

```
In [1]: from tensorflow.keras.datasets import mnist
import tensorflow as tf
import numpy as np
from Lect10Utils import fit_evaluation
import matplotlib.pyplot as plt

from tensorflow import keras
from tensorflow.keras import layers
from tensorflow.keras import optimizers
from tensorflow.keras import regularizers
from tensorflow.data import Dataset
```

```
In [8]: #start with 10000 training samples and 10000 test samples
n_train_samples = 60000
n_test_samples = 10000
batch_size = 32

(train_x, train_y), (test_x, test_y) = mnist.load_data()

train_x = train_x.reshape(n_train_samples, 28*28).astype("float64")/255
test_x = test_x.reshape(n_test_samples, 28*28).astype("float64")/255

#create training data set - batch size = 32
train_ds = Dataset.from_tensor_slices((train_x, train_y)).batch(batch_size)
test_ds = Dataset.from_tensor_slices((test_x, test_y)).batch(batch_size)
test_1d_32_ds = test_ds

#create ptraining, validation, and testing datasets
val_split = 0.10
train_ds_size = len(list(train_ds))
val_ds_size = int(val_split*train_ds_size)
ptrain_ds_size = train_ds_size-val_ds_size
print(f"training batches = {train_ds_size}, validation batches = {val_ds_size}")

ptrain_ds = train_ds.take(ptrain_ds_size)
val_ds = train_ds.skip(ptrain_ds_size).take(val_ds_size)
```

```
training batches = 1875, validation batches = 187, ptraining batches = 1688
2025-02-09 16:14:16.832468: I tensorflow/core/framework/local_rendezvous.cc:
405] Local rendezvous is aborting with status: OUT_OF_RANGE: End of sequence
```

```
In [3]: n_hidden1 = 512
n_hidden2 = 128

inputs = keras.Input(shape=(28*28,))
x = layers.Dense(n_hidden1, activation="relu",
                  kernel_regularizer=None,
                  )(inputs)
x = layers.Dense(n_hidden2, activation="relu",
                  kernel_regularizer=None,
                  )(x)

outputs = layers.Dense(10, activation="softmax")(x)
```

```
model = keras.Model(inputs=inputs, outputs=outputs)

model.summary()
```

Model: "functional"

Layer (type)	Output Shape	Par
input_layer (InputLayer)	(None, 784)	
dense (Dense)	(None, 512)	401
dense_1 (Dense)	(None, 128)	65
dense_2 (Dense)	(None, 10)	1

Total params: 468,874 (1.79 MB)

Trainable params: 468,874 (1.79 MB)

Non-trainable params: 0 (0.00 B)


```
In [4]: rmsprop = optimizers.RMSprop(
    learning_rate=0.001, # Starting learning rate
    rho=0.9, # Equivalent to decay factor
    momentum=0.7, # Adds momentum to updates
    epsilon=1e-7, # Helps with numerical stability 1e-7
    centered=True # Normalizes gradients (unique to TensorFlow)
)


model.compile(optimizer=rmsprop,
              loss = "sparse_categorical_crossentropy",
              metrics = ["accuracy"])
```


```
In [43]: #create a callback to save the best model with respect to validation loss
filename = "models/lecture10_case1.keras"
callbacks = [
    keras.callbacks.ModelCheckpoint(
        filepath = filename,
        save_best_only = True,
        monitor = "val_loss")]


#train model with ptraining data, and use val_ds for validation
number_epochs = 50


history = model.fit(ptrain_ds, epochs = number_epochs,
                   validation_data = val_ds,
                   callbacks = callbacks)
```


Epoch 1/50  
**1688/1688**  **7s** 4ms/step - accuracy: 0.9033 - loss: 0.3281  
- val\_accuracy: 0.9651 - val\_loss: 0.1245


Epoch 2/50  
**1688/1688**  **6s** 3ms/step - accuracy: 0.9641 - loss: 0.1476  
- val\_accuracy: 0.9691 - val\_loss: 0.1383


Epoch 3/50  
**1688/1688**  **6s** 3ms/step - accuracy: 0.9723 - loss: 0.1283  
- val\_accuracy: 0.9626 - val\_loss: 0.1819


Epoch 4/50  
**1688/1688**  **6s** 3ms/step - accuracy: 0.9759 - loss: 0.1189  
- val\_accuracy: 0.9728 - val\_loss: 0.1595


Epoch 5/50  
**1688/1688**  **6s** 3ms/step - accuracy: 0.9792 - loss: 0.1187  
- val\_accuracy: 0.9693 - val\_loss: 0.1804


Epoch 6/50  
**1688/1688**  **6s** 3ms/step - accuracy: 0.9822 - loss: 0.0945  
- val\_accuracy: 0.9669 - val\_loss: 0.2464


Epoch 7/50  
**1688/1688**  **6s** 4ms/step - accuracy: 0.9834 - loss: 0.0935  
- val\_accuracy: 0.9671 - val\_loss: 0.2772


Epoch 8/50  
**1688/1688**  **6s** 4ms/step - accuracy: 0.9854 - loss: 0.0865  
- val\_accuracy: 0.9693 - val\_loss: 0.2422


Epoch 9/50  
**1688/1688**  **6s** 3ms/step - accuracy: 0.9868 - loss: 0.0814  
- val\_accuracy: 0.9726 - val\_loss: 0.2890


Epoch 10/50  
**1688/1688**  **6s** 4ms/step - accuracy: 0.9874 - loss: 0.0769  
- val\_accuracy: 0.9758 - val\_loss: 0.2438


Epoch 11/50  
**1688/1688**  **6s** 3ms/step - accuracy: 0.9893 - loss: 0.0622  
- val\_accuracy: 0.9751 - val\_loss: 0.3393


Epoch 12/50  
**1688/1688**  **6s** 3ms/step - accuracy: 0.9890 - loss: 0.0759  
- val\_accuracy: 0.9774 - val\_loss: 0.2812


Epoch 13/50  
**1688/1688**  **6s** 3ms/step - accuracy: 0.9907 - loss: 0.0583  
- val\_accuracy: 0.9741 - val\_loss: 0.3311


Epoch 14/50  
**1688/1688**  **6s** 3ms/step - accuracy: 0.9904 - loss: 0.0636  
- val\_accuracy: 0.9796 - val\_loss: 0.2108



















Epoch 15/50  
**1688/1688**  **6s** 3ms/step - accuracy: 0.9915 - loss: 0.0510  
- val\_accuracy: 0.9788 - val\_loss: 0.2916

Epoch 16/50  
**1688/1688**  **6s** 3ms/step - accuracy: 0.9922 - loss: 0.0515  
- val\_accuracy: 0.9788 - val\_loss: 0.2836

Epoch 17/50  
**1688/1688**  **6s** 4ms/step - accuracy: 0.9929 - loss: 0.0509  
- val\_accuracy: 0.9806 - val\_loss: 0.2489

Epoch 18/50  
**1688/1688**  **6s** 3ms/step - accuracy: 0.9927 - loss: 0.0457  
- val\_accuracy: 0.9801 - val\_loss: 0.3142

Epoch 19/50  
**1688/1688**  **6s** 3ms/step - accuracy: 0.9930 - loss: 0.0469

```
- val_accuracy: 0.9821 - val_loss: 0.3089
Epoch 20/50
1688/1688  6s 3ms/step - accuracy: 0.9946 - loss: 0.0440
- val_accuracy: 0.9781 - val_loss: 0.3735
Epoch 21/50
1688/1688  6s 4ms/step - accuracy: 0.9948 - loss: 0.0392
- val_accuracy: 0.9789 - val_loss: 0.3855
Epoch 22/50
1688/1688  6s 4ms/step - accuracy: 0.9941 - loss: 0.0428
- val_accuracy: 0.9811 - val_loss: 0.3262
Epoch 23/50
1688/1688  6s 4ms/step - accuracy: 0.9957 - loss: 0.0306
- val_accuracy: 0.9815 - val_loss: 0.2965
Epoch 24/50
1688/1688  6s 3ms/step - accuracy: 0.9965 - loss: 0.0236
- val_accuracy: 0.9831 - val_loss: 0.3169
Epoch 25/50
1688/1688  6s 3ms/step - accuracy: 0.9968 - loss: 0.0224
- val_accuracy: 0.9799 - val_loss: 0.3356
Epoch 26/50
1688/1688  6s 3ms/step - accuracy: 0.9971 - loss: 0.0212
- val_accuracy: 0.9826 - val_loss: 0.3319
Epoch 27/50
1688/1688  6s 4ms/step - accuracy: 0.9962 - loss: 0.0234
- val_accuracy: 0.9809 - val_loss: 0.4086
Epoch 28/50
1688/1688  6s 4ms/step - accuracy: 0.9965 - loss: 0.0303
- val_accuracy: 0.9816 - val_loss: 0.3121
Epoch 29/50
1688/1688  6s 4ms/step - accuracy: 0.9972 - loss: 0.0190
- val_accuracy: 0.9831 - val_loss: 0.3020
Epoch 30/50
1688/1688  6s 4ms/step - accuracy: 0.9973 - loss: 0.0179
- val_accuracy: 0.9798 - val_loss: 0.4408
Epoch 31/50
1688/1688  6s 3ms/step - accuracy: 0.9969 - loss: 0.0201
- val_accuracy: 0.9813 - val_loss: 0.4204
Epoch 32/50
1688/1688  6s 3ms/step - accuracy: 0.9970 - loss: 0.0200
- val_accuracy: 0.9811 - val_loss: 0.3854
Epoch 33/50
1688/1688  6s 4ms/step - accuracy: 0.9984 - loss: 0.0103
- val_accuracy: 0.9831 - val_loss: 0.3351
Epoch 34/50
1688/1688  6s 3ms/step - accuracy: 0.9975 - loss: 0.0196
- val_accuracy: 0.9826 - val_loss: 0.4208
Epoch 35/50
1688/1688  6s 3ms/step - accuracy: 0.9979 - loss: 0.0174
- val_accuracy: 0.9841 - val_loss: 0.3610
Epoch 36/50
1688/1688  6s 3ms/step - accuracy: 0.9985 - loss: 0.0115
- val_accuracy: 0.9826 - val_loss: 0.3808
Epoch 37/50
1688/1688  6s 3ms/step - accuracy: 0.9984 - loss: 0.0113
- val_accuracy: 0.9820 - val_loss: 0.4028
Epoch 38/50
```

