: 1.5882 - val_accuracy: 0.3485
Epoch 7/15
12469/12469 [=====] - 71s 6ms/step - loss: 1.5890 - accuracy: 0.3495 - val_loss: 1.5797 - val_accuracy: 0.3521
Epoch 8/15
12469/12469 [=====] - 71s 6ms/step - loss: 1.5832 - accuracy: 0.3508 - val_loss: 1.5748 - val_accuracy: 0.3538
Epoch 9/15
12469/12469 [=====] - 71s 6ms/step - loss: 1.5782 - accuracy: 0.3524 - val_loss: 1.5703 - val_accuracy: 0.3556
Epoch 10/15
12469/12469 [=====] - 71s 6ms/step - loss: 1.5726 - accuracy: 0.3547 - val_loss: 1.5665 - val_accuracy: 0.3561
Epoch 11/15
12469/12469 [=====] - 71s 6ms/step - loss: 1.5678 - accuracy: 0.3561 - val_loss: 1.5633 - val_accuracy: 0.3555
Epoch 12/15
12469/12469 [=====] - 83s 7ms/step - loss: 1.5647 - accuracy: 0.3569 - val_loss: 1.5611 - val_accuracy: 0.3560
Epoch 13/15
12469/12469 [=====] - 72s 6ms/step - loss: 1.5626 - accuracy: 0.3574 - val_loss: 1.5596 - val_accuracy: 0.3567
Epoch 14/15
12469/12469 [=====] - 72s 6ms/step - loss: 1.5610 - accuracy: 0.3578 - val_loss: 1.5584 - val_accuracy: 0.3570
Epoch 15/15
12469/12469 [=====] - 72s 6ms/step - loss: 1.5597 - accuracy: 0.3581 - val_loss: 1.5572 - val_accuracy: 0.3583

```

LSTM

7. Raw + Derivative

a. Hyperparameter tuning

i. Learning Rate : 0.1

```
Epoch 10/20
1247/1247 [=====] - 7s 5ms/step - loss: 2.3470 - accuracy: 0.1009 - val_loss: 2.3309 - val_accuracy: 0.0986
Epoch 11/20
1247/1247 [=====] - 7s 5ms/step - loss: 2.3517 - accuracy: 0.1009 - val_loss: 2.3404 - val_accuracy: 0.0976
Epoch 12/20
1247/1247 [=====] - 7s 5ms/step - loss: 2.3482 - accuracy: 0.0986 - val_loss: 2.3808 - val_accuracy: 0.0971
Epoch 13/20
1247/1247 [=====] - 7s 5ms/step - loss: 2.3500 - accuracy: 0.1013 - val_loss: 2.3204 - val_accuracy: 0.0976
Epoch 14/20
1247/1247 [=====] - 7s 6ms/step - loss: 2.3500 - accuracy: 0.0977 - val_loss: 2.3343 - val_accuracy: 0.1000
Epoch 15/20
1247/1247 [=====] - 7s 6ms/step - loss: 2.3475 - accuracy: 0.1005 - val_loss: 2.3658 - val_accuracy: 0.1010
Epoch 16/20
1247/1247 [=====] - 7s 5ms/step - loss: 2.3523 - accuracy: 0.0993 - val_loss: 2.3884 - val_accuracy: 0.0981
Epoch 17/20
1247/1247 [=====] - 7s 5ms/step - loss: 2.3485 - accuracy: 0.0996 - val_loss: 2.3464 - val_accuracy: 0.0976
Epoch 18/20
1247/1247 [=====] - 7s 6ms/step - loss: 2.3496 - accuracy: 0.0982 - val_loss: 2.3381 - val_accuracy: 0.1010
Epoch 19/20
1247/1247 [=====] - 7s 5ms/step - loss: 2.3491 - accuracy: 0.0984 - val_loss: 2.3695 - val_accuracy: 0.1010
Epoch 20/20
1247/1247 [=====] - 7s 5ms/step - loss: 2.3486 - accuracy: 0.0996 - val_loss: 2.3503 - val_accuracy: 0.1014
```

ii. Learning Rate : 0.01

```
Epoch 10/20
1247/1247 [=====] - 7s 5ms/step - loss: 2.1215 - accuracy: 0.1592 - val_loss: 2.1169 - val_accuracy: 0.1595
Epoch 11/20
1247/1247 [=====] - 7s 5ms/step - loss: 2.1171 - accuracy: 0.1632 - val_loss: 2.1234 - val_accuracy: 0.1538
Epoch 12/20
1247/1247 [=====] - 7s 5ms/step - loss: 2.1231 - accuracy: 0.1611 - val_loss: 2.1241 - val_accuracy: 0.1581
Epoch 13/20
1247/1247 [=====] - 7s 5ms/step - loss: 2.1191 - accuracy: 0.1620 - val_loss: 2.1174 - val_accuracy: 0.1810
Epoch 14/20
1247/1247 [=====] - 7s 5ms/step - loss: 2.1280 - accuracy: 0.1615 - val_loss: 2.1221 - val_accuracy: 0.1700
Epoch 15/20
1247/1247 [=====] - 7s 5ms/step - loss: 2.1189 - accuracy: 0.1625 - val_loss: 2.1444 - val_accuracy: 0.1624
Epoch 16/20
1247/1247 [=====] - 8s 6ms/step - loss: 2.1178 - accuracy: 0.1692 - val_loss: 2.1148 - val_accuracy: 0.1762
Epoch 17/20
1247/1247 [=====] - 7s 5ms/step - loss: 2.1116 - accuracy: 0.1698 - val_loss: 2.1147 - val_accuracy: 0.1619
Epoch 18/20
1247/1247 [=====] - 7s 6ms/step - loss: 2.1176 - accuracy: 0.1598 - val_loss: 2.1255 - val_accuracy: 0.1595
Epoch 19/20
1247/1247 [=====] - 7s 6ms/step - loss: 2.1153 - accuracy: 0.1606 - val_loss: 2.1136 - val_accuracy: 0.1581
Epoch 20/20
1247/1247 [=====] - 7s 5ms/step - loss: 2.1106 - accuracy: 0.1676 - val_loss: 2.1060 - val_accuracy: 0.1714
```

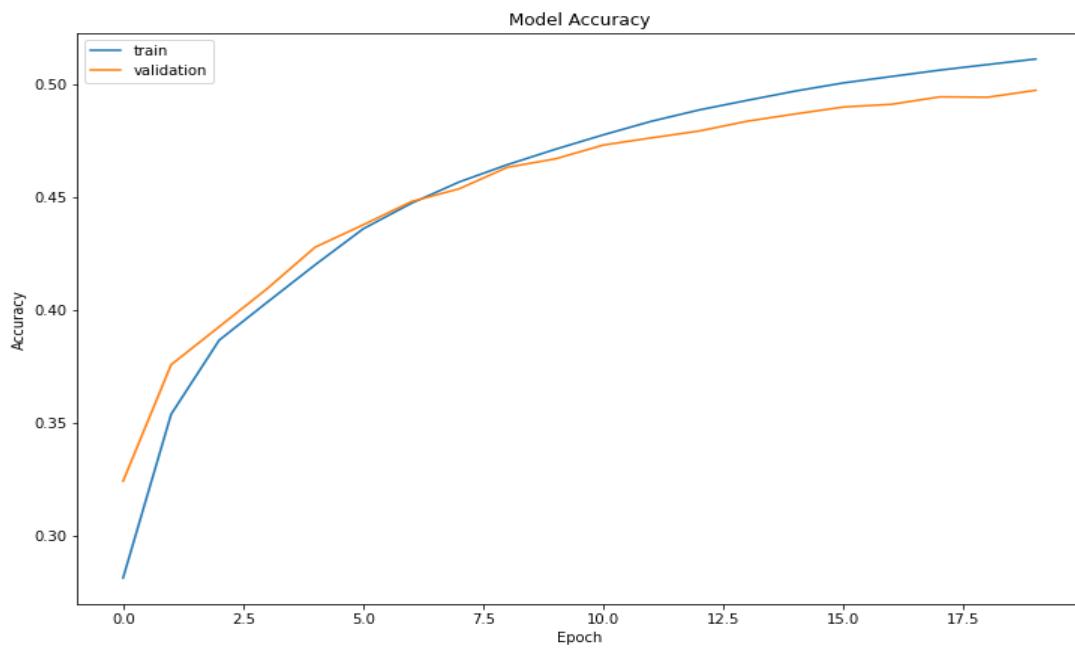
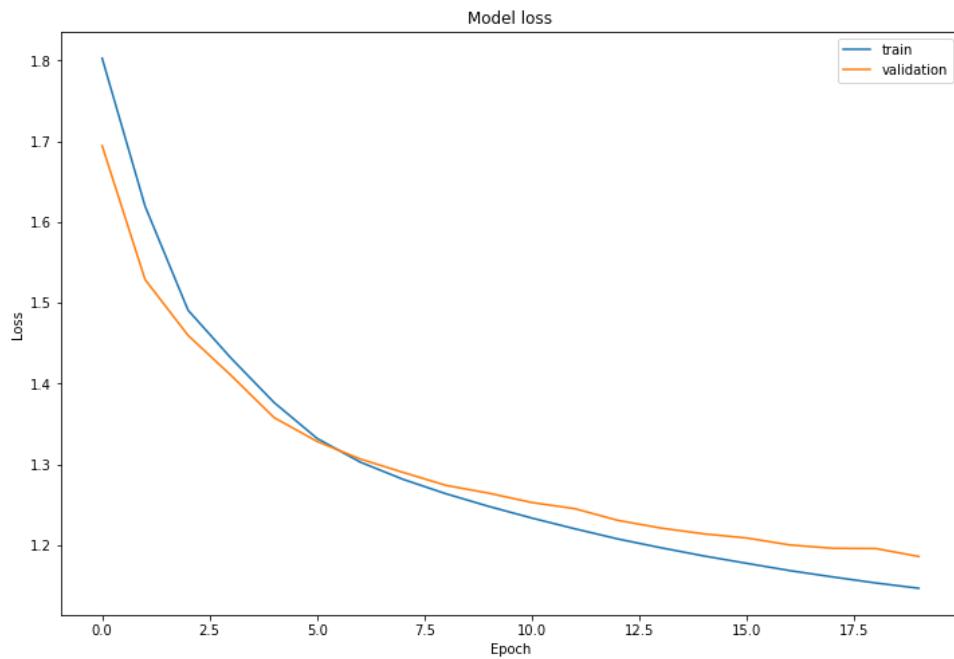
iii. Learning Rate : 0.001

```
Epoch 10/20
1247/1247 [=====] - 7s 6ms/step - loss: 2.0237 - accuracy: 0.2023 - val_loss: 2.0093 - val_accuracy: 0.2100
Epoch 11/20
1247/1247 [=====] - 7s 6ms/step - loss: 2.0193 - accuracy: 0.2082 - val_loss: 2.0223 - val_accuracy: 0.1976
Epoch 12/20
1247/1247 [=====] - 7s 6ms/step - loss: 2.0098 - accuracy: 0.2104 - val_loss: 2.0152 - val_accuracy: 0.2167
Epoch 13/20
1247/1247 [=====] - 7s 6ms/step - loss: 2.0158 - accuracy: 0.2090 - val_loss: 2.0167 - val_accuracy: 0.2010
Epoch 14/20
1247/1247 [=====] - 7s 6ms/step - loss: 2.0144 - accuracy: 0.2076 - val_loss: 2.0286 - val_accuracy: 0.2200
Epoch 15/20
1247/1247 [=====] - 7s 6ms/step - loss: 2.0149 - accuracy: 0.2061 - val_loss: 2.0286 - val_accuracy: 0.1876
Epoch 16/20
1247/1247 [=====] - 7s 6ms/step - loss: 2.0104 - accuracy: 0.2108 - val_loss: 2.0450 - val_accuracy: 0.1805
Epoch 17/20
1247/1247 [=====] - 7s 6ms/step - loss: 2.0062 - accuracy: 0.2138 - val_loss: 2.0318 - val_accuracy: 0.1914
Epoch 18/20
1247/1247 [=====] - 7s 5ms/step - loss: 2.0086 - accuracy: 0.2138 - val_loss: 2.0319 - val_accuracy: 0.2195
Epoch 19/20
1247/1247 [=====] - 7s 5ms/step - loss: 2.0095 - accuracy: 0.2110 - val_loss: 2.0366 - val_accuracy: 0.2076
Epoch 20/20
1247/1247 [=====] - 7s 6ms/step - loss: 2.0107 - accuracy: 0.2114 - val_loss: 2.0275 - val_accuracy: 0.2033
```

iv. Learning Rate : 0.0001

```
Epoch 10/20
1247/1247 [=====] - 7s 6ms/step - loss: 1.7612 - accuracy: 0.2920 - val_loss: 1.8305 - val_accuracy: 0.2838
Epoch 11/20
1247/1247 [=====] - 7s 6ms/step - loss: 1.7601 - accuracy: 0.2926 - val_loss: 1.8401 - val_accuracy: 0.2838
Epoch 12/20
1247/1247 [=====] - 7s 5ms/step - loss: 1.7608 - accuracy: 0.2929 - val_loss: 1.8299 - val_accuracy: 0.2786
Epoch 13/20
1247/1247 [=====] - 7s 5ms/step - loss: 1.7704 - accuracy: 0.2881 - val_loss: 1.8123 - val_accuracy: 0.2814
Epoch 14/20
1247/1247 [=====] - 7s 6ms/step - loss: 1.7743 - accuracy: 0.2881 - val_loss: 1.8281 - val_accuracy: 0.2776
Epoch 15/20
1247/1247 [=====] - 7s 5ms/step - loss: 1.7759 - accuracy: 0.2906 - val_loss: 1.8287 - val_accuracy: 0.2695
Epoch 16/20
1247/1247 [=====] - 7s 6ms/step - loss: 1.7769 - accuracy: 0.2890 - val_loss: 1.8284 - val_accuracy: 0.2843
Epoch 17/20
1247/1247 [=====] - 7s 5ms/step - loss: 1.7817 - accuracy: 0.2886 - val_loss: 1.8348 - val_accuracy: 0.2767
Epoch 18/20
1247/1247 [=====] - 7s 6ms/step - loss: 1.7836 - accuracy: 0.2857 - val_loss: 1.8350 - val_accuracy: 0.2762
Epoch 19/20
1247/1247 [=====] - 8s 6ms/step - loss: 1.7837 - accuracy: 0.2873 - val_loss: 1.8437 - val_accuracy: 0.2671
Epoch 20/20
1247/1247 [=====] - 7s 5ms/step - loss: 1.7860 - accuracy: 0.2872 - val_loss: 1.8303 - val_accuracy: 0.2752
```

b. Training (70 %) on best Learning Rate (I chose 0.0001 LR as it has highest val_accuracy above all other LR's)



8. Raw + Integration

a. Hyperparameter tuning

i. Learning Rate : 0.1

```
Epoch 1/15
1247/1247 [=====] - 20s 12ms/step - loss: 2.3166 - accuracy: 0.1010 - val_loss: 2.3129 - val_accuracy: 0.1010
Epoch 2/15
1247/1247 [=====] - 14s 12ms/step - loss: 2.3147 - accuracy: 0.0993 - val_loss: 2.3098 - val_accuracy: 0.1000
Epoch 3/15
1247/1247 [=====] - 14s 12ms/step - loss: 2.3158 - accuracy: 0.1004 - val_loss: 2.3063 - val_accuracy: 0.1005
Epoch 4/15
1247/1247 [=====] - 15s 12ms/step - loss: 2.3149 - accuracy: 0.1021 - val_loss: 2.3174 - val_accuracy: 0.1005
Epoch 5/15
1247/1247 [=====] - 15s 12ms/step - loss: 2.3155 - accuracy: 0.0988 - val_loss: 2.3126 - val_accuracy: 0.1000
Epoch 6/15
1247/1247 [=====] - 14s 12ms/step - loss: 2.3148 - accuracy: 0.1003 - val_loss: 2.3102 - val_accuracy: 0.1000
Epoch 7/15
1247/1247 [=====] - 14s 12ms/step - loss: 2.3161 - accuracy: 0.0983 - val_loss: 2.3169 - val_accuracy: 0.1000
Epoch 8/15
1247/1247 [=====] - 15s 12ms/step - loss: 2.3158 - accuracy: 0.1005 - val_loss: 2.3170 - val_accuracy: 0.0990
Epoch 9/15
1247/1247 [=====] - 15s 12ms/step - loss: 2.3160 - accuracy: 0.0991 - val_loss: 2.3156 - val_accuracy: 0.1000
Epoch 10/15
1247/1247 [=====] - 15s 12ms/step - loss: 2.3162 - accuracy: 0.0962 - val_loss: 2.3179 - val_accuracy: 0.0990
Epoch 11/15
1247/1247 [=====] - 16s 13ms/step - loss: 2.3149 - accuracy: 0.1016 - val_loss: 2.3197 - val_accuracy: 0.1010
Epoch 12/15
1247/1247 [=====] - 15s 12ms/step - loss: 2.3164 - accuracy: 0.0987 - val_loss: 2.3132 - val_accuracy: 0.1000
Epoch 13/15
1247/1247 [=====] - 14s 12ms/step - loss: 2.3146 - accuracy: 0.1021 - val_loss: 2.3079 - val_accuracy: 0.1000
Epoch 14/15
1247/1247 [=====] - 15s 12ms/step - loss: 2.3162 - accuracy: 0.0981 - val_loss: 2.3100 - val_accuracy: 0.0990
Epoch 15/15
1247/1247 [=====] - 14s 12ms/step - loss: 2.3154 - accuracy: 0.1006 - val_loss: 2.3227 - val_accuracy: 0.1010
```

ii. Learning Rate : 0.01