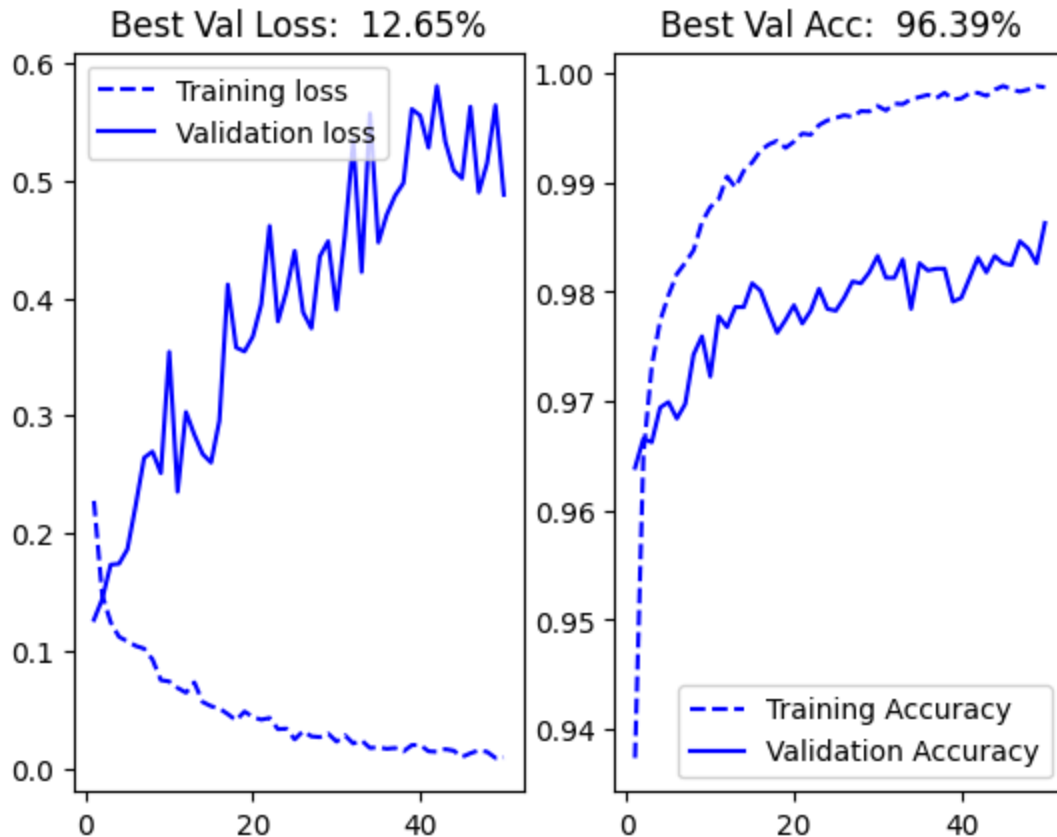
```

1688/1688 ————— 6s 4ms/step - accuracy: 0.9985 - loss: 0.0111
- val_accuracy: 0.9823 - val_loss: 0.4289
Epoch 39/50
1688/1688 ————— 6s 3ms/step - accuracy: 0.9982 - loss: 0.0137
- val_accuracy: 0.9813 - val_loss: 0.4039
Epoch 40/50
1688/1688 ————— 6s 4ms/step - accuracy: 0.9985 - loss: 0.0103
- val_accuracy: 0.9826 - val_loss: 0.4122
Epoch 41/50
1688/1688 ————— 6s 4ms/step - accuracy: 0.9988 - loss: 0.0092
- val_accuracy: 0.9808 - val_loss: 0.4387
Epoch 42/50
1688/1688 ————— 6s 4ms/step - accuracy: 0.9985 - loss: 0.0103
- val_accuracy: 0.9828 - val_loss: 0.4394
Epoch 43/50
1688/1688 ————— 6s 4ms/step - accuracy: 0.9987 - loss: 0.0101
- val_accuracy: 0.9825 - val_loss: 0.4373
Epoch 44/50
1688/1688 ————— 6s 4ms/step - accuracy: 0.9987 - loss: 0.0090
- val_accuracy: 0.9831 - val_loss: 0.4393
Epoch 45/50
1688/1688 ————— 6s 4ms/step - accuracy: 0.9992 - loss: 0.0068
- val_accuracy: 0.9836 - val_loss: 0.4252
Epoch 46/50
1688/1688 ————— 6s 4ms/step - accuracy: 0.9986 - loss: 0.0105
- val_accuracy: 0.9843 - val_loss: 0.3998
Epoch 47/50
1688/1688 ————— 6s 4ms/step - accuracy: 0.9992 - loss: 0.0059
- val_accuracy: 0.9843 - val_loss: 0.3415
Epoch 48/50
1688/1688 ————— 6s 4ms/step - accuracy: 0.9991 - loss: 0.0050
- val_accuracy: 0.9823 - val_loss: 0.4701
Epoch 49/50
1688/1688 ————— 6s 3ms/step - accuracy: 0.9987 - loss: 0.0097
- val_accuracy: 0.9816 - val_loss: 0.4499
Epoch 50/50
1688/1688 ————— 6s 4ms/step - accuracy: 0.9992 - loss: 0.0051
- val_accuracy: 0.9833 - val_loss: 0.4469

```

```
In [19]: fit_evaluation(history,filename,val_ds)
```

```
187/187 ————— 0s 912us/step - accuracy: 0.9646 - loss: 0.1090
```



```
In [9]: batch_size = 1024
        case_number = 2
        filename = f"models/lecture10_case{case_number}.keras"

        #create training data set - batch size = 1024
        train_ds = Dataset.from_tensor_slices((train_x, train_y)).batch(batch_size)
        test_ds = Dataset.from_tensor_slices((test_x, test_y)).batch(batch_size)
        test_1d_1024_ds = test_ds

        #create ptraining, validation, and testing datasets
        val_split = 0.10
        train_ds_size = len(list(train_ds))
        val_ds_size = int(val_split*train_ds_size)
        ptrain_ds_size = train_ds_size-val_ds_size
        print(f"training batches = {train_ds_size}, validation batches = {val_ds_size}")

        ptrain_ds = train_ds.take(ptrain_ds_size)
        val_ds = train_ds.skip(ptrain_ds_size).take(val_ds_size)
```

training batches = 59, validation batches = 5, ptraining batches = 54

```
In [6]: tf.keras.backend.clear_session()

        #rebuild the model so the weights are randomly initialized
        n_hidden1 = 512
        n_hidden2 = 128

        inputs = keras.Input(shape=(28*28,))
        x = layers.Dense(n_hidden1, activation="relu",
                          kernel_regularizer=None,
```

```

        )(inputs)
x = layers.Dense(n_hidden2, activation="relu",
                  kernel_regularizer = None,
                  )(x)

outputs = layers.Dense(10, activation="softmax")(x)
model = keras.Model(inputs=inputs, outputs=outputs)

#recompile model with rmsprop optimizer

rmsprop = optimizers.RMSprop(
    learning_rate=0.001, # Starting learning rate
    rho=0.9, # Equivalent to decay factor
    momentum=0.7, # Adds momentum to updates
    epsilon=1e-7, # Helps with numerical stability 1e-7
    centered=True # Normalizes gradients (unique to TensorFlow)
)

model.compile(optimizer=rmsprop,
              loss = "sparse_categorical_crossentropy",
              metrics = ["accuracy"])

#create a callback to save the best model with respect to validation loss


callbacks = [
    keras.callbacks.ModelCheckpoint(
        filepath = filename,
        save_best_only = True,
        monitor = "val_loss")]


#train model with ptraining data, and use val_ds for validation
number_epochs = 50


history = model.fit(ptrain_ds, epochs = number_epochs,
                    validation_data = val_ds,
                    callbacks = callbacks)


#evaluate
fit_evaluation(history, filename, val_ds)


```


Epoch 1/50  
54/54  1s 18ms/step - accuracy: 0.7685 - loss: 0.7371 - val\_accuracy: 0.9622 - val\_loss: 0.1342