```
Epoch 1/15
1247/1247 [=====] - 20s 13ms/step - loss: 2.1056 - accuracy: 0.1689 - val_loss: 2.0519 - val_accuracy: 0.1948
Epoch 2/15
1247/1247 [=====] - 14s 11ms/step - loss: 2.0123 - accuracy: 0.2111 - val_loss: 1.9419 - val_accuracy: 0.2362
Epoch 3/15
1247/1247 [=====] - 14s 12ms/step - loss: 1.8355 - accuracy: 0.2728 - val_loss: 1.7663 - val_accuracy: 0.2967
Epoch 4/15
1247/1247 [=====] - 15s 12ms/step - loss: 1.7076 - accuracy: 0.3032 - val_loss: 1.6854 - val_accuracy: 0.3148
Epoch 5/15
1247/1247 [=====] - 14s 11ms/step - loss: 1.6223 - accuracy: 0.3289 - val_loss: 1.6104 - val_accuracy: 0.3295
Epoch 6/15
1247/1247 [=====] - 15s 12ms/step - loss: 1.5575 - accuracy: 0.3513 - val_loss: 1.5644 - val_accuracy: 0.3552
Epoch 7/15
1247/1247 [=====] - 16s 13ms/step - loss: 1.5117 - accuracy: 0.3697 - val_loss: 1.5534 - val_accuracy: 0.3371
Epoch 8/15
1247/1247 [=====] - 16s 13ms/step - loss: 1.4751 - accuracy: 0.3802 - val_loss: 1.5374 - val_accuracy: 0.3652
Epoch 9/15
1247/1247 [=====] - 15s 12ms/step - loss: 1.4474 - accuracy: 0.3872 - val_loss: 1.5245 - val_accuracy: 0.3562
Epoch 10/15
1247/1247 [=====] - 15s 12ms/step - loss: 1.4228 - accuracy: 0.3979 - val_loss: 1.5222 - val_accuracy: 0.3586
Epoch 11/15
1247/1247 [=====] - 15s 12ms/step - loss: 1.4017 - accuracy: 0.4063 - val_loss: 1.5404 - val_accuracy: 0.3614
Epoch 12/15
1247/1247 [=====] - 14s 11ms/step - loss: 1.3816 - accuracy: 0.4136 - val_loss: 1.5212 - val_accuracy: 0.3719
Epoch 13/15
1247/1247 [=====] - 15s 12ms/step - loss: 1.3629 - accuracy: 0.4195 - val_loss: 1.5376 - val_accuracy: 0.3738
Epoch 14/15
1247/1247 [=====] - 14s 12ms/step - loss: 1.3410 - accuracy: 0.4287 - val_loss: 1.5600 - val_accuracy: 0.3548
Epoch 15/15
1247/1247 [=====] - 14s 12ms/step - loss: 1.3230 - accuracy: 0.4368 - val_loss: 1.5559 - val_accuracy: 0.3733
```

iii. Learning Rate : 0.001

```
Epoch 1/15
1247/1247 [=====] - 21s 12ms/step - loss: 2.1916 - accuracy: 0.1436 - val_loss: 2.1066 - val_accuracy: 0.1671
Epoch 2/15
1247/1247 [=====] - 15s 12ms/step - loss: 2.1015 - accuracy: 0.1676 - val_loss: 2.0846 - val_accuracy: 0.1757
Epoch 3/15
1247/1247 [=====] - 14s 12ms/step - loss: 2.0795 - accuracy: 0.1829 - val_loss: 2.0623 - val_accuracy: 0.1924
Epoch 4/15
1247/1247 [=====] - 14s 11ms/step - loss: 2.0577 - accuracy: 0.1962 - val_loss: 2.0451 - val_accuracy: 0.1990
Epoch 5/15
1247/1247 [=====] - 16s 13ms/step - loss: 2.0412 - accuracy: 0.2028 - val_loss: 2.0327 - val_accuracy: 0.2110
Epoch 6/15
1247/1247 [=====] - 14s 12ms/step - loss: 2.0331 - accuracy: 0.2052 - val_loss: 2.0308 - val_accuracy: 0.2076
Epoch 7/15
1247/1247 [=====] - 16s 13ms/step - loss: 2.0277 - accuracy: 0.2085 - val_loss: 2.0300 - val_accuracy: 0.2043
Epoch 8/15
1247/1247 [=====] - 15s 12ms/step - loss: 2.0218 - accuracy: 0.2115 - val_loss: 2.0223 - val_accuracy: 0.2210
Epoch 9/15
1247/1247 [=====] - 14s 11ms/step - loss: 2.0143 - accuracy: 0.2152 - val_loss: 2.0112 - val_accuracy: 0.2162
Epoch 10/15
1247/1247 [=====] - 15s 12ms/step - loss: 1.9981 - accuracy: 0.2238 - val_loss: 2.0041 - val_accuracy: 0.2190
Epoch 11/15
1247/1247 [=====] - 15s 12ms/step - loss: 1.9856 - accuracy: 0.2292 - val_loss: 1.9912 - val_accuracy: 0.2324
Epoch 12/15
1247/1247 [=====] - 14s 11ms/step - loss: 1.9722 - accuracy: 0.2328 - val_loss: 1.9828 - val_accuracy: 0.2267
Epoch 13/15
1247/1247 [=====] - 14s 12ms/step - loss: 1.9575 - accuracy: 0.2379 - val_loss: 1.9704 - val_accuracy: 0.2390
Epoch 14/15
1247/1247 [=====] - 15s 12ms/step - loss: 1.9407 - accuracy: 0.2413 - val_loss: 1.9461 - val_accuracy: 0.2457
Epoch 15/15
1247/1247 [=====] - 15s 12ms/step - loss: 1.9213 - accuracy: 0.2484 - val_loss: 1.9396 - val_accuracy: 0.2362
```

iv. Learning Rate : 0.0001

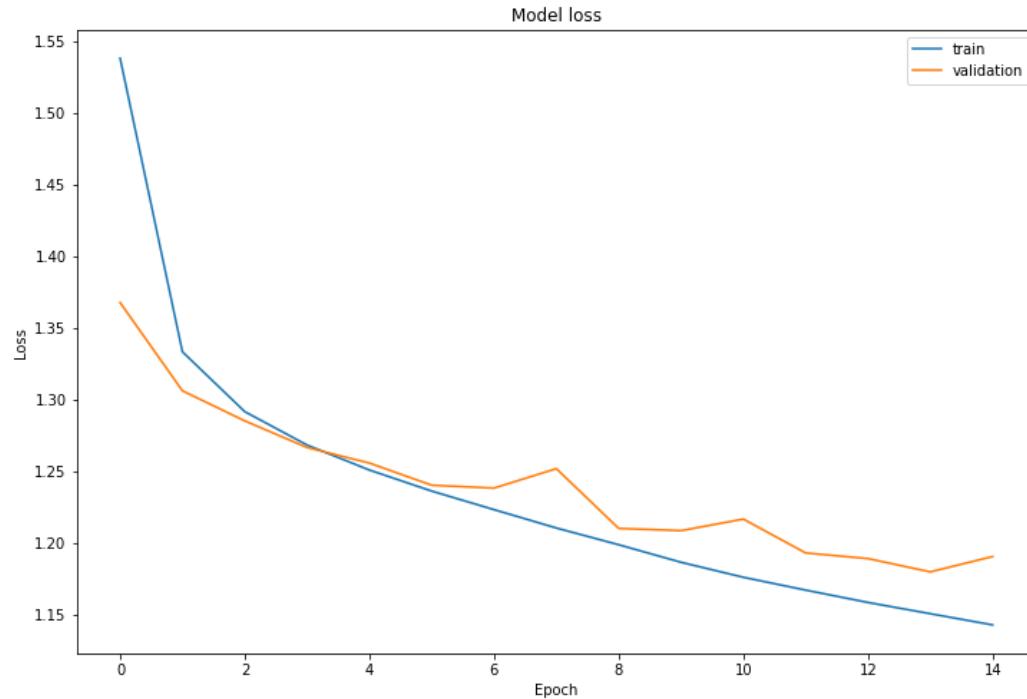
```
Epoch 1/15
1247/1247 [=====] - 20s 13ms/step - loss: 2.3483 - accuracy: 0.0998 - val_loss: 2.3135 - val_accuracy: 0.1010
Epoch 2/15
1247/1247 [=====] - 15s 12ms/step - loss: 2.3088 - accuracy: 0.1034 - val_loss: 2.3055 - val_accuracy: 0.1114
Epoch 3/15
1247/1247 [=====] - 15s 12ms/step - loss: 2.3036 - accuracy: 0.1110 - val_loss: 2.2991 - val_accuracy: 0.1010
Epoch 4/15
1247/1247 [=====] - 15s 12ms/step - loss: 2.2873 - accuracy: 0.1448 - val_loss: 2.2752 - val_accuracy: 0.1562
Epoch 5/15
1247/1247 [=====] - 15s 12ms/step - loss: 2.2602 - accuracy: 0.1472 - val_loss: 2.2503 - val_accuracy: 0.1348
Epoch 6/15
1247/1247 [=====] - 14s 11ms/step - loss: 2.2350 - accuracy: 0.1423 - val_loss: 2.2264 - val_accuracy: 0.1514
Epoch 7/15
1247/1247 [=====] - 16s 13ms/step - loss: 2.2115 - accuracy: 0.1487 - val_loss: 2.1995 - val_accuracy: 0.1490
Epoch 8/15
1247/1247 [=====] - 15s 12ms/step - loss: 2.1876 - accuracy: 0.1577 - val_loss: 2.1762 - val_accuracy: 0.1510
Epoch 9/15
1247/1247 [=====] - 14s 11ms/step - loss: 2.1677 - accuracy: 0.1585 - val_loss: 2.1566 - val_accuracy: 0.1576
Epoch 10/15
1247/1247 [=====] - 14s 11ms/step - loss: 2.1523 - accuracy: 0.1624 - val_loss: 2.1449 - val_accuracy: 0.1662
Epoch 11/15
1247/1247 [=====] - 15s 12ms/step - loss: 2.1406 - accuracy: 0.1638 - val_loss: 2.1333 - val_accuracy: 0.1695
Epoch 12/15
1247/1247 [=====] - 14s 11ms/step - loss: 2.1315 - accuracy: 0.1637 - val_loss: 2.1250 - val_accuracy: 0.1657
Epoch 13/15
1247/1247 [=====] - 14s 11ms/step - loss: 2.1242 - accuracy: 0.1675 - val_loss: 2.1195 - val_accuracy: 0.1643
Epoch 14/15
1247/1247 [=====] - 15s 12ms/step - loss: 2.1185 - accuracy: 0.1639 - val_loss: 2.1150 - val_accuracy: 0.1695
Epoch 15/15
1247/1247 [=====] - 14s 11ms/step - loss: 2.1133 - accuracy: 0.1672 - val_loss: 2.1111 - val_accuracy: 0.1686
```

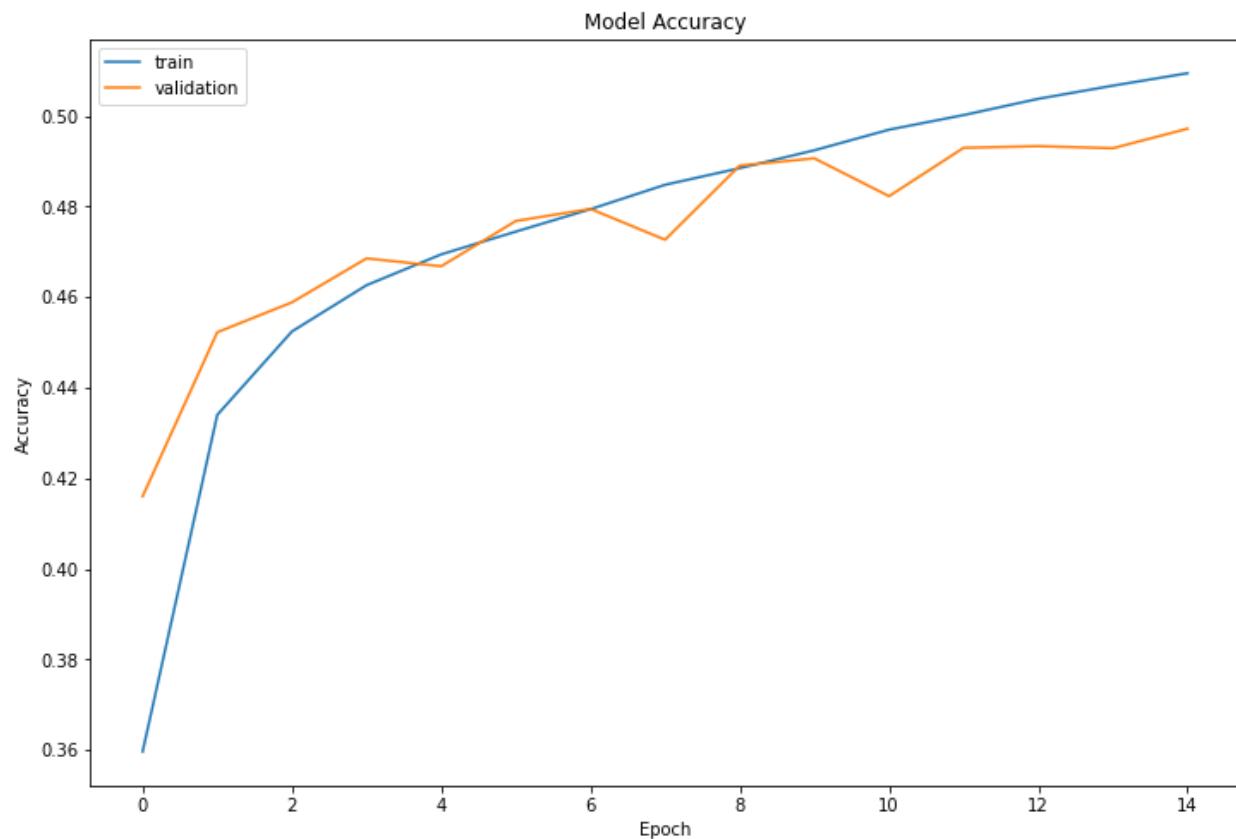
- b. Training on best Learning Rate 0.01 (I chose 0.01 LR as it has highest val_accuracy above all other LR's)

```

Epoch 1/15
24938/24938 [=====] - 228s 9ms/step - loss: 1.5383 - accuracy: 0.3596 - val_loss: 1.3678 - val_accuracy: 0.4160
Epoch 2/15
24938/24938 [=====] - 227s 9ms/step - loss: 1.3335 - accuracy: 0.4340 - val_loss: 1.3063 - val_accuracy: 0.4522
Epoch 3/15
24938/24938 [=====] - 223s 9ms/step - loss: 1.2917 - accuracy: 0.4524 - val_loss: 1.2853 - val_accuracy: 0.4588
Epoch 4/15
24938/24938 [=====] - 224s 9ms/step - loss: 1.2684 - accuracy: 0.4626 - val_loss: 1.2667 - val_accuracy: 0.4685
Epoch 5/15
24938/24938 [=====] - 222s 9ms/step - loss: 1.2510 - accuracy: 0.4694 - val_loss: 1.2558 - val_accuracy: 0.4668
Epoch 6/15
24938/24938 [=====] - 225s 9ms/step - loss: 1.2363 - accuracy: 0.4745 - val_loss: 1.2404 - val_accuracy: 0.4768
Epoch 7/15
24938/24938 [=====] - 220s 9ms/step - loss: 1.2234 - accuracy: 0.4794 - val_loss: 1.2384 - val_accuracy: 0.4795
Epoch 8/15
24938/24938 [=====] - 225s 9ms/step - loss: 1.2105 - accuracy: 0.4848 - val_loss: 1.2519 - val_accuracy: 0.4727
Epoch 9/15
24938/24938 [=====] - 221s 9ms/step - loss: 1.1989 - accuracy: 0.4885 - val_loss: 1.2103 - val_accuracy: 0.4890
Epoch 10/15
24938/24938 [=====] - 224s 9ms/step - loss: 1.1866 - accuracy: 0.4924 - val_loss: 1.2087 - val_accuracy: 0.4906
Epoch 11/15
24938/24938 [=====] - 220s 9ms/step - loss: 1.1762 - accuracy: 0.4970 - val_loss: 1.2168 - val_accuracy: 0.4823
Epoch 12/15
24938/24938 [=====] - 226s 9ms/step - loss: 1.1672 - accuracy: 0.5002 - val_loss: 1.1931 - val_accuracy: 0.4930
Epoch 13/15
24938/24938 [=====] - 222s 9ms/step - loss: 1.1586 - accuracy: 0.5038 - val_loss: 1.1892 - val_accuracy: 0.4933
Epoch 14/15
24938/24938 [=====] - 225s 9ms/step - loss: 1.1508 - accuracy: 0.5067 - val_loss: 1.1799 - val_accuracy: 0.4929
Epoch 15/15
24938/24938 [=====] - 221s 9ms/step - loss: 1.1429 - accuracy: 0.5094 - val_loss: 1.1906 - val_accuracy: 0.4972

```





9. Derivative + Integration

a. Hyperparameter tuning

i. Learning Rate : 0.1

```
Epoch 1/15
1247/1247 [=====] - 16s 10ms/step - loss: 2.1604 - accuracy: 0.1604 - val_loss: 2.1746 - val_accuracy: 0.1443
Epoch 2/15
1247/1247 [=====] - 12s 10ms/step - loss: 2.1409 - accuracy: 0.1590 - val_loss: 2.1528 - val_accuracy: 0.1576
Epoch 3/15
1247/1247 [=====] - 12s 10ms/step - loss: 2.1405 - accuracy: 0.1597 - val_loss: 2.1815 - val_accuracy: 0.1581
Epoch 4/15
1247/1247 [=====] - 12s 10ms/step - loss: 2.1285 - accuracy: 0.1596 - val_loss: 2.1178 - val_accuracy: 0.1638
Epoch 5/15
1247/1247 [=====] - 12s 10ms/step - loss: 2.1214 - accuracy: 0.1644 - val_loss: 2.1088 - val_accuracy: 0.1619
Epoch 6/15
1247/1247 [=====] - 13s 10ms/step - loss: 2.1306 - accuracy: 0.1596 - val_loss: 2.1121 - val_accuracy: 0.1610
Epoch 7/15
1247/1247 [=====] - 12s 10ms/step - loss: 2.1170 - accuracy: 0.1627 - val_loss: 2.1225 - val_accuracy: 0.1624
Epoch 8/15
1247/1247 [=====] - 12s 10ms/step - loss: 2.1137 - accuracy: 0.1638 - val_loss: 2.1358 - val_accuracy: 0.1595
Epoch 9/15
1247/1247 [=====] - 12s 10ms/step - loss: 2.1212 - accuracy: 0.1617 - val_loss: 2.1154 - val_accuracy: 0.1652
Epoch 10/15
1247/1247 [=====] - 12s 10ms/step - loss: 2.1156 - accuracy: 0.1611 - val_loss: 2.1218 - val_accuracy: 0.1562
Epoch 11/15
1247/1247 [=====] - 12s 10ms/step - loss: 2.1199 - accuracy: 0.1612 - val_loss: 2.1141 - val_accuracy: 0.1590
Epoch 12/15
1247/1247 [=====] - 12s 10ms/step - loss: 2.1192 - accuracy: 0.1616 - val_loss: 2.1288 - val_accuracy: 0.1681
Epoch 13/15
1247/1247 [=====] - 12s 10ms/step - loss: 2.1121 - accuracy: 0.1689 - val_loss: 2.1110 - val_accuracy: 0.1614
Epoch 14/15
1247/1247 [=====] - 12s 10ms/step - loss: 2.1117 - accuracy: 0.1644 - val_loss: 2.1296 - val_accuracy: 0.1581
Epoch 15/15
1247/1247 [=====] - 12s 10ms/step - loss: 2.1175 - accuracy: 0.1588 - val_loss: 2.1247 - val_accuracy: 0.1738
```

ii. Learning Rate : 0.01

```
Epoch 1/15
1247/1247 [=====] - 16s 10ms/step - loss: 1.8266 - accuracy: 0.2659 - val_loss: 1.7111 - val_accuracy: 0.3038
Epoch 2/15
1247/1247 [=====] - 12s 10ms/step - loss: 1.6386 - accuracy: 0.3274 - val_loss: 1.6311 - val_accuracy: 0.3314
Epoch 3/15
1247/1247 [=====] - 12s 10ms/step - loss: 1.5645 - accuracy: 0.3531 - val_loss: 1.6343 - val_accuracy: 0.3338
Epoch 4/15
1247/1247 [=====] - 12s 10ms/step - loss: 1.5184 - accuracy: 0.3666 - val_loss: 1.6535 - val_accuracy: 0.3148
Epoch 5/15
1247/1247 [=====] - 12s 10ms/step - loss: 1.4772 - accuracy: 0.3810 - val_loss: 1.6427 - val_accuracy: 0.3462
Epoch 6/15
1247/1247 [=====] - 13s 11ms/step - loss: 1.4486 - accuracy: 0.3889 - val_loss: 1.6463 - val_accuracy: 0.3386
Epoch 7/15
1247/1247 [=====] - 13s 10ms/step - loss: 1.4211 - accuracy: 0.4000 - val_loss: 1.6619 - val_accuracy: 0.3343
Epoch 8/15
1247/1247 [=====] - 12s 9ms/step - loss: 1.4063 - accuracy: 0.4071 - val_loss: 1.6507 - val_accuracy: 0.3429
Epoch 9/15
1247/1247 [=====] - 12s 10ms/step - loss: 1.3839 - accuracy: 0.4180 - val_loss: 1.6681 - val_accuracy: 0.3490
Epoch 10/15
1247/1247 [=====] - 12s 10ms/step - loss: 1.3707 - accuracy: 0.4193 - val_loss: 1.6990 - val_accuracy: 0.3476
Epoch 11/15
1247/1247 [=====] - 12s 10ms/step - loss: 1.3676 - accuracy: 0.4206 - val_loss: 1.6909 - val_accuracy: 0.3352
Epoch 12/15
1247/1247 [=====] - 12s 10ms/step - loss: 1.3525 - accuracy: 0.4250 - val_loss: 1.6922 - val_accuracy: 0.3195
Epoch 13/15
1247/1247 [=====] - 12s 10ms/step - loss: 1.3408 - accuracy: 0.4284 - val_loss: 1.6923 - val_accuracy: 0.3405
Epoch 14/15
1247/1247 [=====] - 13s 10ms/step - loss: 1.3257 - accuracy: 0.4329 - val_loss: 1.6987 - val_accuracy: 0.3433
Epoch 15/15
1247/1247 [=====] - 13s 10ms/step - loss: 1.3190 - accuracy: 0.4367 - val_loss: 1.7027 - val_accuracy: 0.3405
```

iii. Learning Rate : 0.001

```
Epoch 1/15
1247/1247 [=====] - 16s 10ms/step - loss: 1.9117 - accuracy: 0.2537 - val_loss: 1.7806 - val_accuracy: 0.2876
Epoch 2/15
1247/1247 [=====] - 12s 10ms/step - loss: 1.7063 - accuracy: 0.3292 - val_loss: 1.6850 - val_accuracy: 0.3252
Epoch 3/15
1247/1247 [=====] - 14s 11ms/step - loss: 1.5923 - accuracy: 0.3617 - val_loss: 1.6109 - val_accuracy: 0.3529
Epoch 4/15
1247/1247 [=====] - 12s 10ms/step - loss: 1.5100 - accuracy: 0.3887 - val_loss: 1.5752 - val_accuracy: 0.3648
Epoch 5/15
1247/1247 [=====] - 12s 10ms/step - loss: 1.4357 - accuracy: 0.4072 - val_loss: 1.5676 - val_accuracy: 0.3600
Epoch 6/15
1247/1247 [=====] - 12s 10ms/step - loss: 1.3670 - accuracy: 0.4290 - val_loss: 1.5682 - val_accuracy: 0.3586
Epoch 7/15
1247/1247 [=====] - 12s 10ms/step - loss: 1.3030 - accuracy: 0.4510 - val_loss: 1.6019 - val_accuracy: 0.3724
Epoch 8/15
1247/1247 [=====] - 13s 10ms/step - loss: 1.2391 - accuracy: 0.4720 - val_loss: 1.6334 - val_accuracy: 0.3710
Epoch 9/15
1247/1247 [=====] - 12s 10ms/step - loss: 1.1822 - accuracy: 0.4891 - val_loss: 1.7056 - val_accuracy: 0.3681
Epoch 10/15
1247/1247 [=====] - 12s 10ms/step - loss: 1.1281 - accuracy: 0.5053 - val_loss: 1.7670 - val_accuracy: 0.3767
Epoch 11/15
1247/1247 [=====] - 12s 10ms/step - loss: 1.0798 - accuracy: 0.5238 - val_loss: 1.8251 - val_accuracy: 0.3648
Epoch 12/15
1247/1247 [=====] - 12s 9ms/step - loss: 1.0329 - accuracy: 0.5407 - val_loss: 1.8943 - val_accuracy: 0.3795
Epoch 13/15
1247/1247 [=====] - 12s 10ms/step - loss: 0.9924 - accuracy: 0.5584 - val_loss: 1.9964 - val_accuracy: 0.3657
Epoch 14/15
1247/1247 [=====] - 12s 10ms/step - loss: 0.9556 - accuracy: 0.5715 - val_loss: 2.0404 - val_accuracy: 0.3690
Epoch 15/15
1247/1247 [=====] - 12s 10ms/step - loss: 0.9203 - accuracy: 0.5846 - val_loss: 2.0996 - val_accuracy: 0.3614
```

iv. Learning Rate : 0.0001

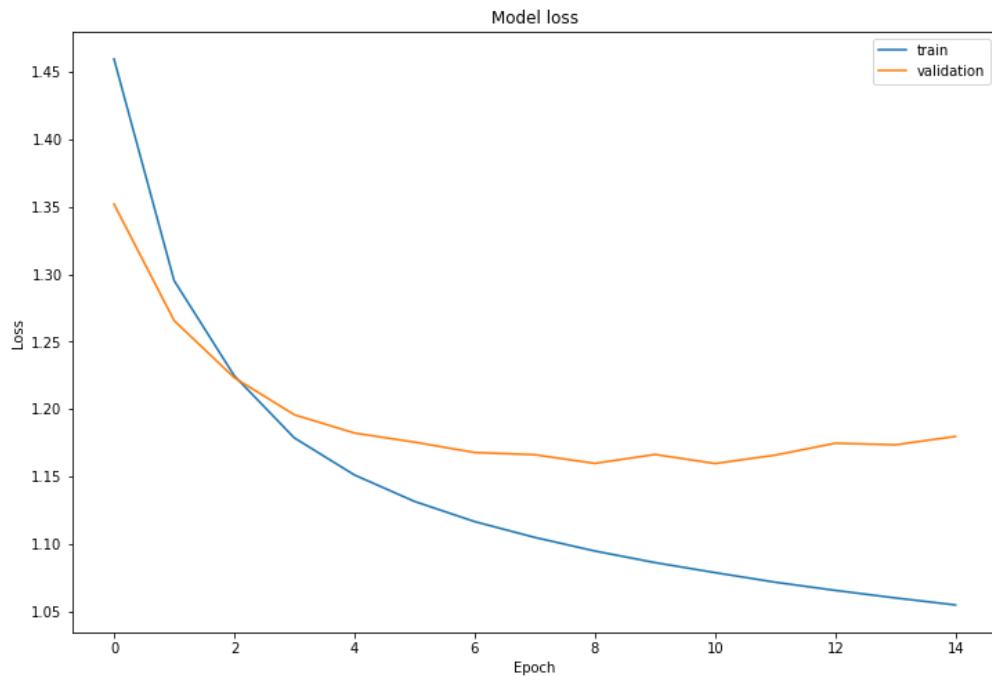
```
Epoch 1/15
1247/1247 [=====] - 16s 10ms/step - loss: 2.2426 - accuracy: 0.1583 - val_loss: 2.0929 - val_accuracy: 0.2024
Epoch 2/15
1247/1247 [=====] - 12s 10ms/step - loss: 1.9943 - accuracy: 0.2227 - val_loss: 1.9265 - val_accuracy: 0.2457
Epoch 3/15
1247/1247 [=====] - 12s 10ms/step - loss: 1.8787 - accuracy: 0.2592 - val_loss: 1.8689 - val_accuracy: 0.2752
Epoch 4/15
1247/1247 [=====] - 12s 10ms/step - loss: 1.8342 - accuracy: 0.2779 - val_loss: 1.8425 - val_accuracy: 0.2705
Epoch 5/15
1247/1247 [=====] - 12s 9ms/step - loss: 1.8065 - accuracy: 0.2853 - val_loss: 1.8314 - val_accuracy: 0.2710
Epoch 6/15
1247/1247 [=====] - 12s 10ms/step - loss: 1.7846 - accuracy: 0.2932 - val_loss: 1.8103 - val_accuracy: 0.2767
Epoch 7/15
1247/1247 [=====] - 12s 10ms/step - loss: 1.7663 - accuracy: 0.2981 - val_loss: 1.8025 - val_accuracy: 0.2852
Epoch 8/15
1247/1247 [=====] - 14s 11ms/step - loss: 1.7495 - accuracy: 0.3054 - val_loss: 1.7927 - val_accuracy: 0.2848
Epoch 9/15
1247/1247 [=====] - 12s 10ms/step - loss: 1.7336 - accuracy: 0.3121 - val_loss: 1.7888 - val_accuracy: 0.2881
Epoch 10/15
1247/1247 [=====] - 12s 10ms/step - loss: 1.7194 - accuracy: 0.3195 - val_loss: 1.7836 - val_accuracy: 0.2967
Epoch 11/15
1247/1247 [=====] - 12s 10ms/step - loss: 1.7053 - accuracy: 0.3265 - val_loss: 1.7766 - val_accuracy: 0.2990
Epoch 12/15
1247/1247 [=====] - 12s 10ms/step - loss: 1.6918 - accuracy: 0.3312 - val_loss: 1.7769 - val_accuracy: 0.3071
Epoch 13/15
1247/1247 [=====] - 12s 10ms/step - loss: 1.6793 - accuracy: 0.3373 - val_loss: 1.7715 - val_accuracy: 0.2995
Epoch 14/15
1247/1247 [=====] - 12s 10ms/step - loss: 1.6664 - accuracy: 0.3439 - val_loss: 1.7801 - val_accuracy: 0.2971
Epoch 15/15
1247/1247 [=====] - 12s 9ms/step - loss: 1.6549 - accuracy: 0.3483 - val_loss: 1.7751 - val_accuracy: 0.3038
```

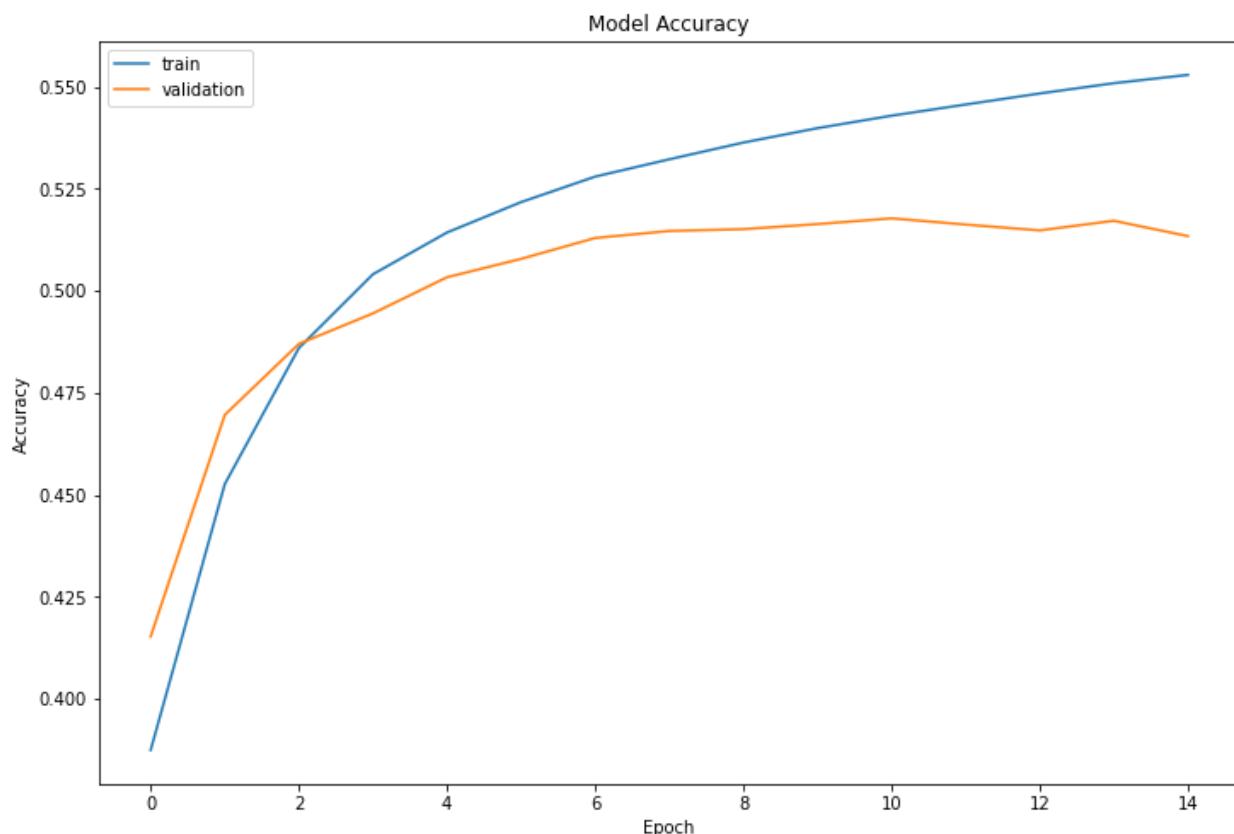
- b. Training on best Learning Rate 0.001 (I chose 0.001 LR as it has highest val_accuracy above all other LR's)