Epoch 2/50  
54/54  1s 17ms/step - accuracy: 0.9552 - loss: 0.1472 - val\_accuracy: 0.9734 - val\_loss: 0.0973


Epoch 3/50  
54/54  1s 16ms/step - accuracy: 0.9731 - loss: 0.0890 - val\_accuracy: 0.9764 - val\_loss: 0.0824


Epoch 4/50  
54/54  1s 16ms/step - accuracy: 0.9825 - loss: 0.0585 - val\_accuracy: 0.9753 - val\_loss: 0.0812


Epoch 5/50  
54/54  1s 16ms/step - accuracy: 0.9869 - loss: 0.0440 - val\_accuracy: 0.9722 - val\_loss: 0.1001


Epoch 6/50  
54/54  1s 16ms/step - accuracy: 0.9876 - loss: 0.0392 - val\_accuracy: 0.9641 - val\_loss: 0.1351


Epoch 7/50  
54/54  1s 16ms/step - accuracy: 0.9887 - loss: 0.0324 - val\_accuracy: 0.9681 - val\_loss: 0.1252


Epoch 8/50  
54/54  1s 16ms/step - accuracy: 0.9921 - loss: 0.0248 - val\_accuracy: 0.9770 - val\_loss: 0.1000


Epoch 9/50  
54/54  1s 17ms/step - accuracy: 0.9930 - loss: 0.0216 - val\_accuracy: 0.9736 - val\_loss: 0.1201


Epoch 10/50  
54/54  1s 17ms/step - accuracy: 0.9942 - loss: 0.0174 - val\_accuracy: 0.9800 - val\_loss: 0.0907


Epoch 11/50  
54/54  1s 16ms/step - accuracy: 0.9947 - loss: 0.0164 - val\_accuracy: 0.9773 - val\_loss: 0.1185


Epoch 12/50  
54/54  1s 17ms/step - accuracy: 0.9956 - loss: 0.0126 - val\_accuracy: 0.9800 - val\_loss: 0.1072


Epoch 13/50  
54/54  1s 17ms/step - accuracy: 0.9950 - loss: 0.0141 - val\_accuracy: 0.9811 - val\_loss: 0.0917


Epoch 14/50  
54/54  1s 17ms/step - accuracy: 0.9972 - loss: 0.0084 - val\_accuracy: 0.9804 - val\_loss: 0.1112

Epoch 15/50  
54/54  1s 18ms/step - accuracy: 0.9970 - loss: 0.0080 - val\_accuracy: 0.9743 - val\_loss: 0.1449

Epoch 16/50  
54/54  1s 17ms/step - accuracy: 0.9965 - loss: 0.0104 - val\_accuracy: 0.9813 - val\_loss: 0.0999

Epoch 17/50  
54/54  1s 17ms/step - accuracy: 0.9980 - loss: 0.0054 - val\_accuracy: 0.9815 - val\_loss: 0.1082

Epoch 18/50  
54/54  1s 17ms/step - accuracy: 0.9975 - loss: 0.0074 - val\_accuracy: 0.9800 - val\_loss: 0.1173

Epoch 19/50  
54/54  1s 16ms/step - accuracy: 0.9986 - loss: 0.0043 -

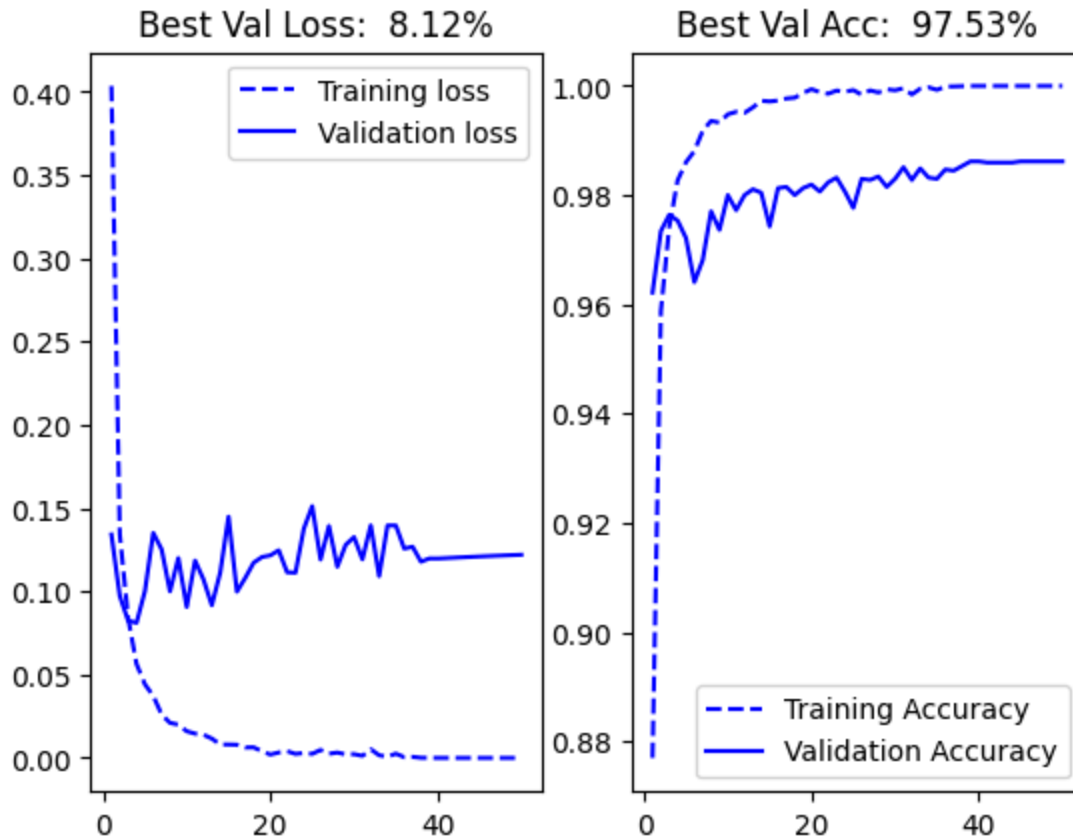


```

val_accuracy: 0.9813 - val_loss: 0.1207
Epoch 20/50
54/54 ————— 1s 17ms/step - accuracy: 0.9994 - loss: 0.0022 -
val_accuracy: 0.9819 - val_loss: 0.1217
Epoch 21/50
54/54 ————— 1s 17ms/step - accuracy: 0.9986 - loss: 0.0035 -
val_accuracy: 0.9807 - val_loss: 0.1247
Epoch 22/50
54/54 ————— 1s 18ms/step - accuracy: 0.9989 - loss: 0.0037 -
val_accuracy: 0.9824 - val_loss: 0.1115
Epoch 23/50
54/54 ————— 1s 16ms/step - accuracy: 0.9992 - loss: 0.0023 -
val_accuracy: 0.9832 - val_loss: 0.1113
Epoch 24/50
54/54 ————— 1s 17ms/step - accuracy: 0.9989 - loss: 0.0027 -
val_accuracy: 0.9807 - val_loss: 0.1377
Epoch 25/50
54/54 ————— 1s 17ms/step - accuracy: 0.9990 - loss: 0.0030 -
val_accuracy: 0.9777 - val_loss: 0.1513
Epoch 26/50
54/54 ————— 1s 17ms/step - accuracy: 0.9987 - loss: 0.0040 -
val_accuracy: 0.9830 - val_loss: 0.1191
Epoch 27/50
54/54 ————— 1s 17ms/step - accuracy: 0.9992 - loss: 0.0024 -
val_accuracy: 0.9828 - val_loss: 0.1393
Epoch 28/50
54/54 ————— 1s 16ms/step - accuracy: 0.9991 - loss: 0.0025 -
val_accuracy: 0.9834 - val_loss: 0.1148
Epoch 29/50
54/54 ————— 1s 16ms/step - accuracy: 0.9995 - loss: 0.0020 -
val_accuracy: 0.9815 - val_loss: 0.1280
Epoch 30/50
54/54 ————— 1s 16ms/step - accuracy: 0.9994 - loss: 0.0016 -
val_accuracy: 0.9830 - val_loss: 0.1326
Epoch 31/50
54/54 ————— 1s 17ms/step - accuracy: 0.9993 - loss: 0.0015 -
val_accuracy: 0.9851 - val_loss: 0.1193
Epoch 32/50
54/54 ————— 1s 17ms/step - accuracy: 0.9991 - loss: 0.0033 -
val_accuracy: 0.9828 - val_loss: 0.1397
Epoch 33/50
54/54 ————— 1s 17ms/step - accuracy: 0.9993 - loss: 0.0022 -
val_accuracy: 0.9849 - val_loss: 0.1092
Epoch 34/50
54/54 ————— 1s 17ms/step - accuracy: 0.9998 - loss: 7.5360e-0
4 - val_accuracy: 0.9832 - val_loss: 0.1396
Epoch 35/50
54/54 ————— 1s 17ms/step - accuracy: 0.9994 - loss: 0.0022 -
val_accuracy: 0.9830 - val_loss: 0.1396
Epoch 36/50
54/54 ————— 1s 17ms/step - accuracy: 0.9998 - loss: 7.4426e-0
4 - val_accuracy: 0.9847 - val_loss: 0.1257
Epoch 37/50
54/54 ————— 1s 17ms/step - accuracy: 0.9999 - loss: 6.7500e-0
4 - val_accuracy: 0.9845 - val_loss: 0.1269
Epoch 38/50

```

```
54/54 ————— 1s 17ms/step - accuracy: 0.9999 - loss: 1.4924e-04 - val_accuracy: 0.9853 - val_loss: 0.1178
Epoch 39/50
54/54 ————— 1s 17ms/step - accuracy: 1.0000 - loss: 3.4956e-05 - val_accuracy: 0.9862 - val_loss: 0.1198
Epoch 40/50
54/54 ————— 1s 17ms/step - accuracy: 1.0000 - loss: 1.5096e-05 - val_accuracy: 0.9862 - val_loss: 0.1198
Epoch 41/50
54/54 ————— 1s 17ms/step - accuracy: 1.0000 - loss: 1.2641e-05 - val_accuracy: 0.9860 - val_loss: 0.1200
Epoch 42/50
54/54 ————— 1s 17ms/step - accuracy: 1.0000 - loss: 1.1357e-05 - val_accuracy: 0.9860 - val_loss: 0.1203
Epoch 43/50
54/54 ————— 1s 17ms/step - accuracy: 1.0000 - loss: 1.0423e-05 - val_accuracy: 0.9860 - val_loss: 0.1205
Epoch 44/50
54/54 ————— 1s 17ms/step - accuracy: 1.0000 - loss: 9.6892e-06 - val_accuracy: 0.9860 - val_loss: 0.1208
Epoch 45/50
54/54 ————— 1s 17ms/step - accuracy: 1.0000 - loss: 9.0895e-06 - val_accuracy: 0.9862 - val_loss: 0.1210
Epoch 46/50
54/54 ————— 1s 17ms/step - accuracy: 1.0000 - loss: 8.5831e-06 - val_accuracy: 0.9862 - val_loss: 0.1212
Epoch 47/50
54/54 ————— 1s 17ms/step - accuracy: 1.0000 - loss: 8.1472e-06 - val_accuracy: 0.9862 - val_loss: 0.1214
Epoch 48/50
54/54 ————— 1s 18ms/step - accuracy: 1.0000 - loss: 7.7647e-06 - val_accuracy: 0.9862 - val_loss: 0.1216
Epoch 49/50
54/54 ————— 1s 18ms/step - accuracy: 1.0000 - loss: 7.4259e-06 - val_accuracy: 0.9862 - val_loss: 0.1218
Epoch 50/50
54/54 ————— 1s 17ms/step - accuracy: 1.0000 - loss: 7.1216e-06 - val_accuracy: 0.9862 - val_loss: 0.1220
5/5 ————— 0s 7ms/step - accuracy: 0.9755 - loss: 0.0771
```



```
In [8]: tf.keras.backend.clear_session()
case_number = 3
filename = f"models/lecture10_case{case_number}.keras"

#rebuild the model so the weights are randomly initialized
n_hidden1 = 512
n_hidden2 = 128

lam = 0.01
L2_regularizer = regularizers.l2(lam)

inputs = keras.Input(shape=(28*28,))
x = layers.Dense(n_hidden1, activation="relu",
                  kernel_regularizer=L2_regularizer,
                  )(inputs)
x = layers.Dense(n_hidden2, activation="relu",
                  kernel_regularizer=L2_regularizer,
                  )(x)

outputs = layers.Dense(10, activation="softmax")(x)
model = keras.Model(inputs=inputs, outputs=outputs)

#recompile model with rmsprop optimizer

rmsprop = optimizers.RMSprop(
    learning_rate=0.001, # Starting learning rate
    rho=0.9, # Equivalent to decay factor
    momentum=0.7, # Adds momentum to updates
    epsilon=1e-7, # Helps with numerical stability 1e-7
```

```
        centered=True # Normalizes gradients (unique to TensorFlow)
    )

model.compile(optimizer=rmsprop,
              loss = "sparse_categorical_crossentropy",
              metrics = ["accuracy"])


#create a callback to save the best model with respect to validation loss


callbacks = [
    keras.callbacks.ModelCheckpoint(
        filepath = filename,
        save_best_only = True,
        monitor = "val_loss")]


#train model with ptraining data, and use val_ds for validation
number_epochs = 100


history = model.fit(ptrain_ds, epochs = number_epochs,
                   validation_data = val_ds,
                   callbacks = callbacks)


#evaluate
fit_evaluation(history, filename, val_ds)
```


Epoch 1/100  
54/54  1s 19ms/step - accuracy: 0.7482 - loss: 4.2485 - val\_accuracy: 0.9330 - val\_loss: 0.7088


Epoch 2/100  
54/54  1s 18ms/step - accuracy: 0.9040 - loss: 0.7255 - val\_accuracy: 0.9401 - val\_loss: 0.5453


Epoch 3/100  
54/54  1s 18ms/step - accuracy: 0.9138 - loss: 0.5939 - val\_accuracy: 0.9507 - val\_loss: 0.4761


Epoch 4/100  
54/54  1s 18ms/step - accuracy: 0.9224 - loss: 0.5379 - val\_accuracy: 0.9503 - val\_loss: 0.4470


Epoch 5/100  
54/54  1s 18ms/step - accuracy: 0.9271 - loss: 0.5014 - val\_accuracy: 0.9568 - val\_loss: 0.4112


Epoch 6/100  
54/54  1s 18ms/step - accuracy: 0.9336 - loss: 0.4687 - val\_accuracy: 0.9605 - val\_loss: 0.3887


Epoch 7/100  
54/54  1s 17ms/step - accuracy: 0.9380 - loss: 0.4420 - val\_accuracy: 0.9626 - val\_loss: 0.3679


Epoch 8/100  
54/54  1s 18ms/step - accuracy: 0.9413 - loss: 0.4202 - val\_accuracy: 0.9643 - val\_loss: 0.3508


Epoch 9/100  
54/54  1s 18ms/step - accuracy: 0.9438 - loss: 0.4021 - val\_accuracy: 0.9639 - val\_loss: 0.3388


Epoch 10/100  
54/54  1s 18ms/step - accuracy: 0.9468 - loss: 0.3863 - val\_accuracy: 0.9651 - val\_loss: 0.3276


Epoch 11/100  
54/54  1s 18ms/step - accuracy: 0.9486 - loss: 0.3723 - val\_accuracy: 0.9664 - val\_loss: 0.3163


Epoch 12/100  
54/54  1s 19ms/step - accuracy: 0.9499 - loss: 0.3598 - val\_accuracy: 0.9677 - val\_loss: 0.3081


Epoch 13/100  
54/54  1s 17ms/step - accuracy: 0.9521 - loss: 0.3480 - val\_accuracy: 0.9688 - val\_loss: 0.2990


Epoch 14/100  
54/54  1s 19ms/step - accuracy: 0.9533 - loss: 0.3383 - val\_accuracy: 0.9707 - val\_loss: 0.2910

Epoch 15/100  
54/54  1s 18ms/step - accuracy: 0.9547 - loss: 0.3282 - val\_accuracy: 0.9711 - val\_loss: 0.2850


Epoch 16/100  
54/54  1s 18ms/step - accuracy: 0.9565 - loss: 0.3203 - val\_accuracy: 0.9713 - val\_loss: 0.2781


Epoch 17/100  
54/54  1s 18ms/step - accuracy: 0.9578 - loss: 0.3124 - val\_accuracy: 0.9719 - val\_loss: 0.2737


Epoch 18/100  
54/54  1s 17ms/step - accuracy: 0.9580 - loss: 0.3067 - val\_accuracy: 0.9719 - val\_loss: 0.2700