```

Epoch 1/15
24938/24938 [=====] - 259s 10ms/step - loss: 1.4596 - accuracy: 0.3875 - val_loss: 1.3520 - val_accuracy: 0.4153
Epoch 2/15
24938/24938 [=====] - 255s 10ms/step - loss: 1.2953 - accuracy: 0.4526 - val_loss: 1.2656 - val_accuracy: 0.4696
Epoch 3/15
24938/24938 [=====] - 249s 10ms/step - loss: 1.2247 - accuracy: 0.4860 - val_loss: 1.2232 - val_accuracy: 0.4870
Epoch 4/15
24938/24938 [=====] - 244s 10ms/step - loss: 1.1786 - accuracy: 0.5040 - val_loss: 1.1958 - val_accuracy: 0.4945
Epoch 5/15
24938/24938 [=====] - 239s 10ms/step - loss: 1.1511 - accuracy: 0.5143 - val_loss: 1.1822 - val_accuracy: 0.5033
Epoch 6/15
24938/24938 [=====] - 240s 10ms/step - loss: 1.1314 - accuracy: 0.5217 - val_loss: 1.1754 - val_accuracy: 0.5078
Epoch 7/15
24938/24938 [=====] - 237s 9ms/step - loss: 1.1165 - accuracy: 0.5280 - val_loss: 1.1677 - val_accuracy: 0.5129
Epoch 8/15
24938/24938 [=====] - 237s 10ms/step - loss: 1.1048 - accuracy: 0.5322 - val_loss: 1.1661 - val_accuracy: 0.5146
Epoch 9/15
24938/24938 [=====] - 237s 10ms/step - loss: 1.0947 - accuracy: 0.5363 - val_loss: 1.1596 - val_accuracy: 0.5151
Epoch 10/15
24938/24938 [=====] - 246s 10ms/step - loss: 1.0861 - accuracy: 0.5398 - val_loss: 1.1663 - val_accuracy: 0.5163
Epoch 11/15
24938/24938 [=====] - 243s 10ms/step - loss: 1.0786 - accuracy: 0.5429 - val_loss: 1.1596 - val_accuracy: 0.5177
Epoch 12/15
24938/24938 [=====] - 240s 10ms/step - loss: 1.0715 - accuracy: 0.5456 - val_loss: 1.1658 - val_accuracy: 0.5162
Epoch 13/15
24938/24938 [=====] - 242s 10ms/step - loss: 1.0655 - accuracy: 0.5483 - val_loss: 1.1746 - val_accuracy: 0.5148
Epoch 14/15
24938/24938 [=====] - 243s 10ms/step - loss: 1.0599 - accuracy: 0.5508 - val_loss: 1.1734 - val_accuracy: 0.5171
Epoch 15/15
24938/24938 [=====] - 247s 10ms/step - loss: 1.0547 - accuracy: 0.5529 - val_loss: 1.1796 - val_accuracy: 0.5134

```





Big Picture

Vanilla RNN

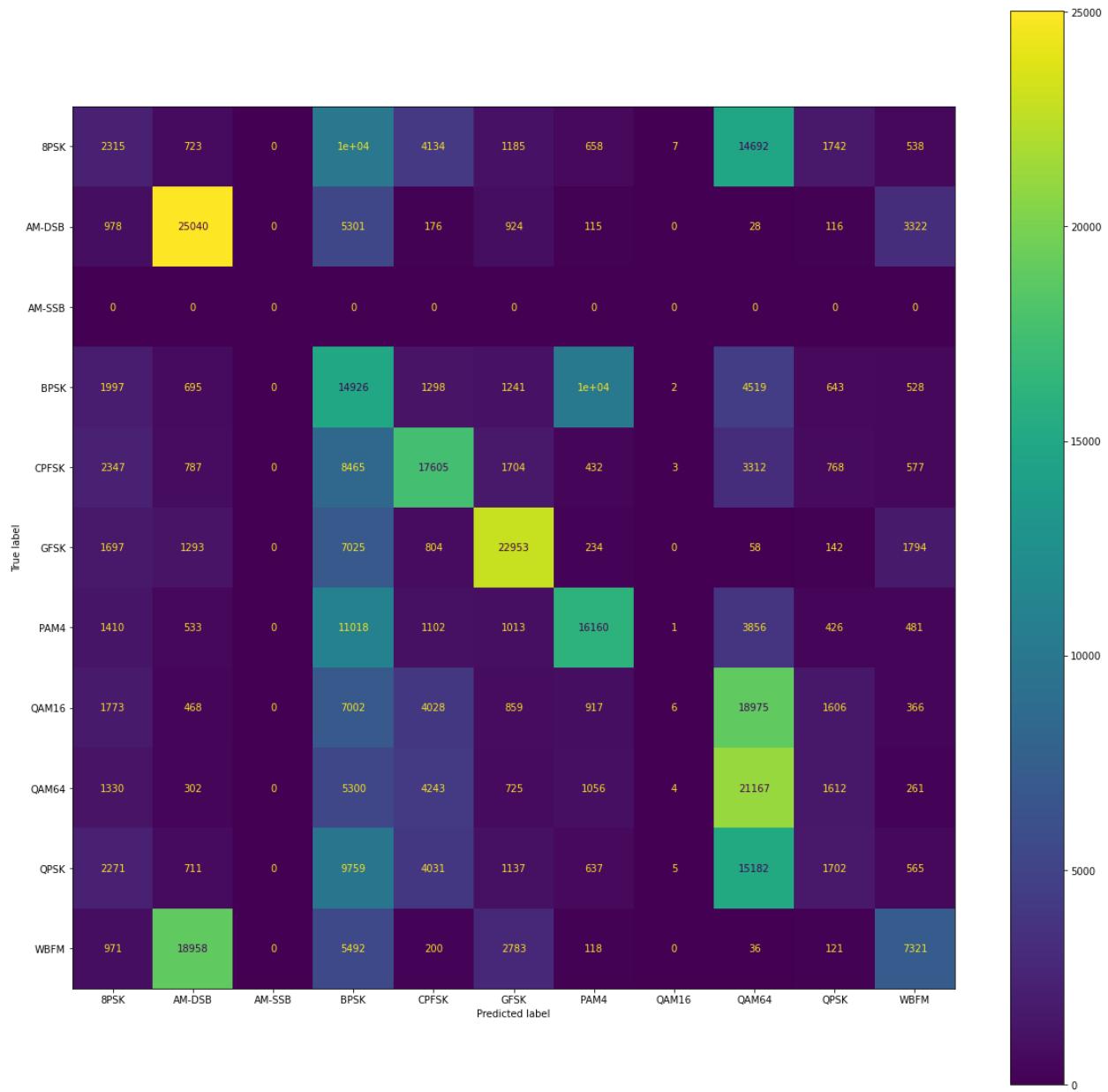
1. Raw + Derivative

a. Testing

```
▶ test_dataset = tf.data.Dataset.from_tensor_slices((X_test, y_test)).batch(64)
rnn_model.evaluate(test_dataset)

□ 5625/5625 [=====] - 11s 2ms/step - loss: 1.5616 - accuracy: 0.3589
[1.5615804195404053, 0.35887500643730164]
```

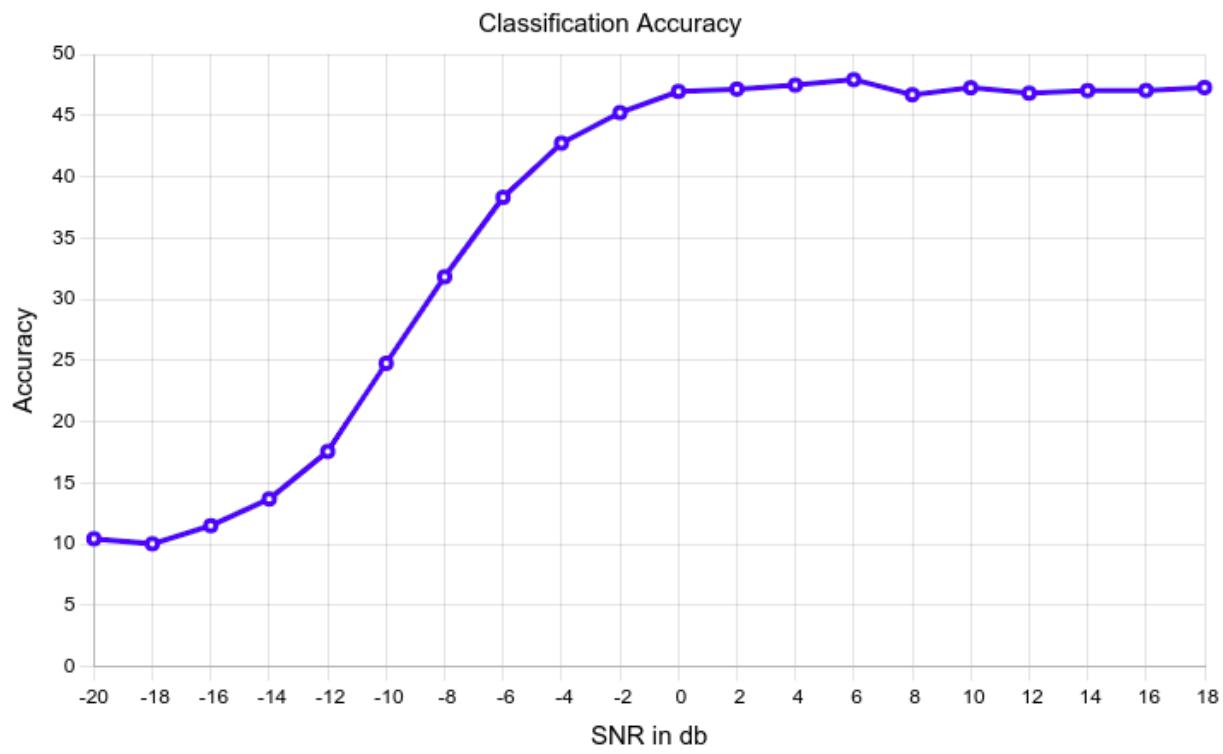
b. Confusion Matrix



Confusing elements : (AM-DSB,WBFM), (QAM64,QAM16), (QAM64,8PSK)

c. SNR with accuracy

```
SNR-20
282/282 [=====] - 2s 3ms/step - loss: 2.3620 - accuracy: 0.1044
SNR-18
282/282 [=====] - 1s 3ms/step - loss: 2.3497 - accuracy: 0.1003
SNR-16
282/282 [=====] - 1s 3ms/step - loss: 2.3107 - accuracy: 0.1151
SNR-14
282/282 [=====] - 1s 2ms/step - loss: 2.2411 - accuracy: 0.1369
SNR-12
282/282 [=====] - 1s 2ms/step - loss: 2.1408 - accuracy: 0.1757
SNR-10
282/282 [=====] - 1s 2ms/step - loss: 1.9826 - accuracy: 0.2476
SNR-8
282/282 [=====] - 1s 2ms/step - loss: 1.7959 - accuracy: 0.3183
SNR-6
282/282 [=====] - 1s 2ms/step - loss: 1.6161 - accuracy: 0.3831
SNR-4
282/282 [=====] - 1s 2ms/step - loss: 1.4130 - accuracy: 0.4274
SNR-2
282/282 [=====] - 1s 2ms/step - loss: 1.2689 - accuracy: 0.4523
SNR0
282/282 [=====] - 1s 2ms/step - loss: 1.1931 - accuracy: 0.4696
SNR2
282/282 [=====] - 1s 2ms/step - loss: 1.1752 - accuracy: 0.4715
SNR4
282/282 [=====] - 1s 2ms/step - loss: 1.1731 - accuracy: 0.4748
SNR6
282/282 [=====] - 1s 2ms/step - loss: 1.1661 - accuracy: 0.4792
SNR8
282/282 [=====] - 1s 2ms/step - loss: 1.1837 - accuracy: 0.4669
SNR10
282/282 [=====] - 1s 2ms/step - loss: 1.1669 - accuracy: 0.4726
SNR12
282/282 [=====] - 1s 2ms/step - loss: 1.1790 - accuracy: 0.4682
SNR14
282/282 [=====] - 1s 2ms/step - loss: 1.1689 - accuracy: 0.4703
SNR16
282/282 [=====] - 1s 2ms/step - loss: 1.1760 - accuracy: 0.4704
SNR18
282/282 [=====] - 1s 2ms/step - loss: 1.1690 - accuracy: 0.4728
```



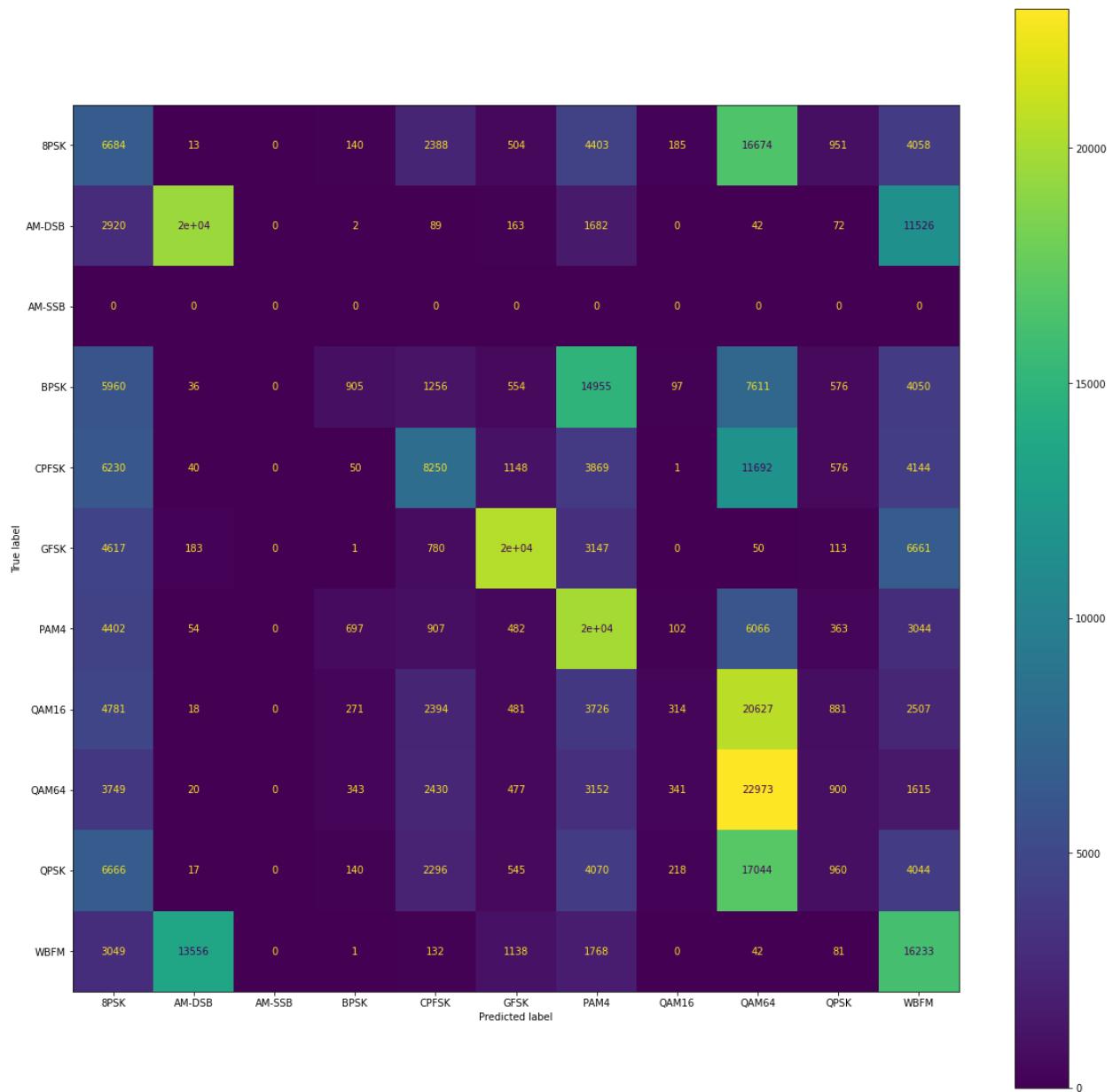
2. Raw + Integration

a. Testing

```
▶ test_dataset = tf.data.Dataset.from_tensor_slices((X_test, y_test)).batch(64)
rnn_model.evaluate(test_dataset)