Epoch 19/100  
54/54  1s 18ms/step - accuracy: 0.9581 - loss: 0.3018 -


```
val_accuracy: 0.9717 - val_loss: 0.2654
Epoch 20/100
54/54 ━━━━━━━━━━━ 1s 19ms/step - accuracy: 0.9591 - loss: 0.2970 -
val_accuracy: 0.9711 - val_loss: 0.2628
Epoch 21/100
54/54 ━━━━━━━━━━━ 1s 17ms/step - accuracy: 0.9593 - loss: 0.2925 -
val_accuracy: 0.9732 - val_loss: 0.2594
Epoch 22/100
54/54 ━━━━━━━━━━━ 1s 18ms/step - accuracy: 0.9599 - loss: 0.2876 -
val_accuracy: 0.9719 - val_loss: 0.2562
Epoch 23/100
54/54 ━━━━━━━━━━━ 1s 18ms/step - accuracy: 0.9610 - loss: 0.2840 -
val_accuracy: 0.9728 - val_loss: 0.2545
Epoch 24/100
54/54 ━━━━━━━━━━━ 1s 18ms/step - accuracy: 0.9613 - loss: 0.2809 -
val_accuracy: 0.9726 - val_loss: 0.2517
Epoch 25/100
54/54 ━━━━━━━━━━━ 1s 18ms/step - accuracy: 0.9613 - loss: 0.2776 -
val_accuracy: 0.9732 - val_loss: 0.2494
Epoch 26/100
54/54 ━━━━━━━━━━━ 1s 17ms/step - accuracy: 0.9619 - loss: 0.2744 -
val_accuracy: 0.9726 - val_loss: 0.2474
Epoch 27/100
54/54 ━━━━━━━━━━━ 1s 17ms/step - accuracy: 0.9621 - loss: 0.2717 -
val_accuracy: 0.9736 - val_loss: 0.2436
Epoch 28/100
54/54 ━━━━━━━━━━━ 1s 18ms/step - accuracy: 0.9623 - loss: 0.2693 -
val_accuracy: 0.9741 - val_loss: 0.2420
Epoch 29/100
54/54 ━━━━━━━━━━━ 1s 17ms/step - accuracy: 0.9627 - loss: 0.2664 -
val_accuracy: 0.9741 - val_loss: 0.2401
Epoch 30/100
54/54 ━━━━━━━━━━━ 1s 18ms/step - accuracy: 0.9629 - loss: 0.2646 -
val_accuracy: 0.9739 - val_loss: 0.2399
Epoch 31/100
54/54 ━━━━━━━━━━━ 1s 18ms/step - accuracy: 0.9632 - loss: 0.2628 -
val_accuracy: 0.9741 - val_loss: 0.2366
Epoch 32/100
54/54 ━━━━━━━━━━━ 1s 19ms/step - accuracy: 0.9636 - loss: 0.2599 -
val_accuracy: 0.9741 - val_loss: 0.2346
Epoch 33/100
54/54 ━━━━━━━━━━━ 1s 18ms/step - accuracy: 0.9637 - loss: 0.2579 -
val_accuracy: 0.9736 - val_loss: 0.2358
Epoch 34/100
54/54 ━━━━━━━━━━━ 1s 18ms/step - accuracy: 0.9642 - loss: 0.2557 -
val_accuracy: 0.9722 - val_loss: 0.2340
Epoch 35/100
54/54 ━━━━━━━━━━━ 1s 18ms/step - accuracy: 0.9648 - loss: 0.2544 -
val_accuracy: 0.9734 - val_loss: 0.2314
Epoch 36/100
54/54 ━━━━━━━━━━━ 1s 17ms/step - accuracy: 0.9645 - loss: 0.2524 -
val_accuracy: 0.9758 - val_loss: 0.2303
Epoch 37/100
54/54 ━━━━━━━━━━━ 1s 19ms/step - accuracy: 0.9648 - loss: 0.2507 -
val_accuracy: 0.9741 - val_loss: 0.2296
Epoch 38/100
```


54/54  1s 19ms/step - accuracy: 0.9646 - loss: 0.2503 -  
val\_accuracy: 0.9747 - val\_loss: 0.2284  
Epoch 39/100


54/54  1s 18ms/step - accuracy: 0.9652 - loss: 0.2487 -  
val\_accuracy: 0.9743 - val\_loss: 0.2272  
Epoch 40/100


54/54  1s 18ms/step - accuracy: 0.9652 - loss: 0.2479 -  
val\_accuracy: 0.9743 - val\_loss: 0.2273  
Epoch 41/100


54/54  1s 18ms/step - accuracy: 0.9650 - loss: 0.2472 -  
val\_accuracy: 0.9756 - val\_loss: 0.2264  
Epoch 42/100


54/54  1s 18ms/step - accuracy: 0.9648 - loss: 0.2459 -  
val\_accuracy: 0.9760 - val\_loss: 0.2240  
Epoch 43/100


54/54  1s 19ms/step - accuracy: 0.9645 - loss: 0.2455 -  
val\_accuracy: 0.9753 - val\_loss: 0.2228  
Epoch 44/100


54/54  1s 17ms/step - accuracy: 0.9650 - loss: 0.2446 -  
val\_accuracy: 0.9747 - val\_loss: 0.2244  
Epoch 45/100


54/54  1s 19ms/step - accuracy: 0.9660 - loss: 0.2433 -  
val\_accuracy: 0.9749 - val\_loss: 0.2231  
Epoch 46/100


54/54  1s 18ms/step - accuracy: 0.9652 - loss: 0.2416 -  
val\_accuracy: 0.9747 - val\_loss: 0.2234  
Epoch 47/100


54/54  1s 18ms/step - accuracy: 0.9656 - loss: 0.2407 -  
val\_accuracy: 0.9745 - val\_loss: 0.2217  
Epoch 48/100


54/54  1s 18ms/step - accuracy: 0.9662 - loss: 0.2397 -  
val\_accuracy: 0.9747 - val\_loss: 0.2222  
Epoch 49/100


54/54  1s 18ms/step - accuracy: 0.9651 - loss: 0.2400 -  
val\_accuracy: 0.9760 - val\_loss: 0.2219  
Epoch 50/100


54/54  1s 17ms/step - accuracy: 0.9655 - loss: 0.2386 -  
val\_accuracy: 0.9751 - val\_loss: 0.2222  
Epoch 51/100


54/54  1s 18ms/step - accuracy: 0.9654 - loss: 0.2376 -  
val\_accuracy: 0.9747 - val\_loss: 0.2198  
Epoch 52/100




















54/54  1s 18ms/step - accuracy: 0.9657 - loss: 0.2359 -  
val\_accuracy: 0.9751 - val\_loss: 0.2203  
Epoch 53/100

54/54  1s 19ms/step - accuracy: 0.9662 - loss: 0.2366 -  
val\_accuracy: 0.9751 - val\_loss: 0.2197  
Epoch 54/100



















54/54  1s 19ms/step - accuracy: 0.9663 - loss: 0.2349 -  
val\_accuracy: 0.9745 - val\_loss: 0.2228  
Epoch 55/100


54/54  1s 17ms/step - accuracy: 0.9656 - loss: 0.2350 -  
val\_accuracy: 0.9732 - val\_loss: 0.2226  
Epoch 56/100


54/54  1s 18ms/step - accuracy: 0.9668 - loss: 0.2330 -  
val\_accuracy: 0.9734 - val\_loss: 0.2222