□ 5625/5625 [=====] - 17s 3ms/step - loss: 1.6728 - accuracy: 0.3226
[1.6727735996246338, 0.3226499855518341]
```

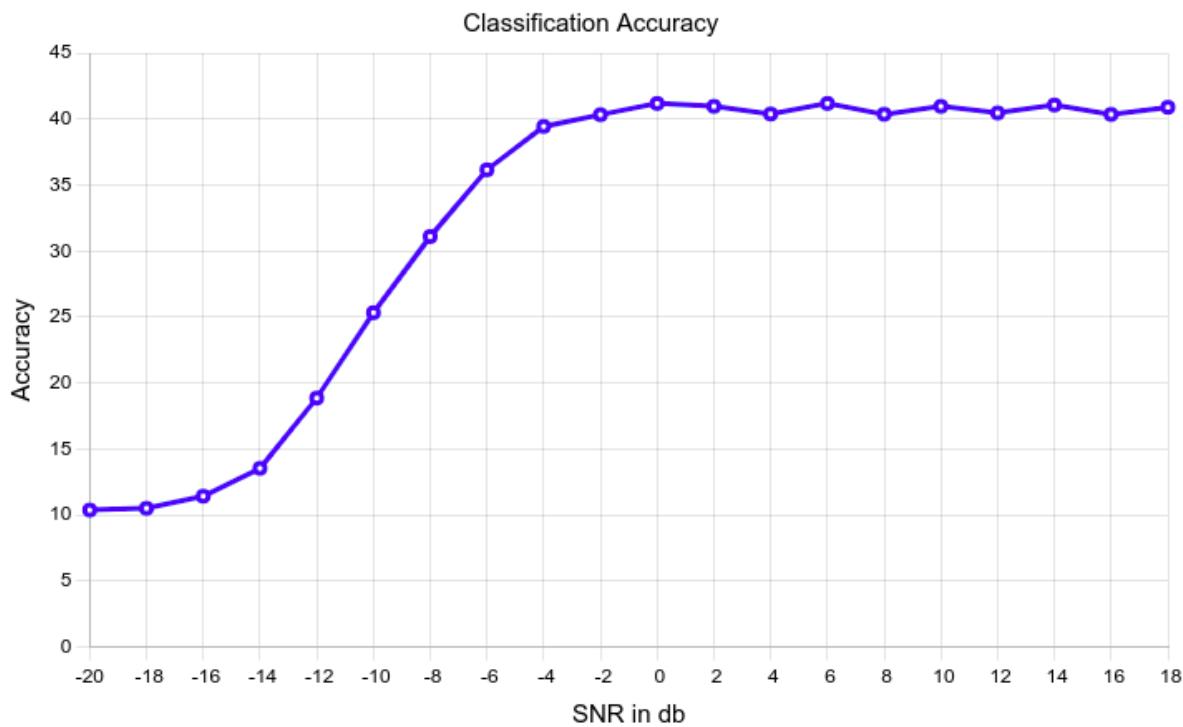
b. Confusion Matrix



Confusing elements: (AM-DSB,WBFM), (QAM64,QAM16),(PAM4,BPSK),(QAM64,8PSK)

c. SNR with accuracy

```
SNR-20
282/282 [=====] - 2s 3ms/step - loss: 2.3934 - accuracy: 0.1038
SNR-18
282/282 [=====] - 1s 3ms/step - loss: 2.3869 - accuracy: 0.1051
SNR-16
282/282 [=====] - 1s 3ms/step - loss: 2.3546 - accuracy: 0.1143
SNR-14
282/282 [=====] - 1s 2ms/step - loss: 2.2966 - accuracy: 0.1354
SNR-12
282/282 [=====] - 1s 3ms/step - loss: 2.2032 - accuracy: 0.1886
SNR-10
282/282 [=====] - 1s 3ms/step - loss: 2.0494 - accuracy: 0.2533
SNR-8
282/282 [=====] - 1s 3ms/step - loss: 1.8644 - accuracy: 0.3110
SNR-6
282/282 [=====] - 1s 2ms/step - loss: 1.6707 - accuracy: 0.3615
SNR-4
282/282 [=====] - 1s 3ms/step - loss: 1.4845 - accuracy: 0.3944
SNR-2
282/282 [=====] - 1s 3ms/step - loss: 1.3866 - accuracy: 0.4033
SNR0
282/282 [=====] - 1s 3ms/step - loss: 1.3330 - accuracy: 0.4118
SNR2
282/282 [=====] - 1s 3ms/step - loss: 1.3358 - accuracy: 0.4096
SNR4
282/282 [=====] - 1s 3ms/step - loss: 1.3334 - accuracy: 0.4083
SNR6
282/282 [=====] - 1s 3ms/step - loss: 1.3293 - accuracy: 0.4118
SNR8
282/282 [=====] - 1s 3ms/step - loss: 1.3470 - accuracy: 0.4036
SNR10
282/282 [=====] - 1s 3ms/step - loss: 1.3320 - accuracy: 0.4096
SNR12
282/282 [=====] - 1s 3ms/step - loss: 1.3421 - accuracy: 0.4046
SNR14
282/282 [=====] - 1s 3ms/step - loss: 1.3280 - accuracy: 0.4106
SNR16
282/282 [=====] - 1s 3ms/step - loss: 1.3474 - accuracy: 0.4035
SNR18
282/282 [=====] - 1s 2ms/step - loss: 1.3372 - accuracy: 0.4089
```



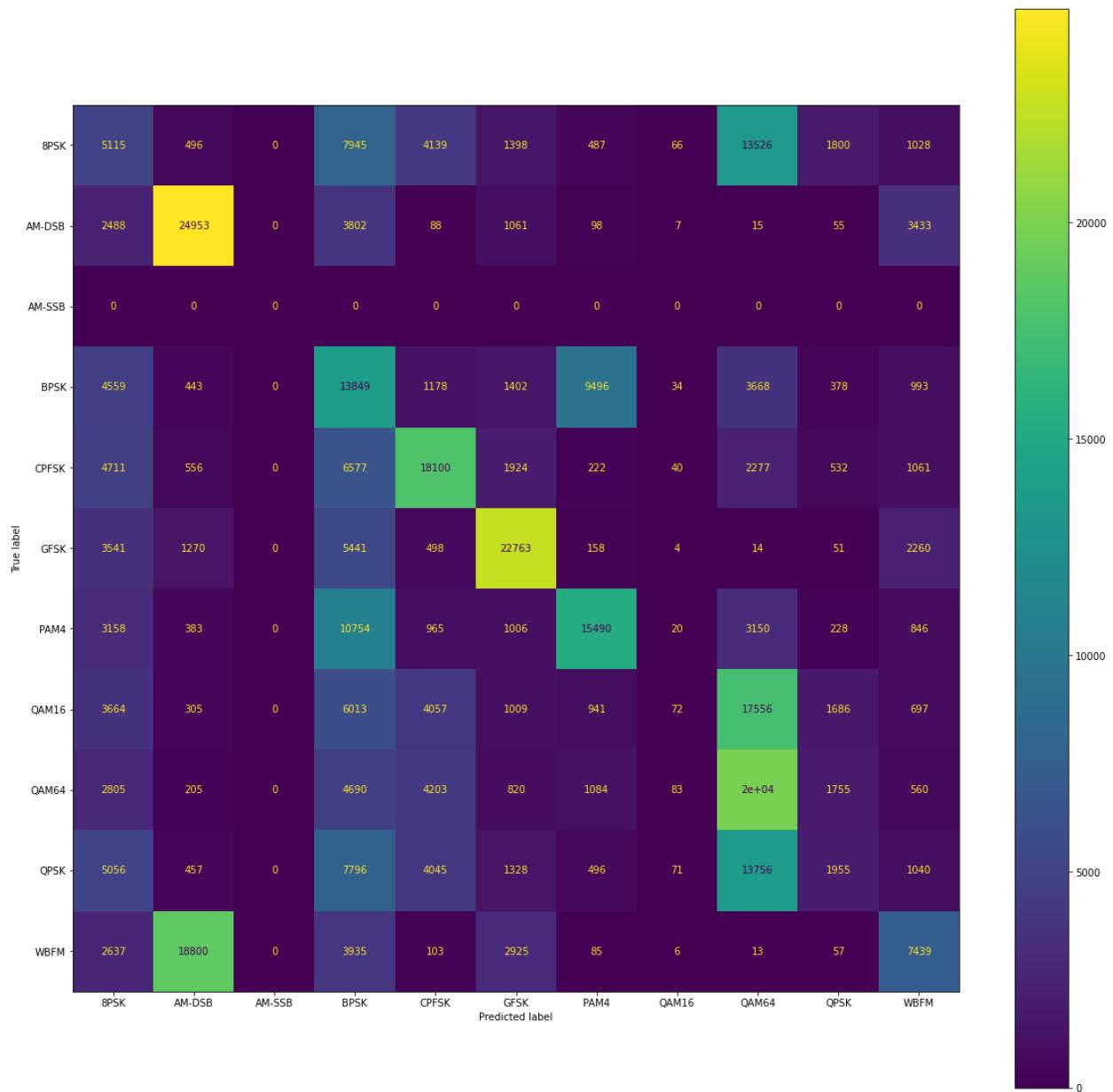
3. Derivative + Integration

a. Testing

```
[29] test_dataset = tf.data.Dataset.from_tensor_slices((X_test, y_test)).batch(64)
      rnn_model.evaluate(test_dataset)

5625/5625 [=====] - 14s 2ms/step - loss: 1.5591 - accuracy: 0.3598
[1.5591039657592773, 0.3598083257675171]
```

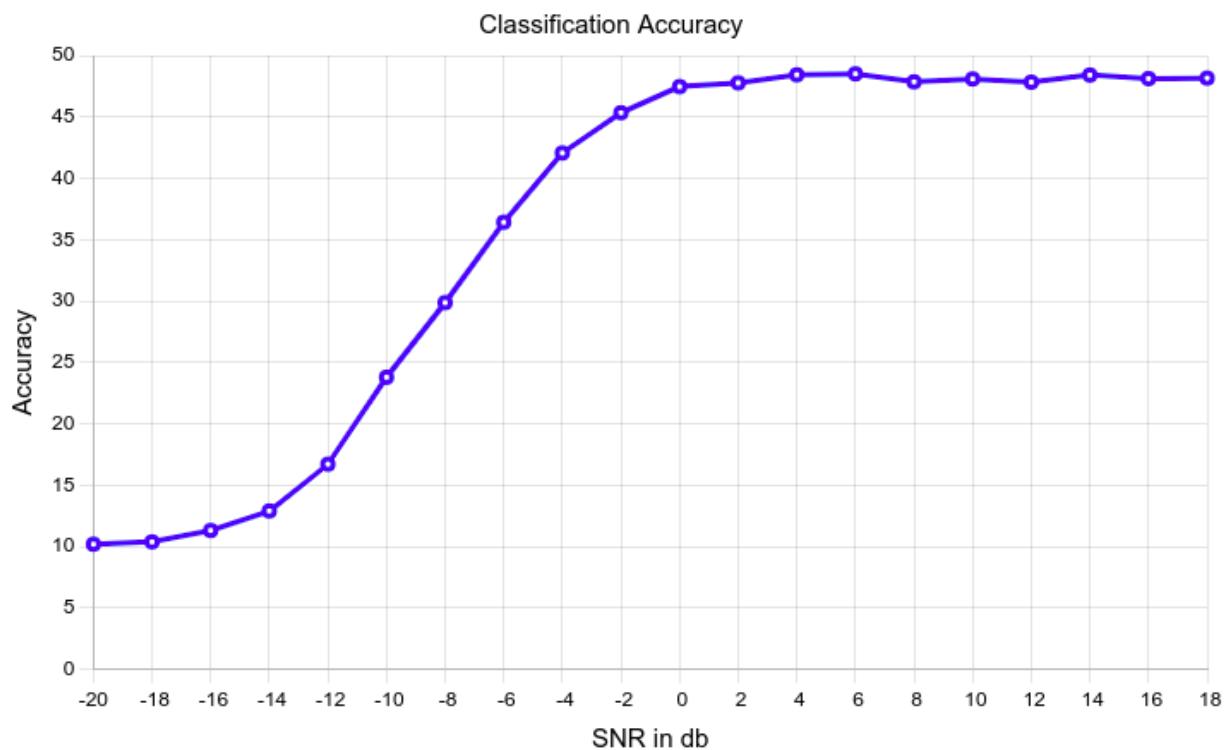
b. Confusion Matrix



Confusing elements : (AM-DSB,WBFM), (QAM64,QAM16),(QAM64,8PSK)

c. SNR with accuracy

```
SNR-20
282/282 [=====] - 2s 2ms/step - loss: 2.3603 - accuracy: 0.1019
SNR-18
282/282 [=====] - 1s 2ms/step - loss: 2.3480 - accuracy: 0.1038
SNR-16
282/282 [=====] - 1s 2ms/step - loss: 2.3151 - accuracy: 0.1131
SNR-14
282/282 [=====] - 1s 2ms/step - loss: 2.2562 - accuracy: 0.1290
SNR-12
282/282 [=====] - 1s 2ms/step - loss: 2.1556 - accuracy: 0.1671
SNR-10
282/282 [=====] - 1s 2ms/step - loss: 1.9922 - accuracy: 0.2379
SNR-8
282/282 [=====] - 1s 2ms/step - loss: 1.8077 - accuracy: 0.2987
SNR-6
282/282 [=====] - 1s 2ms/step - loss: 1.6429 - accuracy: 0.3642
SNR-4
282/282 [=====] - 1s 2ms/step - loss: 1.4554 - accuracy: 0.4206
SNR-2
282/282 [=====] - 1s 2ms/step - loss: 1.2868 - accuracy: 0.4534
SNR0
282/282 [=====] - 1s 2ms/step - loss: 1.1898 - accuracy: 0.4747
SNR2
282/282 [=====] - 1s 2ms/step - loss: 1.1595 - accuracy: 0.4777
SNR4
282/282 [=====] - 1s 2ms/step - loss: 1.1560 - accuracy: 0.4843
SNR6
282/282 [=====] - 1s 2ms/step - loss: 1.1445 - accuracy: 0.4851
SNR8
282/282 [=====] - 1s 2ms/step - loss: 1.1575 - accuracy: 0.4786
SNR10
282/282 [=====] - 1s 2ms/step - loss: 1.1453 - accuracy: 0.4809
SNR12
282/282 [=====] - 1s 2ms/step - loss: 1.1582 - accuracy: 0.4783
SNR14
282/282 [=====] - 1s 2ms/step - loss: 1.1489 - accuracy: 0.4841
SNR16
282/282 [=====] - 1s 2ms/step - loss: 1.1524 - accuracy: 0.4812
SNR18
282/282 [=====] - 1s 2ms/step - loss: 1.1497 - accuracy: 0.4816
```



- Average of Three combination accuracies at SNR :0 = $(47.47 + 41.18 + 46.96)/3 = 45.203\%$

CNN

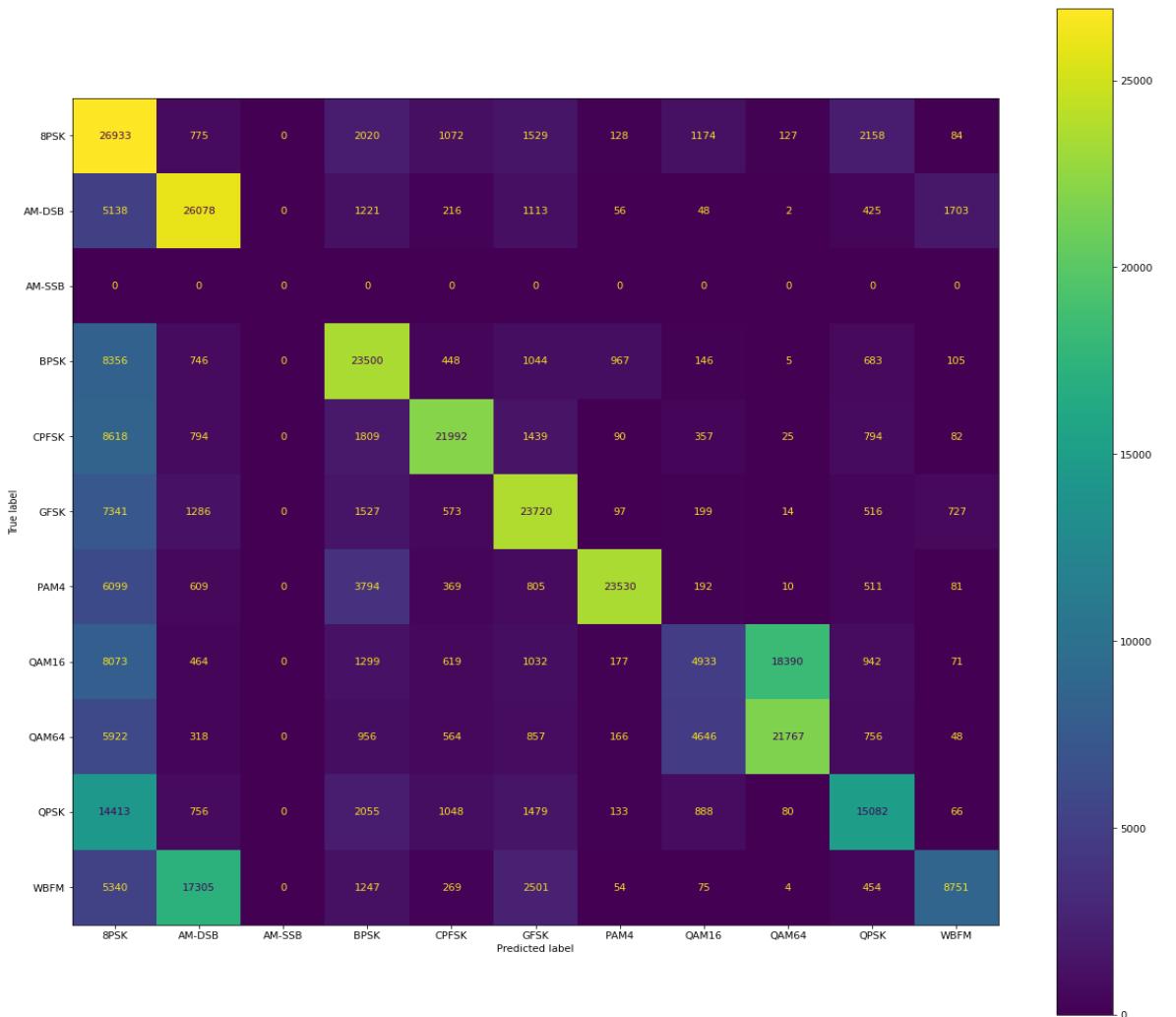
4. Raw + Derivative

a. Testing

```
test_dataset = tf.data.Dataset.from_tensor_slices((X_test, y_test)).batch(64)
conv_model.evaluate(test_dataset)

5625/5625 [=====] - 23s 4ms/step - loss: 1.1080 - accuracy: 0.5434
[1.1080158948898315, 0.543422221374512]
```

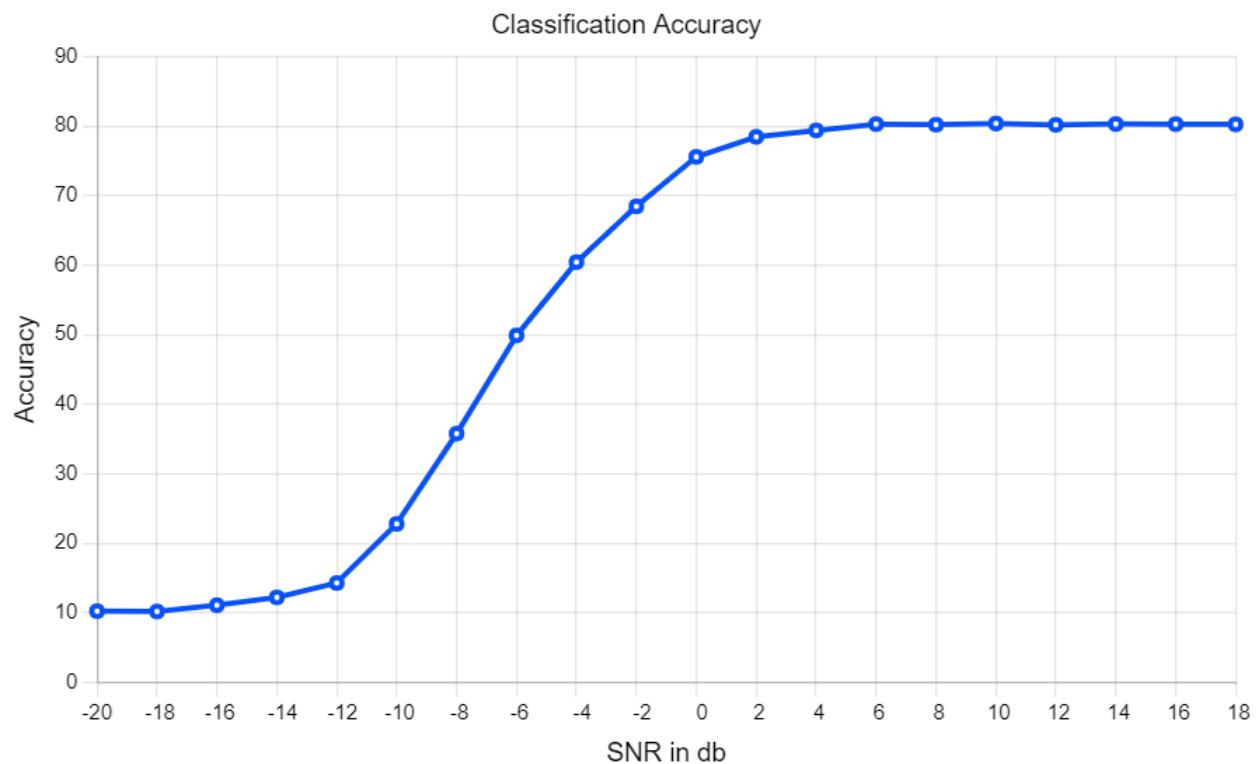
b. Confusion Matrix



Confusing elements : (AM-DSB,WBFM), (8PSK,QPSK),(QAM64,QAM16)

c. SNR with accuracy

```
SNR-20
282/282 [=====] - 1s 4ms/step - loss: 2.3722 - accuracy: 0.1023
SNR-18
282/282 [=====] - 1s 3ms/step - loss: 2.3612 - accuracy: 0.1018
SNR-16
282/282 [=====] - 1s 4ms/step - loss: 2.3344 - accuracy: 0.1109
SNR-14
282/282 [=====] - 1s 3ms/step - loss: 2.2751 - accuracy: 0.1221
SNR-12
282/282 [=====] - 1s 3ms/step - loss: 2.1728 - accuracy: 0.1428
SNR-10
282/282 [=====] - 1s 3ms/step - loss: 1.9370 - accuracy: 0.2278
SNR-8
282/282 [=====] - 1s 3ms/step - loss: 1.6375 - accuracy: 0.3576
SNR-6
282/282 [=====] - 1s 3ms/step - loss: 1.3208 - accuracy: 0.4989
SNR-4
282/282 [=====] - 1s 3ms/step - loss: 0.9538 - accuracy: 0.6043
SNR-2
282/282 [=====] - 1s 3ms/step - loss: 0.6789 - accuracy: 0.6845
SNR0
282/282 [=====] - 1s 3ms/step - loss: 0.4874 - accuracy: 0.7557
SNR2
282/282 [=====] - 1s 3ms/step - loss: 0.4164 - accuracy: 0.7844
SNR4
282/282 [=====] - 1s 3ms/step - loss: 0.3898 - accuracy: 0.7937
SNR6
282/282 [=====] - 1s 3ms/step - loss: 0.3762 - accuracy: 0.8028
SNR8
282/282 [=====] - 1s 4ms/step - loss: 0.3757 - accuracy: 0.8019
SNR10
282/282 [=====] - 1s 3ms/step - loss: 0.3748 - accuracy: 0.8036
SNR12
282/282 [=====] - 1s 3ms/step - loss: 0.3762 - accuracy: 0.8017
SNR14
282/282 [=====] - 1s 3ms/step - loss: 0.3755 - accuracy: 0.8029
SNR16
282/282 [=====] - 1s 4ms/step - loss: 0.3771 - accuracy: 0.8027
SNR18
282/282 [=====] - 1s 4ms/step - loss: 0.3779 - accuracy: 0.8024
```



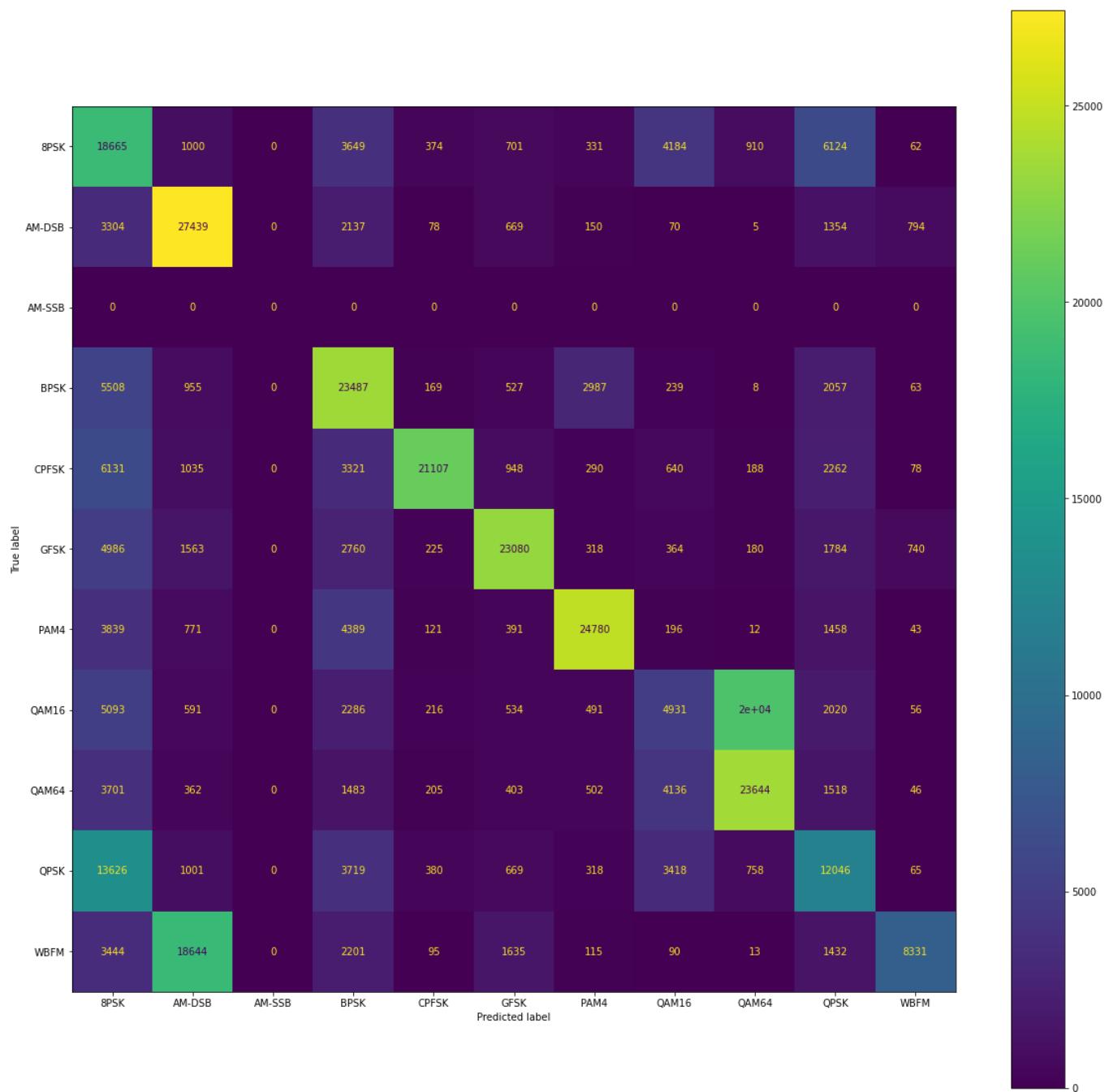
5. Raw + Integration

a. Testing

```
▶ test_dataset = tf.data.Dataset.from_tensor_slices((X_test, y_test)).batch(64)
conv_model.evaluate(test_dataset)

5625/5625 [=====] - 33s 4ms/step - loss: 1.1446 - accuracy: 0.5209
[1.1446237564086914, 0.5208610892295837]
```

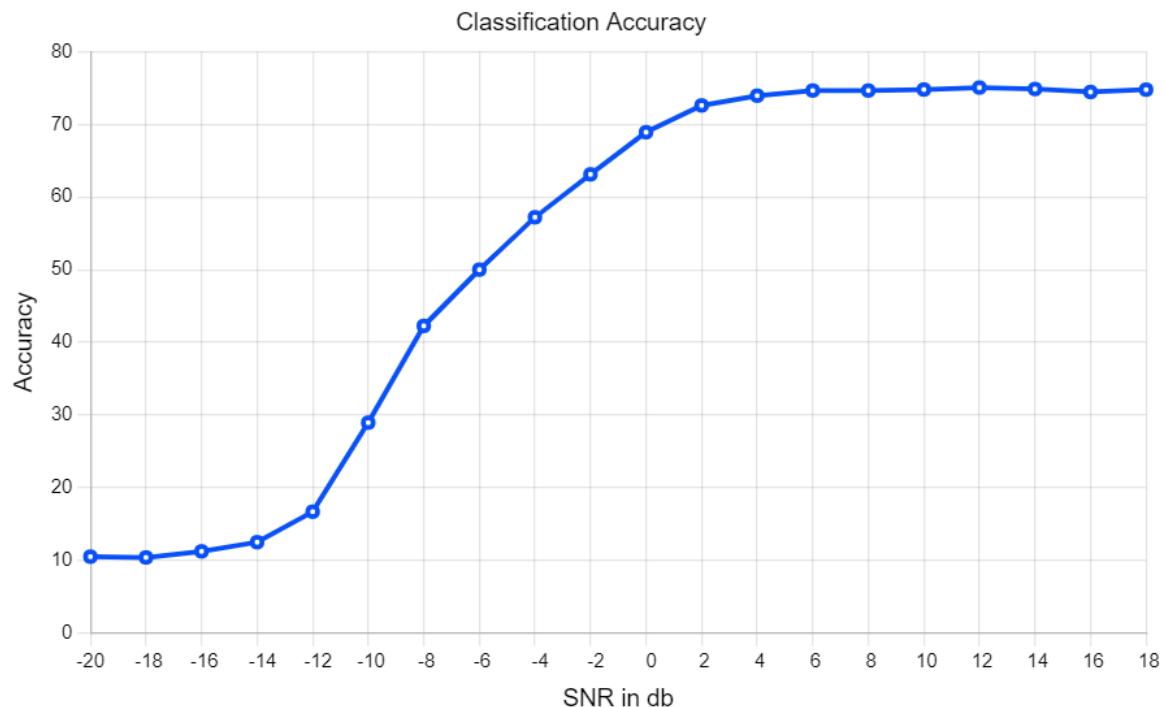
b. Confusion Matrix



Confusing elements: (AM-DSB,WBFM),(8PSK,QPSK),(QAM64,QAM16)

c. SNR with accuracy

```
SNR-20
282/282 [=====] - 1s 5ms/step - loss: 2.3648 - accuracy: 0.1049
SNR-18
282/282 [=====] - 1s 4ms/step - loss: 2.3546 - accuracy: 0.1038
SNR-16
282/282 [=====] - 1s 4ms/step - loss: 2.3158 - accuracy: 0.1122
SNR-14
282/282 [=====] - 1s 4ms/step - loss: 2.2446 - accuracy: 0.1248
SNR-12
282/282 [=====] - 1s 4ms/step - loss: 2.1168 - accuracy: 0.1668
SNR-10
282/282 [=====] - 1s 4ms/step - loss: 1.8673 - accuracy: 0.2894
SNR-8
282/282 [=====] - 1s 4ms/step - loss: 1.5609 - accuracy: 0.4226
SNR-6
282/282 [=====] - 1s 4ms/step - loss: 1.2851 - accuracy: 0.5000
SNR-4
282/282 [=====] - 1s 4ms/step - loss: 0.9869 - accuracy: 0.5721
SNR-2
282/282 [=====] - 1s 4ms/step - loss: 0.7888 - accuracy: 0.6312
SNR0
282/282 [=====] - 1s 4ms/step - loss: 0.6278 - accuracy: 0.6892
SNR2
282/282 [=====] - 1s 4ms/step - loss: 0.5388 - accuracy: 0.7261
SNR4
282/282 [=====] - 1s 4ms/step - loss: 0.4984 - accuracy: 0.7395
SNR6
282/282 [=====] - 1s 4ms/step - loss: 0.4805 - accuracy: 0.7466
SNR8
282/282 [=====] - 1s 4ms/step - loss: 0.4824 - accuracy: 0.7480
SNR10
282/282 [=====] - 1s 4ms/step - loss: 0.4783 - accuracy: 0.7507
SNR12
282/282 [=====] - 1s 4ms/step - loss: 0.4768 - accuracy: 0.7487
SNR14
282/282 [=====] - 1s 4ms/step - loss: 0.4731 - accuracy: 0.7446
SNR16
282/282 [=====] - 1s 4ms/step - loss: 0.4751 - accuracy: 0.7478
SNR18
282/282 [=====] - 1s 4ms/step - loss: 0.4758 - accuracy: 0.7483
```



6. Derivative + Integration

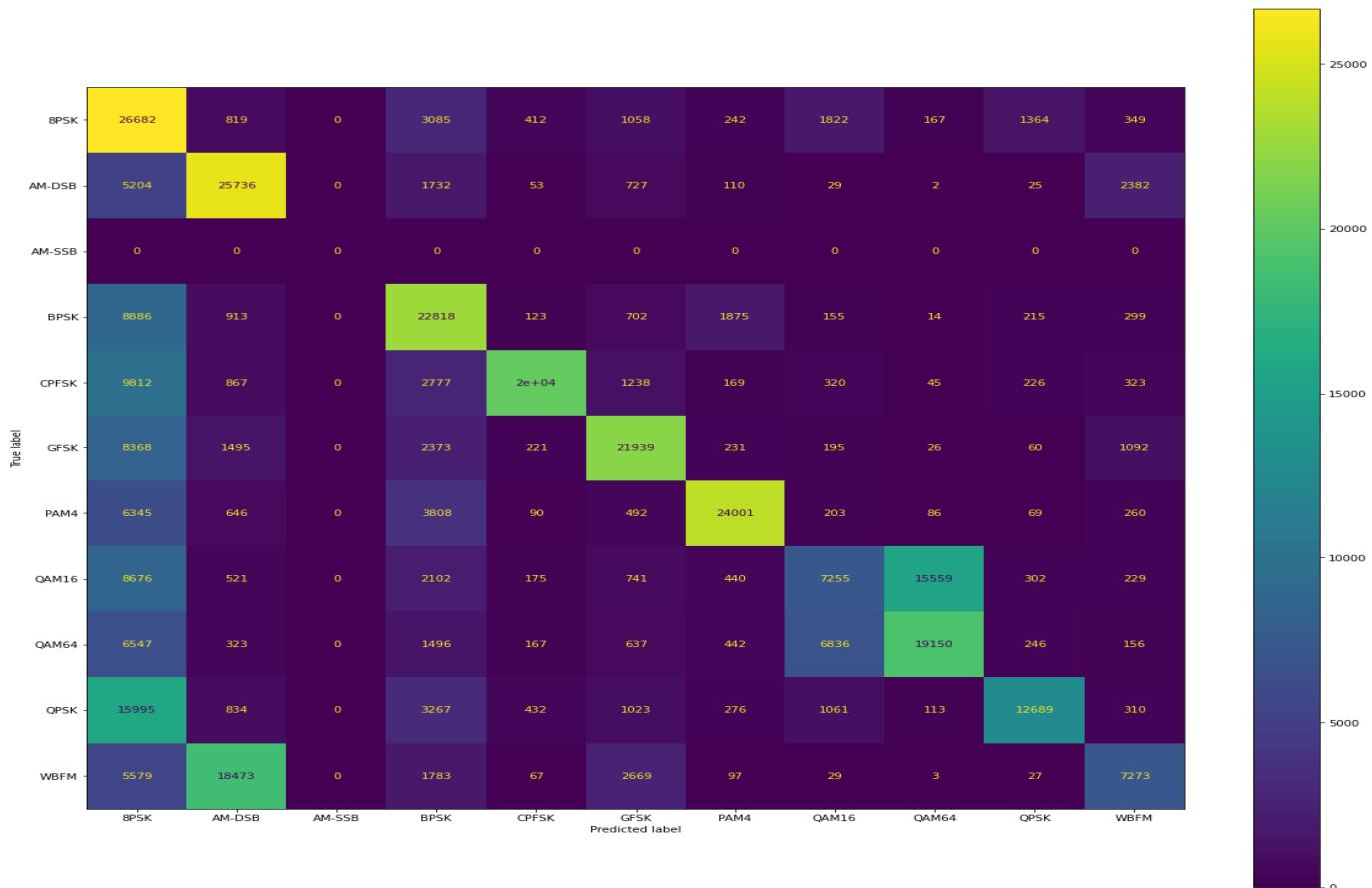
a. Testing