Epoch 57/100  
54/54  1s 19ms/step - accuracy: 0.9659 - loss: 0.2333 -  
val\_accuracy: 0.9730 - val\_loss: 0.2211  
Epoch 58/100  
54/54  1s 18ms/step - accuracy: 0.9660 - loss: 0.2331 -  
val\_accuracy: 0.9730 - val\_loss: 0.2207  
Epoch 59/100  
54/54  1s 17ms/step - accuracy: 0.9676 - loss: 0.2323 -  
val\_accuracy: 0.9730 - val\_loss: 0.2219  
Epoch 60/100  
54/54  1s 18ms/step - accuracy: 0.9661 - loss: 0.2318 -  
val\_accuracy: 0.9730 - val\_loss: 0.2199  
Epoch 61/100  
54/54  1s 20ms/step - accuracy: 0.9669 - loss: 0.2308 -  
val\_accuracy: 0.9749 - val\_loss: 0.2182  
Epoch 62/100  
54/54  1s 18ms/step - accuracy: 0.9663 - loss: 0.2304 -  
val\_accuracy: 0.9739 - val\_loss: 0.2210  
Epoch 63/100  
54/54  1s 16ms/step - accuracy: 0.9670 - loss: 0.2289 -  
val\_accuracy: 0.9732 - val\_loss: 0.2198  
Epoch 64/100  
54/54  1s 16ms/step - accuracy: 0.9665 - loss: 0.2312 -  
val\_accuracy: 0.9690 - val\_loss: 0.2310  
Epoch 65/100  
54/54  1s 18ms/step - accuracy: 0.9667 - loss: 0.2302 -  
val\_accuracy: 0.9722 - val\_loss: 0.2238  
Epoch 66/100  
54/54  1s 17ms/step - accuracy: 0.9668 - loss: 0.2297 -  
val\_accuracy: 0.9700 - val\_loss: 0.2331  
Epoch 67/100  
54/54  1s 17ms/step - accuracy: 0.9668 - loss: 0.2280 -  
val\_accuracy: 0.9730 - val\_loss: 0.2195  
Epoch 68/100  
54/54  1s 17ms/step - accuracy: 0.9667 - loss: 0.2275 -  
val\_accuracy: 0.9732 - val\_loss: 0.2231  
Epoch 69/100  
54/54  1s 17ms/step - accuracy: 0.9670 - loss: 0.2285 -  
val\_accuracy: 0.9739 - val\_loss: 0.2222  
Epoch 70/100  
54/54  1s 16ms/step - accuracy: 0.9680 - loss: 0.2256 -  
val\_accuracy: 0.9730 - val\_loss: 0.2222  
Epoch 71/100  
54/54  1s 17ms/step - accuracy: 0.9673 - loss: 0.2258 -  
val\_accuracy: 0.9726 - val\_loss: 0.2245  
Epoch 72/100  
54/54  1s 18ms/step - accuracy: 0.9672 - loss: 0.2258 -  
val\_accuracy: 0.9734 - val\_loss: 0.2228  
Epoch 73/100  
54/54  1s 18ms/step - accuracy: 0.9676 - loss: 0.2248 -  
val\_accuracy: 0.9732 - val\_loss: 0.2175  
Epoch 74/100  
54/54  1s 20ms/step - accuracy: 0.9684 - loss: 0.2224 -  
val\_accuracy: 0.9722 - val\_loss: 0.2189  
Epoch 75/100  
54/54  1s 18ms/step - accuracy: 0.9681 - loss: 0.2233 -





```
val_accuracy: 0.9730 - val_loss: 0.2180
Epoch 76/100
54/54  1s 18ms/step - accuracy: 0.9678 - loss: 0.2223 -
val_accuracy: 0.9724 - val_loss: 0.2187
Epoch 77/100
54/54  1s 18ms/step - accuracy: 0.9677 - loss: 0.2223 -
val_accuracy: 0.9728 - val_loss: 0.2204
Epoch 78/100
54/54  1s 17ms/step - accuracy: 0.9668 - loss: 0.2227 -
val_accuracy: 0.9713 - val_loss: 0.2190
Epoch 79/100
54/54  1s 18ms/step - accuracy: 0.9680 - loss: 0.2228 -
val_accuracy: 0.9726 - val_loss: 0.2177
Epoch 80/100
54/54  1s 18ms/step - accuracy: 0.9675 - loss: 0.2222 -
val_accuracy: 0.9726 - val_loss: 0.2171
Epoch 81/100
54/54  1s 18ms/step - accuracy: 0.9674 - loss: 0.2216 -
val_accuracy: 0.9743 - val_loss: 0.2158
Epoch 82/100
54/54  1s 18ms/step - accuracy: 0.9678 - loss: 0.2208 -
val_accuracy: 0.9722 - val_loss: 0.2206
Epoch 83/100
54/54  1s 18ms/step - accuracy: 0.9681 - loss: 0.2206 -
val_accuracy: 0.9734 - val_loss: 0.2145
Epoch 84/100
54/54  1s 18ms/step - accuracy: 0.9680 - loss: 0.2208 -
val_accuracy: 0.9732 - val_loss: 0.2153
Epoch 85/100
54/54  1s 17ms/step - accuracy: 0.9671 - loss: 0.2212 -
val_accuracy: 0.9734 - val_loss: 0.2161
Epoch 86/100
54/54  1s 18ms/step - accuracy: 0.9679 - loss: 0.2193 -
val_accuracy: 0.9743 - val_loss: 0.2116
Epoch 87/100
54/54  1s 18ms/step - accuracy: 0.9684 - loss: 0.2189 -
val_accuracy: 0.9726 - val_loss: 0.2150
Epoch 88/100
54/54  1s 18ms/step - accuracy: 0.9685 - loss: 0.2185 -
val_accuracy: 0.9753 - val_loss: 0.2095
Epoch 89/100
54/54  1s 18ms/step - accuracy: 0.9687 - loss: 0.2180 -
val_accuracy: 0.9717 - val_loss: 0.2186
Epoch 90/100
54/54  1s 18ms/step - accuracy: 0.9682 - loss: 0.2181 -
val_accuracy: 0.9722 - val_loss: 0.2132
Epoch 91/100
54/54  1s 18ms/step - accuracy: 0.9684 - loss: 0.2170 -
val_accuracy: 0.9736 - val_loss: 0.2097
Epoch 92/100
54/54  1s 18ms/step - accuracy: 0.9684 - loss: 0.2156 -
val_accuracy: 0.9741 - val_loss: 0.2109
Epoch 93/100
54/54  1s 18ms/step - accuracy: 0.9679 - loss: 0.2160 -
val_accuracy: 0.9764 - val_loss: 0.2060
Epoch 94/100
```


54/54  1s 18ms/step - accuracy: 0.9675 - loss: 0.2159 -  
 val\_accuracy: 0.9739 - val\_loss: 0.2123  
 Epoch 95/100


54/54  1s 17ms/step - accuracy: 0.9685 - loss: 0.2158 -  
 val\_accuracy: 0.9770 - val\_loss: 0.2070  
 Epoch 96/100


54/54  1s 17ms/step - accuracy: 0.9685 - loss: 0.2155 -  
 val\_accuracy: 0.9747 - val\_loss: 0.2077  
 Epoch 97/100

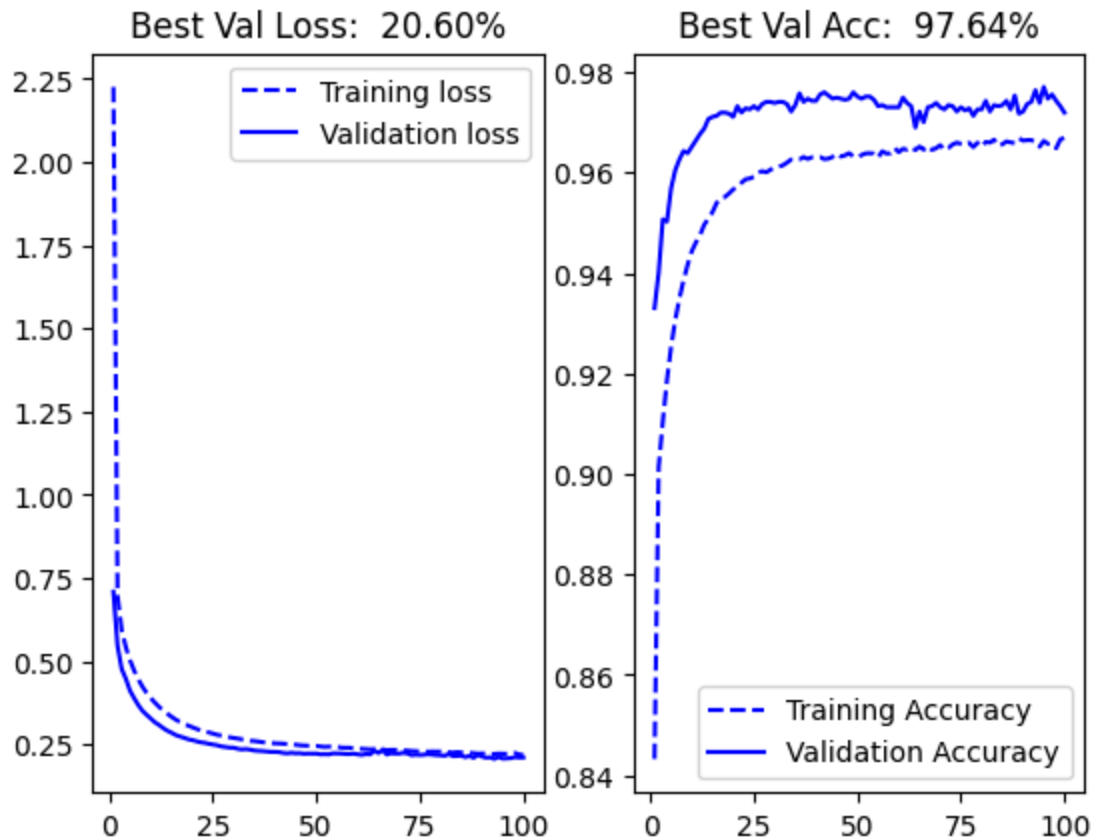
54/54  1s 17ms/step - accuracy: 0.9685 - loss: 0.2145 -  
 val\_accuracy: 0.9756 - val\_loss: 0.2086  
 Epoch 98/100

54/54  1s 18ms/step - accuracy: 0.9674 - loss: 0.2180 -  
 val\_accuracy: 0.9743 - val\_loss: 0.2116  
 Epoch 99/100

54/54  1s 17ms/step - accuracy: 0.9687 - loss: 0.2149 -  
 val\_accuracy: 0.9732 - val\_loss: 0.2101  
 Epoch 100/100

54/54  1s 17ms/step - accuracy: 0.9688 - loss: 0.2132 -  
 val\_accuracy: 0.9719 - val\_loss: 0.2105

5/5  0s 7ms/step - accuracy: 0.9750 - loss: 0.2066



```
In [9]: tf.keras.backend.clear_session()
        case_number = 4
        filename = f"models/lecture10_case{case_number}.keras"

        #rebuild the model so the weights are randomly initialized
        n_hidden1 = 512
        n_hidden2 = 128
```

```
lam = 0.002
L2_regularizer = regularizers.l2(lam)

inputs = keras.Input(shape=(28*28,))
x = layers.Dense(n_hidden1, activation="relu",
                  kernel_regularizer= L2_regularizer,
                  )(inputs)
x = layers.Dense(n_hidden2, activation="relu",
                  kernel_regularizer = L2_regularizer,
                  )(x)

outputs = layers.Dense(10, activation="softmax")(x)
model = keras.Model(inputs=inputs, outputs=outputs)

#recompile model with rmsprop optimizer

rmsprop = optimizers.RMSprop(
    learning_rate=0.001, # Starting learning rate
    rho=0.9, # Equivalent to decay factor
    momentum=0.7, # Adds momentum to updates
    epsilon=1e-7, # Helps with numerical stability 1e-7
    centered=True # Normalizes gradients (unique to TensorFlow)
)

model.compile(optimizer=rmsprop,
              loss = "sparse_categorical_crossentropy",
              metrics = ["accuracy"])




















#create a callback to save the best model with respect to validation loss

callbacks = [
    keras.callbacks.ModelCheckpoint(
        filepath = filename,
        save_best_only = True,
        monitor = "val_loss")]


#train model with ptraining data, and use val_ds for validation
number_epochs = 100


history = model.fit(ptrain_ds, epochs = number_epochs,
                    validation_data = val_ds,
                    callbacks = callbacks)


#evaluate
fit_evaluation(history, filename, val_ds)
```


Epoch 1/100  
54/54  1s 19ms/step - accuracy: 0.7641 - loss: 1.9124 - val\_accuracy: 0.9545 - val\_loss: 0.5453  
Epoch 2/100  
54/54  1s 17ms/step - accuracy: 0.9407 - loss: 0.5244 - val\_accuracy: 0.9668 - val\_loss: 0.3457  
Epoch 3/100  
54/54  1s 20ms/step - accuracy: 0.9523 - loss: 0.3679 - val\_accuracy: 0.9711 - val\_loss: 0.2815  
Epoch 4/100  
54/54  1s 19ms/step - accuracy: 0.9574 - loss: 0.3119 - val\_accuracy: 0.9751 - val\_loss: 0.2516  
Epoch 5/100  
54/54  1s 18ms/step - accuracy: 0.9608 - loss: 0.2838 - val\_accuracy: 0.9745 - val\_loss: 0.2369  
Epoch 6/100  
54/54  1s 19ms/step - accuracy: 0.9638 - loss: 0.2642 - val\_accuracy: 0.9743 - val\_loss: 0.2329  
Epoch 7/100  
54/54  1s 18ms/step - accuracy: 0.9667 - loss: 0.2499 - val\_accuracy: 0.9745 - val\_loss: 0.2288  
Epoch 8/100  
54/54  1s 19ms/step - accuracy: 0.9683 - loss: 0.2364 - val\_accuracy: 0.9749 - val\_loss: 0.2202  
Epoch 9/100  
54/54  1s 18ms/step - accuracy: 0.9697 - loss: 0.2253 - val\_accuracy: 0.9764 - val\_loss: 0.2112  
Epoch 10/100  
54/54  1s 19ms/step - accuracy: 0.9714 - loss: 0.2157 - val\_accuracy: 0.9764 - val\_loss: 0.2053  
Epoch 11/100  
54/54  1s 18ms/step - accuracy: 0.9732 - loss: 0.2085 - val\_accuracy: 0.9764 - val\_loss: 0.2000  
Epoch 12/100  
54/54  1s 19ms/step - accuracy: 0.9742 - loss: 0.2016 - val\_accuracy: 0.9756 - val\_loss: 0.1985  
Epoch 13/100  
54/54  1s 18ms/step - accuracy: 0.9747 - loss: 0.1963 - val\_accuracy: 0.9768 - val\_loss: 0.1924  
Epoch 14/100  
54/54  1s 18ms/step - accuracy: 0.9761 - loss: 0.1898 - val\_accuracy: 0.9762 - val\_loss: 0.1890  
Epoch 15/100  
54/54  1s 18ms/step - accuracy: 0.9768 - loss: 0.1851 - val\_accuracy: 0.9768 - val\_loss: 0.1895  
Epoch 16/100  
54/54  1s 18ms/step - accuracy: 0.9765 - loss: 0.1828 - val\_accuracy: 0.9768 - val\_loss: 0.1868  
Epoch 17/100  
54/54  1s 17ms/step - accuracy: 0.9768 - loss: 0.1776 - val\_accuracy: 0.9775 - val\_loss: 0.1857  
Epoch 18/100  
54/54  1s 18ms/step - accuracy: 0.9779 - loss: 0.1746 - val\_accuracy: 0.9790 - val\_loss: 0.1784  
Epoch 19/100  
54/54  1s 17ms/step - accuracy: 0.9790 - loss: 0.1713 -


```
val_accuracy: 0.9770 - val_loss: 0.1822
Epoch 20/100
54/54 ━━━━━━━━━━━━━━━━━ 1s 18ms/step - accuracy: 0.9795 - loss: 0.1684 -
val_accuracy: 0.9773 - val_loss: 0.1782
Epoch 21/100
54/54 ━━━━━━━━━━━━━━━━━ 1s 18ms/step - accuracy: 0.9807 - loss: 0.1661 -
val_accuracy: 0.9781 - val_loss: 0.1750
Epoch 22/100
54/54 ━━━━━━━━━━━━━━━━━ 1s 17ms/step - accuracy: 0.9799 - loss: 0.1640 -
val_accuracy: 0.9773 - val_loss: 0.1794
Epoch 23/100
54/54 ━━━━━━━━━━━━━━━━━ 1s 17ms/step - accuracy: 0.9799 - loss: 0.1617 -
val_accuracy: 0.9764 - val_loss: 0.1785
Epoch 24/100
54/54 ━━━━━━━━━━━━━━━━━ 1s 17ms/step - accuracy: 0.9803 - loss: 0.1602 -
val_accuracy: 0.9762 - val_loss: 0.1777
Epoch 25/100
54/54 ━━━━━━━━━━━━━━━━━ 1s 18ms/step - accuracy: 0.9803 - loss: 0.1582 -
val_accuracy: 0.9766 - val_loss: 0.1719
Epoch 26/100
54/54 ━━━━━━━━━━━━━━━━━ 1s 20ms/step - accuracy: 0.9808 - loss: 0.1556 -
val_accuracy: 0.9781 - val_loss: 0.1756
Epoch 27/100
54/54 ━━━━━━━━━━━━━━━━━ 1s 18ms/step - accuracy: 0.9812 - loss: 0.1540 -
val_accuracy: 0.9760 - val_loss: 0.1771
Epoch 28/100
54/54 ━━━━━━━━━━━━━━━━━ 1s 18ms/step - accuracy: 0.9799 - loss: 0.1560 -
val_accuracy: 0.9773 - val_loss: 0.1728
Epoch 29/100
54/54 ━━━━━━━━━━━━━━━━━ 1s 18ms/step - accuracy: 0.9809 - loss: 0.1519 -
val_accuracy: 0.9773 - val_loss: 0.1713
Epoch 30/100
54/54 ━━━━━━━━━━━━━━━━━ 1s 18ms/step - accuracy: 0.9812 - loss: 0.1507 -
val_accuracy: 0.9773 - val_loss: 0.1695
Epoch 31/100
54/54 ━━━━━━━━━━━━━━━━━ 1s 18ms/step - accuracy: 0.9813 - loss: 0.1495 -
val_accuracy: 0.9751 - val_loss: 0.1722
Epoch 32/100
54/54 ━━━━━━━━━━━━━━━━━ 1s 17ms/step - accuracy: 0.9809 - loss: 0.1509 -
val_accuracy: 0.9751 - val_loss: 0.1739
Epoch 33/100
54/54 ━━━━━━━━━━━━━━━━━ 1s 17ms/step - accuracy: 0.9822 - loss: 0.1464 -
val_accuracy: 0.9766 - val_loss: 0.1702
Epoch 34/100
54/54 ━━━━━━━━━━━━━━━━━ 1s 18ms/step - accuracy: 0.9823 - loss: 0.1458 -
val_accuracy: 0.9764 - val_loss: 0.1722
Epoch 35/100
54/54 ━━━━━━━━━━━━━━━━━ 1s 17ms/step - accuracy: 0.9818 - loss: 0.1444 -
val_accuracy: 0.9751 - val_loss: 0.1696
Epoch 36/100
54/54 ━━━━━━━━━━━━━━━━━ 1s 18ms/step - accuracy: 0.9810 - loss: 0.1463 -
val_accuracy: 0.9751 - val_loss: 0.1736
Epoch 37/100
54/54 ━━━━━━━━━━━━━━━━━ 1s 18ms/step - accuracy: 0.9804 - loss: 0.1484 -
val_accuracy: 0.9758 - val_loss: 0.1680
Epoch 38/100
```


54/54  1s 17ms/step - accuracy: 0.9826 - loss: 0.1415 -  
val\_accuracy: 0.9756 - val\_loss: 0.1704  
Epoch 39/100


54/54  1s 17ms/step - accuracy: 0.9815 - loss: 0.1445 -  
val\_accuracy: 0.9758 - val\_loss: 0.1648  
Epoch 40/100


54/54  1s 17ms/step - accuracy: 0.9822 - loss: 0.1409 -  
val\_accuracy: 0.9722 - val\_loss: 0.1729  
Epoch 41/100


54/54  1s 18ms/step - accuracy: 0.9811 - loss: 0.1441 -  
val\_accuracy: 0.9753 - val\_loss: 0.1641  
Epoch 42/100


54/54  1s 17ms/step - accuracy: 0.9803 - loss: 0.1445 -  
val\_accuracy: 0.9745 - val\_loss: 0.1675  
Epoch 43/100


54/54  1s 17ms/step - accuracy: 0.9822 - loss: 0.1411 -  
val\_accuracy: 0.9739 - val\_loss: 0.1652  
Epoch 44/100


54/54  1s 17ms/step - accuracy: 0.9829 - loss: 0.1381 -  
val\_accuracy: 0.9753 - val\_loss: 0.1636  
Epoch 45/100


54/54  1s 17ms/step - accuracy: 0.9829 - loss: 0.1373 -  
val\_accuracy: 0.9758 - val\_loss: 0.1643  
Epoch 46/100