```
test_dataset = tf.data.Dataset.from_tensor_slices((X_test, y_test)).batch(64)
conv_model.evaluate(test_dataset)

5625/5625 [=====] - 25s 4ms/step - loss: 1.1654 - accuracy: 0.5216
[1.1654253005981445, 0.5215722322463989]
```

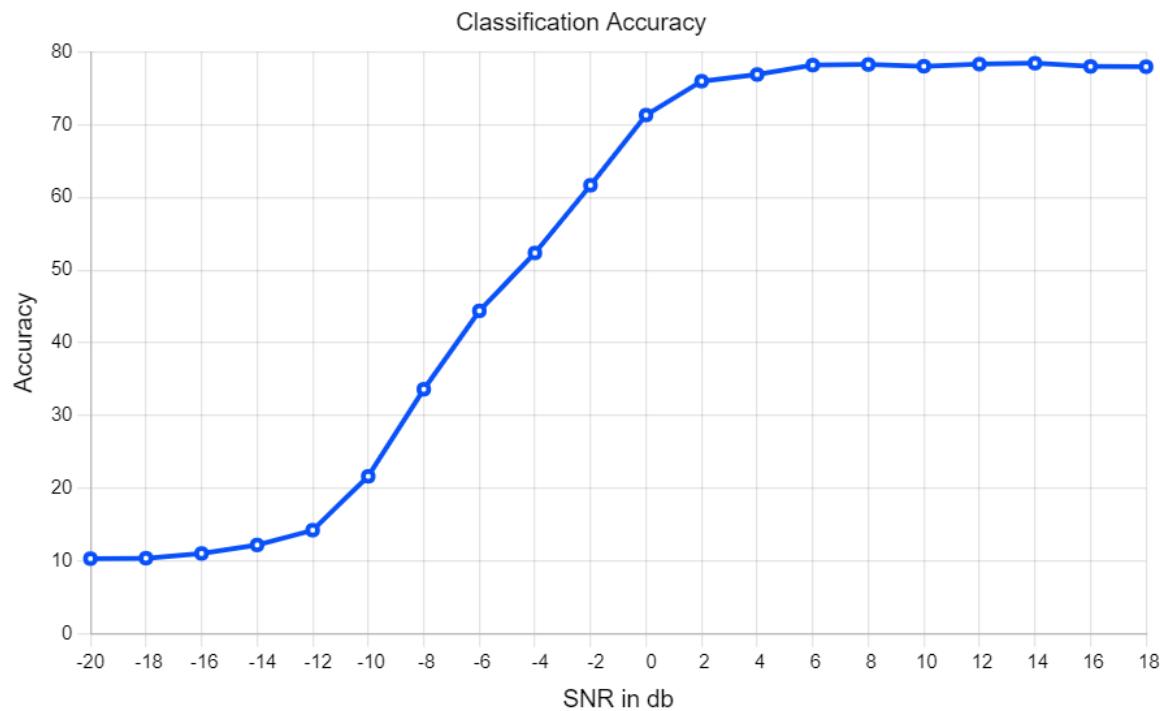
b. Confusion Matrix

Confusing element: (AM-DSB,WBFM), (8PSK, QPSK), (QAM64,QAM16)



c. SNR with accuracy

```
SNR-20
282/282 [=====] - 1s 4ms/step - loss: 2.3646 - accuracy: 0.1032
SNR-18
282/282 [=====] - 1s 4ms/step - loss: 2.3487 - accuracy: 0.1038
SNR-16
282/282 [=====] - 1s 4ms/step - loss: 2.3293 - accuracy: 0.1103
SNR-14
282/282 [=====] - 1s 4ms/step - loss: 2.2812 - accuracy: 0.1220
SNR-12
282/282 [=====] - 1s 4ms/step - loss: 2.1848 - accuracy: 0.1423
SNR-10
282/282 [=====] - 1s 4ms/step - loss: 1.9659 - accuracy: 0.2164
SNR-8
282/282 [=====] - 1s 4ms/step - loss: 1.6916 - accuracy: 0.3361
SNR-6
282/282 [=====] - 1s 4ms/step - loss: 1.4437 - accuracy: 0.4439
SNR-4
282/282 [=====] - 1s 4ms/step - loss: 1.1838 - accuracy: 0.5235
SNR-2
282/282 [=====] - 1s 4ms/step - loss: 0.8767 - accuracy: 0.6166
SNR0
282/282 [=====] - 1s 4ms/step - loss: 0.6038 - accuracy: 0.7131
SNR2
282/282 [=====] - 1s 4ms/step - loss: 0.4956 - accuracy: 0.7597
SNR4
282/282 [=====] - 1s 4ms/step - loss: 0.4570 - accuracy: 0.7689
SNR6
282/282 [=====] - 1s 4ms/step - loss: 0.4378 - accuracy: 0.7818
SNR8
282/282 [=====] - 1s 4ms/step - loss: 0.4390 - accuracy: 0.7826
SNR10
282/282 [=====] - 1s 4ms/step - loss: 0.4435 - accuracy: 0.7803
SNR12
282/282 [=====] - 1s 4ms/step - loss: 0.4347 - accuracy: 0.7831
SNR14
282/282 [=====] - 1s 4ms/step - loss: 0.4352 - accuracy: 0.7844
SNR16
282/282 [=====] - 1s 4ms/step - loss: 0.4442 - accuracy: 0.7800
SNR18
282/282 [=====] - 1s 4ms/step - loss: 0.4474 - accuracy: 0.7796
```



- Average of Three combination accuracies at SNR :0 =
 $(75.57 + 68.92 + 71.31)/3 = 71.933\%$

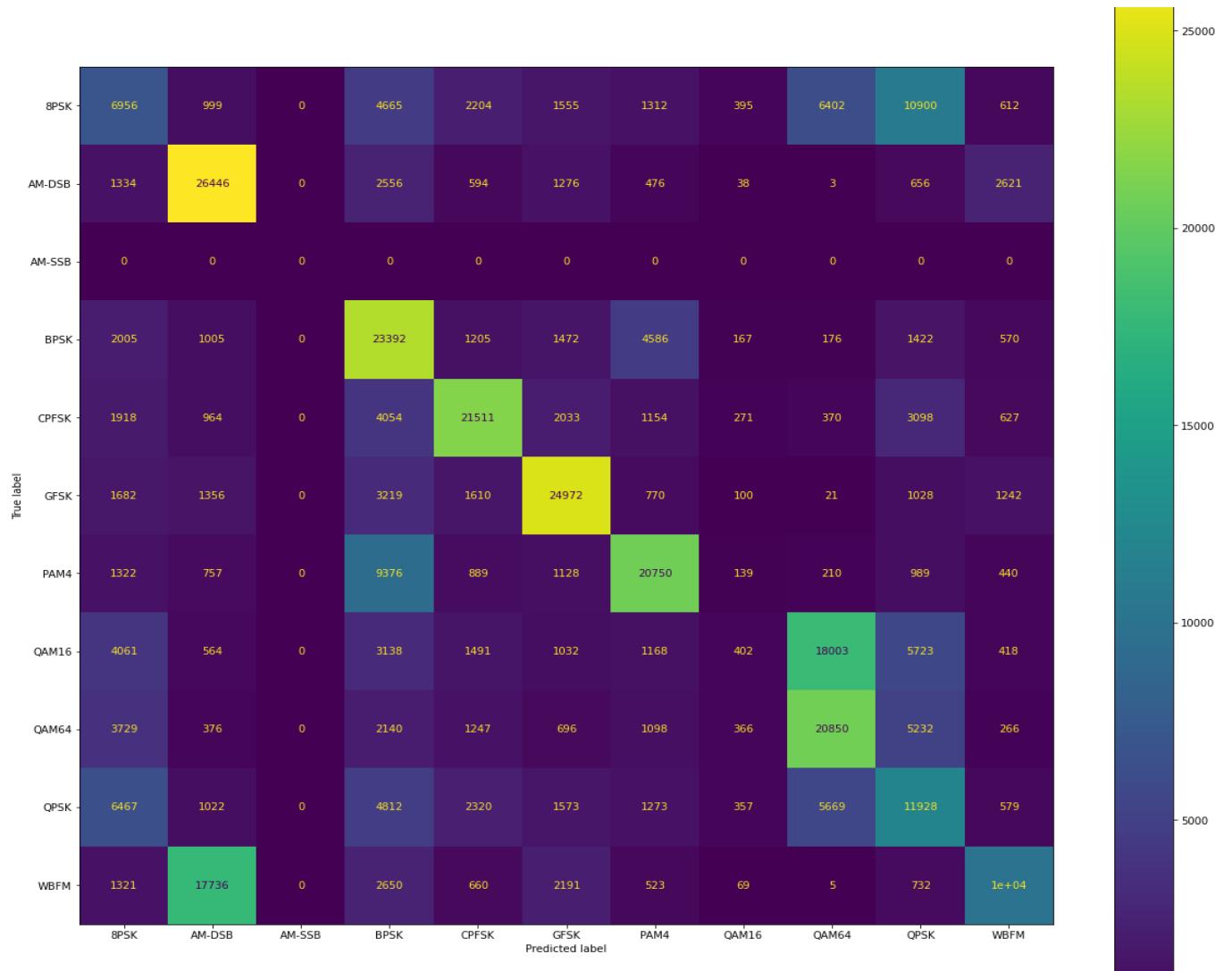
LSTM

7. Raw + Derivative

a. Testing

```
[25] lstm.load_weights(checkpoint_filepath)
<tensorflow.python.training.tracking.util.CheckpointLoadStatus at 0x7f6181754090>
▶ test_dataset = tf.data.Dataset.from_tensor_slices((X_test, y_test)).batch(64)
lstm.evaluate(test_dataset)
5625/5625 [=====] - 29s 4ms/step - loss: 1.2712 - accuracy: 0.4648
[1.2712018489837646, 0.46477776765823364]
```

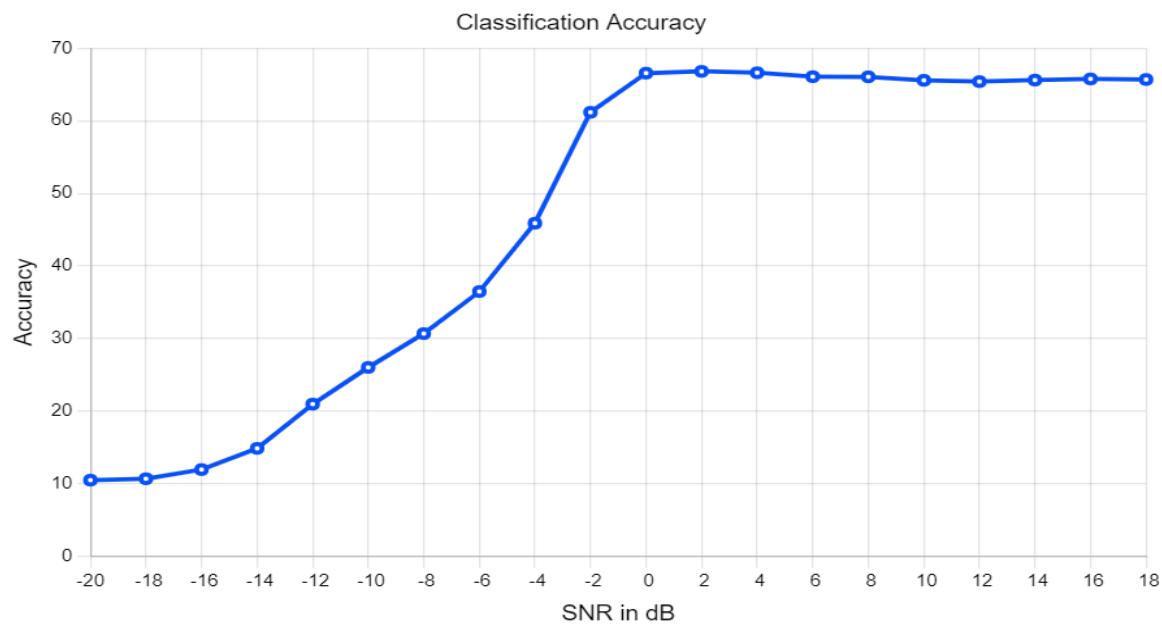
b. Confusion Matrix



Confusing element: (AM-DSB,WBFM), (QAM64,QAM16), (QPSK,8PSK)

c. SNR with accuracy

```
SNR-20
282/282 [=====] - 7s 4ms/step - loss: 2.3717 - accuracy: 0.1048
SNR-18
282/282 [=====] - 1s 4ms/step - loss: 2.3580 - accuracy: 0.1067
SNR-16
282/282 [=====] - 1s 4ms/step - loss: 2.3062 - accuracy: 0.1194
SNR-14
282/282 [=====] - 1s 4ms/step - loss: 2.2120 - accuracy: 0.1486
SNR-12
282/282 [=====] - 1s 4ms/step - loss: 2.0795 - accuracy: 0.2096
SNR-10
282/282 [=====] - 1s 4ms/step - loss: 1.8890 - accuracy: 0.2602
SNR-8
282/282 [=====] - 1s 4ms/step - loss: 1.6601 - accuracy: 0.3068
SNR-6
282/282 [=====] - 1s 5ms/step - loss: 1.4457 - accuracy: 0.3648
SNR-4
282/282 [=====] - 1s 5ms/step - loss: 1.1511 - accuracy: 0.4590
SNR-2
282/282 [=====] - 1s 4ms/step - loss: 0.8447 - accuracy: 0.6119
SNR0
282/282 [=====] - 1s 4ms/step - loss: 0.7149 - accuracy: 0.6659
SNR2
282/282 [=====] - 1s 4ms/step - loss: 0.6938 - accuracy: 0.6683
SNR4
282/282 [=====] - 1s 4ms/step - loss: 0.6951 - accuracy: 0.6664
SNR6
282/282 [=====] - 1s 4ms/step - loss: 0.7093 - accuracy: 0.6610
SNR8
282/282 [=====] - 1s 4ms/step - loss: 0.7132 - accuracy: 0.6608
SNR10
282/282 [=====] - 1s 4ms/step - loss: 0.7177 - accuracy: 0.6560
SNR12
282/282 [=====] - 1s 4ms/step - loss: 0.7146 - accuracy: 0.6542
SNR14
282/282 [=====] - 1s 4ms/step - loss: 0.7177 - accuracy: 0.6563
SNR16
282/282 [=====] - 1s 4ms/step - loss: 0.7142 - accuracy: 0.6579
SNR18
282/282 [=====] - 1s 4ms/step - loss: 0.7156 - accuracy: 0.6571
```



8. Raw + Integration

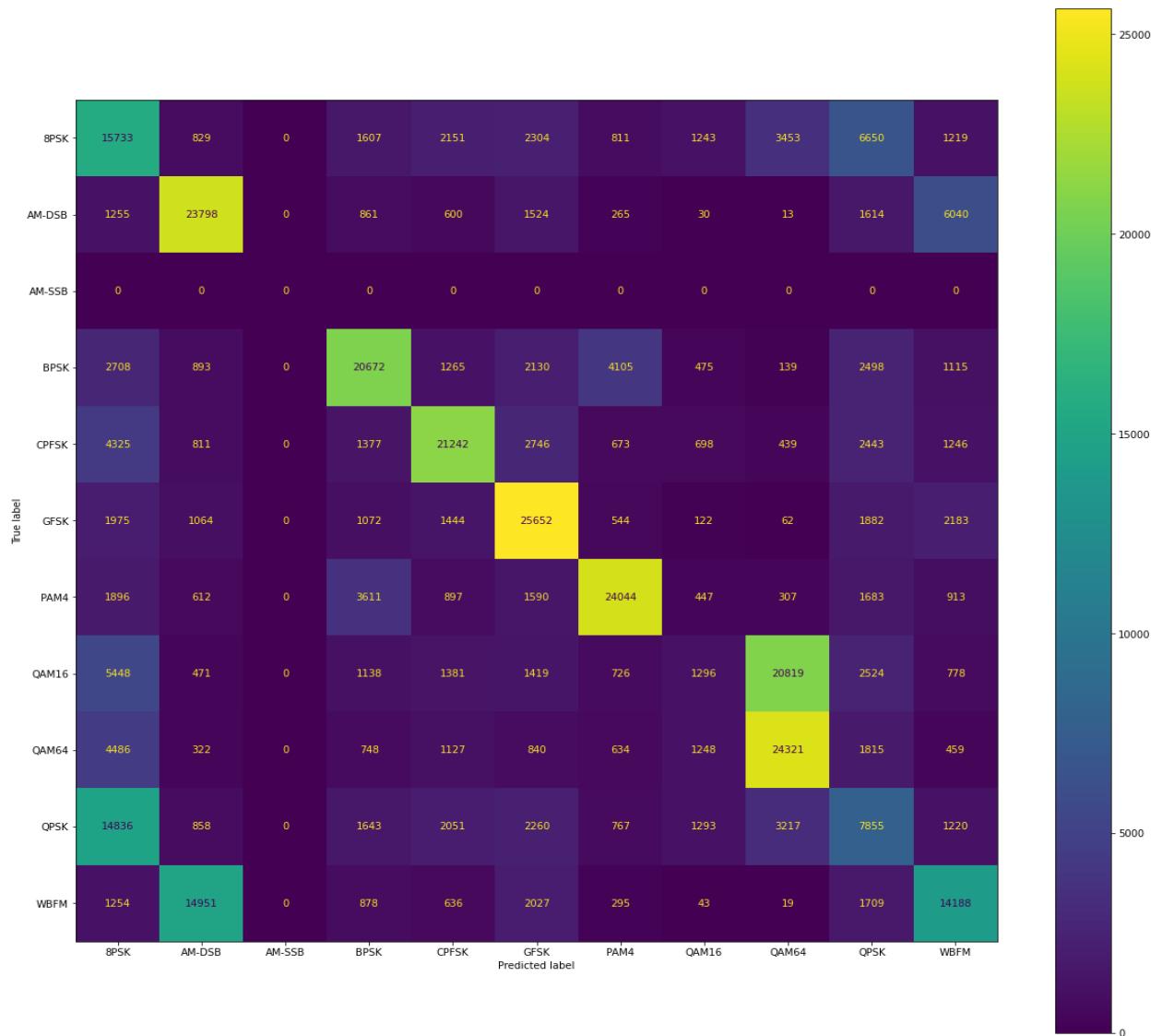
a. Testing

```
[31] lstm.load_weights(checkpoint_filepath)
      <tensorflow.python.training.tracking.util.CheckpointLoadStatus at 0x7fd74f727d90>

▶   test_dataset = tf.data.Dataset.from_tensor_slices((X_test, y_test)).batch(64)
       lstm.evaluate(test_dataset)

5625/5625 [=====] - 28s 4ms/step - loss: 1.1902 - accuracy: 0.4967
[1.1901559829711914, 0.4966694414615631]
```

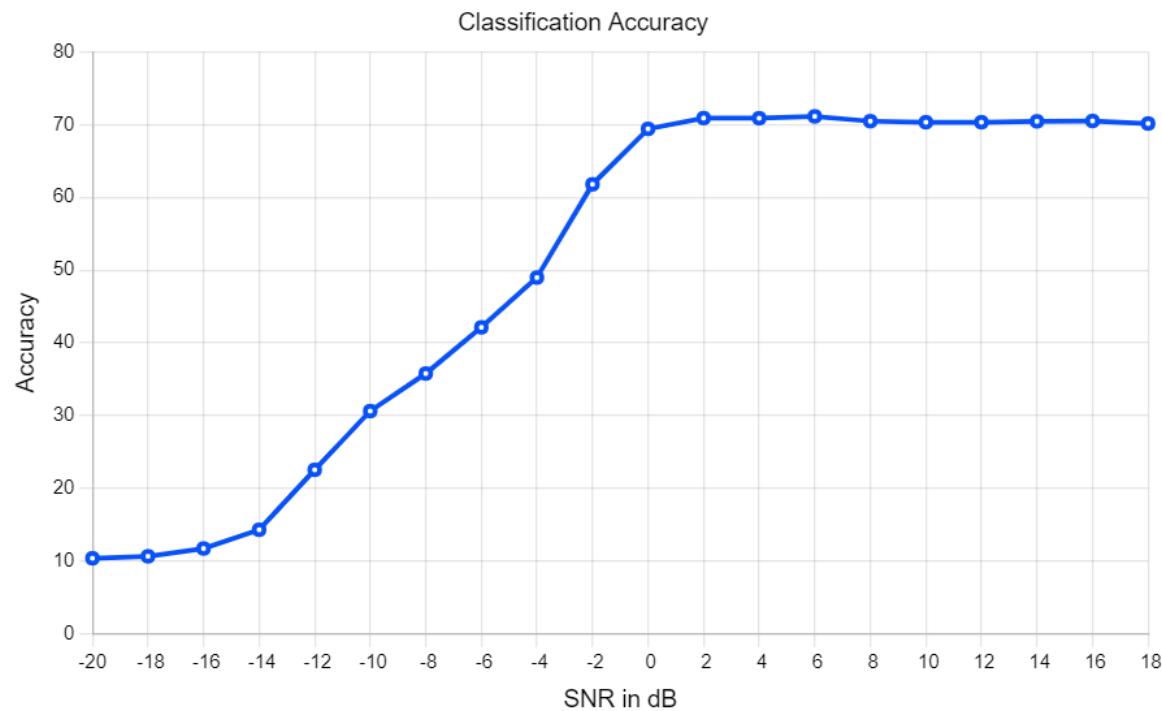
b. Confusion Matrix



Confusing elements: (WBFM,AM-DSB), (8PSK,QPSK), (QAM64,QAM16)

c. SNR with accuracy

```
SNR-20
282/282 [=====] - 7s 4ms/step - loss: 2.3618 - accuracy: 0.1037
SNR-18
282/282 [=====] - 1s 4ms/step - loss: 2.3497 - accuracy: 0.1064
SNR-16
282/282 [=====] - 1s 4ms/step - loss: 2.2945 - accuracy: 0.1171
SNR-14
282/282 [=====] - 1s 4ms/step - loss: 2.1991 - accuracy: 0.1429
SNR-12
282/282 [=====] - 1s 4ms/step - loss: 2.0543 - accuracy: 0.2253
SNR-10
282/282 [=====] - 1s 4ms/step - loss: 1.8564 - accuracy: 0.3061
SNR-8
282/282 [=====] - 1s 4ms/step - loss: 1.5996 - accuracy: 0.3577
SNR-6
282/282 [=====] - 1s 4ms/step - loss: 1.3750 - accuracy: 0.4212
SNR-4
282/282 [=====] - 1s 4ms/step - loss: 1.0967 - accuracy: 0.4897
SNR-2
282/282 [=====] - 1s 4ms/step - loss: 0.8023 - accuracy: 0.6179
SNR0
282/282 [=====] - 1s 4ms/step - loss: 0.6091 - accuracy: 0.6941
SNR2
282/282 [=====] - 1s 4ms/step - loss: 0.5619 - accuracy: 0.7090
SNR4
282/282 [=====] - 1s 4ms/step - loss: 0.5630 - accuracy: 0.7088
SNR6
282/282 [=====] - 1s 4ms/step - loss: 0.5711 - accuracy: 0.7113
SNR8
282/282 [=====] - 1s 4ms/step - loss: 0.5796 - accuracy: 0.7047
SNR10
282/282 [=====] - 1s 4ms/step - loss: 0.5842 - accuracy: 0.7033
SNR12
282/282 [=====] - 1s 4ms/step - loss: 0.5867 - accuracy: 0.7033
SNR14
282/282 [=====] - 1s 4ms/step - loss: 0.5828 - accuracy: 0.7045
SNR16
282/282 [=====] - 1s 4ms/step - loss: 0.5851 - accuracy: 0.7050
SNR18
282/282 [=====] - 1s 4ms/step - loss: 0.5902 - accuracy: 0.7015
```



9. Derivative + Integration

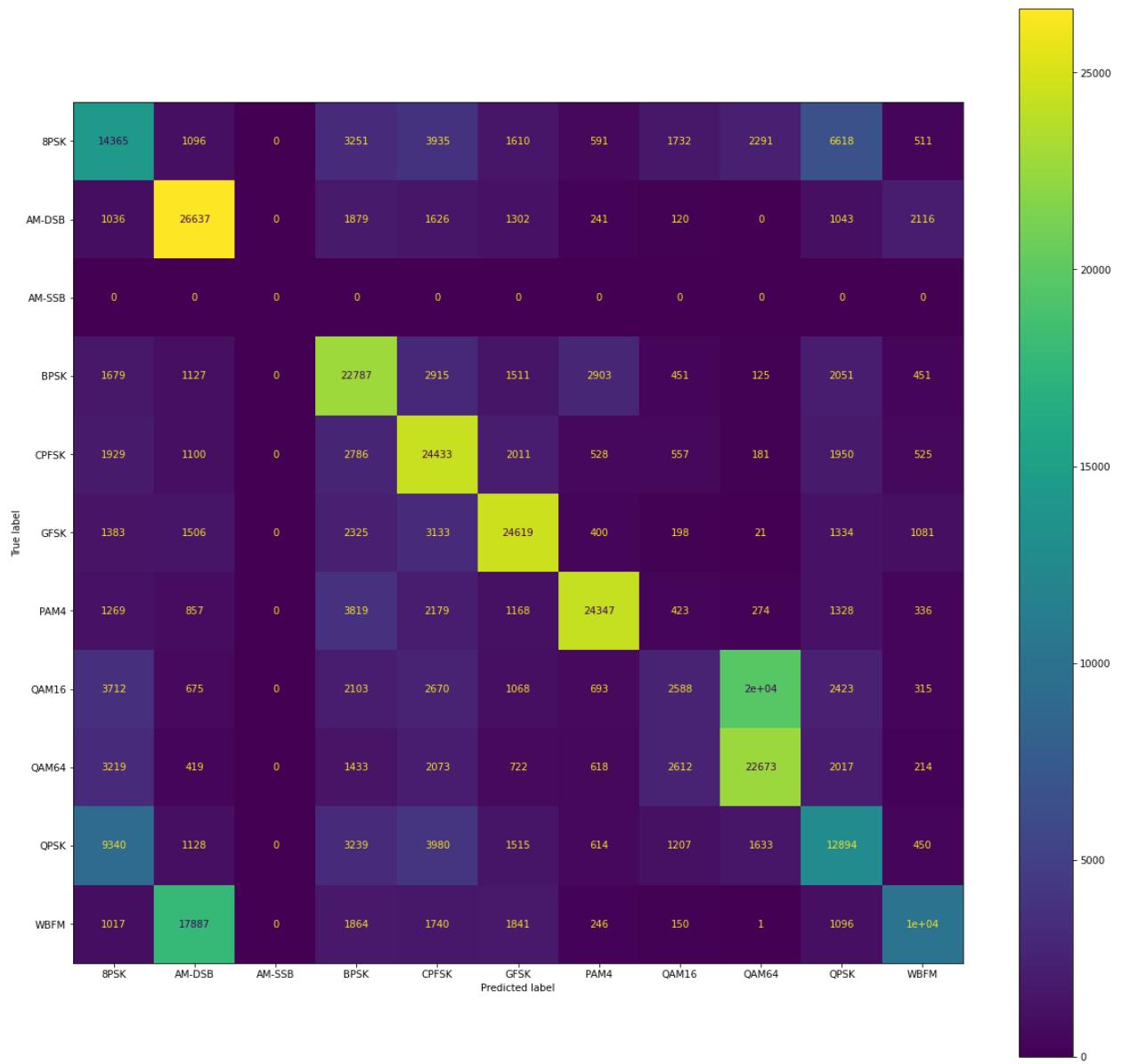
a. Testing

```
[30] lstm.load_weights(checkpoint_filepath)
<tensorflow.python.training.tracking.util.CheckpointLoadStatus at 0x7eff075fe250>

[31] test_dataset = tf.data.Dataset.from_tensor_slices((X_test, y_test)).batch(64)
lstm.evaluate(test_dataset)

5625/5625 [=====] - 28s 4ms/step - loss: 1.1639 - accuracy: 0.5153
[1.1638702154159546, 0.515280544757843]
```

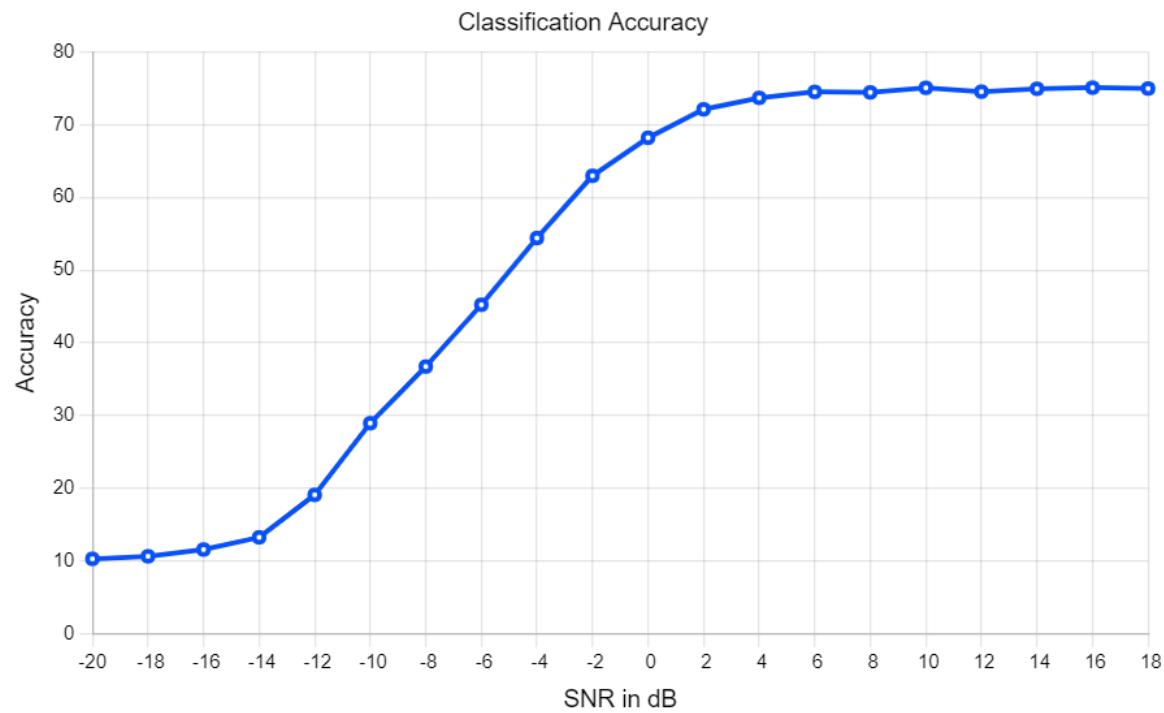
b. Confusion Matrix



Confusing elements : (QPSK,8PSK), (WBFM, AM-DSB),

c. SNR with accuracy

```
SNR-20
282/282 [=====] - 7s 4ms/step - loss: 2.3784 - accuracy: 0.1029
SNR-18
282/282 [=====] - 1s 4ms/step - loss: 2.3670 - accuracy: 0.1064
SNR-16
282/282 [=====] - 1s 4ms/step - loss: 2.3166 - accuracy: 0.1157
SNR-14
282/282 [=====] - 1s 4ms/step - loss: 2.2472 - accuracy: 0.1325
SNR-12
282/282 [=====] - 1s 4ms/step - loss: 2.1182 - accuracy: 0.1909
SNR-10
282/282 [=====] - 1s 4ms/step - loss: 1.9031 - accuracy: 0.2894
SNR-8
282/282 [=====] - 1s 4ms/step - loss: 1.6306 - accuracy: 0.3673
SNR-6
282/282 [=====] - 1s 4ms/step - loss: 1.3416 - accuracy: 0.4523
SNR-4
282/282 [=====] - 1s 4ms/step - loss: 1.0410 - accuracy: 0.5440
SNR-2
282/282 [=====] - 1s 4ms/step - loss: 0.8182 - accuracy: 0.6296
SNR0
282/282 [=====] - 1s 4ms/step - loss: 0.6599 - accuracy: 0.6819
SNR2
282/282 [=====] - 1s 4ms/step - loss: 0.5543 - accuracy: 0.7210
SNR4
282/282 [=====] - 1s 4ms/step - loss: 0.5130 - accuracy: 0.7368
SNR6
282/282 [=====] - 1s 4ms/step - loss: 0.4927 - accuracy: 0.7450
SNR8
282/282 [=====] - 1s 4ms/step - loss: 0.4893 - accuracy: 0.7443
SNR10
282/282 [=====] - 1s 4ms/step - loss: 0.4815 - accuracy: 0.7506
SNR12
282/282 [=====] - 1s 4ms/step - loss: 0.4855 - accuracy: 0.7453
SNR14
282/282 [=====] - 1s 5ms/step - loss: 0.4798 - accuracy: 0.7493
SNR16
282/282 [=====] - 2s 6ms/step - loss: 0.4776 - accuracy: 0.7508
SNR18
282/282 [=====] - 1s 4ms/step - loss: 0.4820 - accuracy: 0.7496
```



- Average of Three combination accuracies at SNR :0 =
 $(66.59 + 69.41 + 69.19)/3 = 68.396\%$