54/54  1s 17ms/step - accuracy: 0.9818 - loss: 0.1389 -  
val\_accuracy: 0.9730 - val\_loss: 0.1678  
Epoch 47/100


54/54  1s 17ms/step - accuracy: 0.9826 - loss: 0.1357 -  
val\_accuracy: 0.9728 - val\_loss: 0.1673  
Epoch 48/100


54/54  1s 18ms/step - accuracy: 0.9823 - loss: 0.1383 -  
val\_accuracy: 0.9711 - val\_loss: 0.1812  
Epoch 49/100


54/54  1s 18ms/step - accuracy: 0.9817 - loss: 0.1379 -  
val\_accuracy: 0.9760 - val\_loss: 0.1631  
Epoch 50/100


54/54  1s 17ms/step - accuracy: 0.9827 - loss: 0.1343 -  
val\_accuracy: 0.9734 - val\_loss: 0.1700  
Epoch 51/100


54/54  1s 18ms/step - accuracy: 0.9838 - loss: 0.1317 -  
val\_accuracy: 0.9751 - val\_loss: 0.1654  
Epoch 52/100




















54/54  1s 18ms/step - accuracy: 0.9826 - loss: 0.1360 -  
val\_accuracy: 0.9734 - val\_loss: 0.1682  
Epoch 53/100

54/54  1s 18ms/step - accuracy: 0.9829 - loss: 0.1352 -  
val\_accuracy: 0.9696 - val\_loss: 0.1776  
Epoch 54/100



















54/54  1s 18ms/step - accuracy: 0.9822 - loss: 0.1362 -  
val\_accuracy: 0.9747 - val\_loss: 0.1654  
Epoch 55/100

54/54  1s 18ms/step - accuracy: 0.9837 - loss: 0.1321 -  
val\_accuracy: 0.9758 - val\_loss: 0.1616  
Epoch 56/100


54/54  1s 19ms/step - accuracy: 0.9824 - loss: 0.1344 -  
val\_accuracy: 0.9756 - val\_loss: 0.1619


Epoch 57/100  
54/54  1s 19ms/step - accuracy: 0.9831 - loss: 0.1335 -  
val\_accuracy: 0.9724 - val\_loss: 0.1674  
Epoch 58/100  
54/54  1s 18ms/step - accuracy: 0.9834 - loss: 0.1307 -  
val\_accuracy: 0.9724 - val\_loss: 0.1689  
Epoch 59/100  
54/54  1s 18ms/step - accuracy: 0.9842 - loss: 0.1292 -  
val\_accuracy: 0.9751 - val\_loss: 0.1622  
Epoch 60/100  
54/54  1s 18ms/step - accuracy: 0.9810 - loss: 0.1350 -  
val\_accuracy: 0.9728 - val\_loss: 0.1703  
Epoch 61/100  
54/54  1s 18ms/step - accuracy: 0.9842 - loss: 0.1278 -  
val\_accuracy: 0.9773 - val\_loss: 0.1545  
Epoch 62/100  
54/54  1s 18ms/step - accuracy: 0.9837 - loss: 0.1283 -  
val\_accuracy: 0.9766 - val\_loss: 0.1551  
Epoch 63/100  
54/54  1s 17ms/step - accuracy: 0.9839 - loss: 0.1269 -  
val\_accuracy: 0.9700 - val\_loss: 0.1726  
Epoch 64/100  
54/54  1s 18ms/step - accuracy: 0.9828 - loss: 0.1307 -  
val\_accuracy: 0.9730 - val\_loss: 0.1619  
Epoch 65/100  
54/54  1s 18ms/step - accuracy: 0.9835 - loss: 0.1287 -  
val\_accuracy: 0.9756 - val\_loss: 0.1566  
Epoch 66/100  
54/54  1s 18ms/step - accuracy: 0.9834 - loss: 0.1285 -  
val\_accuracy: 0.9747 - val\_loss: 0.1615  
Epoch 67/100  
54/54  1s 18ms/step - accuracy: 0.9833 - loss: 0.1291 -  
val\_accuracy: 0.9749 - val\_loss: 0.1669  
Epoch 68/100  
54/54  1s 18ms/step - accuracy: 0.9828 - loss: 0.1281 -  
val\_accuracy: 0.9756 - val\_loss: 0.1578  
Epoch 69/100  
54/54  1s 18ms/step - accuracy: 0.9819 - loss: 0.1281 -  
val\_accuracy: 0.9685 - val\_loss: 0.1756  
Epoch 70/100  
54/54  1s 18ms/step - accuracy: 0.9834 - loss: 0.1252 -  
val\_accuracy: 0.9717 - val\_loss: 0.1651  
Epoch 71/100  
54/54  1s 18ms/step - accuracy: 0.9822 - loss: 0.1289 -  
val\_accuracy: 0.9747 - val\_loss: 0.1579  
Epoch 72/100  
54/54  1s 18ms/step - accuracy: 0.9842 - loss: 0.1243 -  
val\_accuracy: 0.9751 - val\_loss: 0.1564  
Epoch 73/100  
54/54  1s 19ms/step - accuracy: 0.9842 - loss: 0.1248 -  
val\_accuracy: 0.9756 - val\_loss: 0.1534  
Epoch 74/100  
54/54  1s 19ms/step - accuracy: 0.9833 - loss: 0.1256 -  
val\_accuracy: 0.9688 - val\_loss: 0.1734  
Epoch 75/100  
54/54  1s 19ms/step - accuracy: 0.9835 - loss: 0.1260 -





```
val_accuracy: 0.9741 - val_loss: 0.1588
Epoch 76/100
54/54  1s 20ms/step - accuracy: 0.9840 - loss: 0.1231 -
val_accuracy: 0.9698 - val_loss: 0.1671
Epoch 77/100
54/54  1s 17ms/step - accuracy: 0.9849 - loss: 0.1221 -
val_accuracy: 0.9730 - val_loss: 0.1629
Epoch 78/100
54/54  1s 19ms/step - accuracy: 0.9850 - loss: 0.1227 -
val_accuracy: 0.9656 - val_loss: 0.1859
Epoch 79/100
54/54  1s 18ms/step - accuracy: 0.9830 - loss: 0.1270 -
val_accuracy: 0.9715 - val_loss: 0.1684
Epoch 80/100
54/54  1s 18ms/step - accuracy: 0.9845 - loss: 0.1236 -
val_accuracy: 0.9758 - val_loss: 0.1533
Epoch 81/100
54/54  1s 17ms/step - accuracy: 0.9853 - loss: 0.1206 -
val_accuracy: 0.9709 - val_loss: 0.1561
Epoch 82/100
54/54  1s 18ms/step - accuracy: 0.9850 - loss: 0.1197 -
val_accuracy: 0.9734 - val_loss: 0.1571
Epoch 83/100
54/54  1s 18ms/step - accuracy: 0.9839 - loss: 0.1241 -
val_accuracy: 0.9728 - val_loss: 0.1669
Epoch 84/100
54/54  1s 20ms/step - accuracy: 0.9812 - loss: 0.1276 -
val_accuracy: 0.9726 - val_loss: 0.1671
Epoch 85/100
54/54  1s 19ms/step - accuracy: 0.9834 - loss: 0.1236 -
val_accuracy: 0.9707 - val_loss: 0.1724
Epoch 86/100
54/54  1s 18ms/step - accuracy: 0.9844 - loss: 0.1213 -
val_accuracy: 0.9753 - val_loss: 0.1526
Epoch 87/100
54/54  1s 17ms/step - accuracy: 0.9837 - loss: 0.1219 -
val_accuracy: 0.9717 - val_loss: 0.1655
Epoch 88/100
54/54  1s 19ms/step - accuracy: 0.9849 - loss: 0.1205 -
val_accuracy: 0.9732 - val_loss: 0.1587
Epoch 89/100
54/54  1s 18ms/step - accuracy: 0.9844 - loss: 0.1210 -
val_accuracy: 0.9741 - val_loss: 0.1556
Epoch 90/100
54/54  1s 18ms/step - accuracy: 0.9826 - loss: 0.1260 -
val_accuracy: 0.9741 - val_loss: 0.1572
Epoch 91/100
54/54  1s 17ms/step - accuracy: 0.9843 - loss: 0.1216 -
val_accuracy: 0.9726 - val_loss: 0.1596
Epoch 92/100
54/54  1s 18ms/step - accuracy: 0.9836 - loss: 0.1234 -
val_accuracy: 0.9728 - val_loss: 0.1546
Epoch 93/100
54/54  1s 18ms/step - accuracy: 0.9829 - loss: 0.1260 -
val_accuracy: 0.9736 - val_loss: 0.1613
Epoch 94/100
```





54/54  1s 18ms/step - accuracy: 0.9832 - loss: 0.1228 - val\_accuracy: 0.9751 - val\_loss: 0.1528  
Epoch 95/100


54/54  1s 18ms/step - accuracy: 0.9824 - loss: 0.1265 - val\_accuracy: 0.9732 - val\_loss: 0.1579  
Epoch 96/100


54/54  1s 17ms/step - accuracy: 0.9857 - loss: 0.1197 - val\_accuracy: 0.9743 - val\_loss: 0.1568  
Epoch 97/100

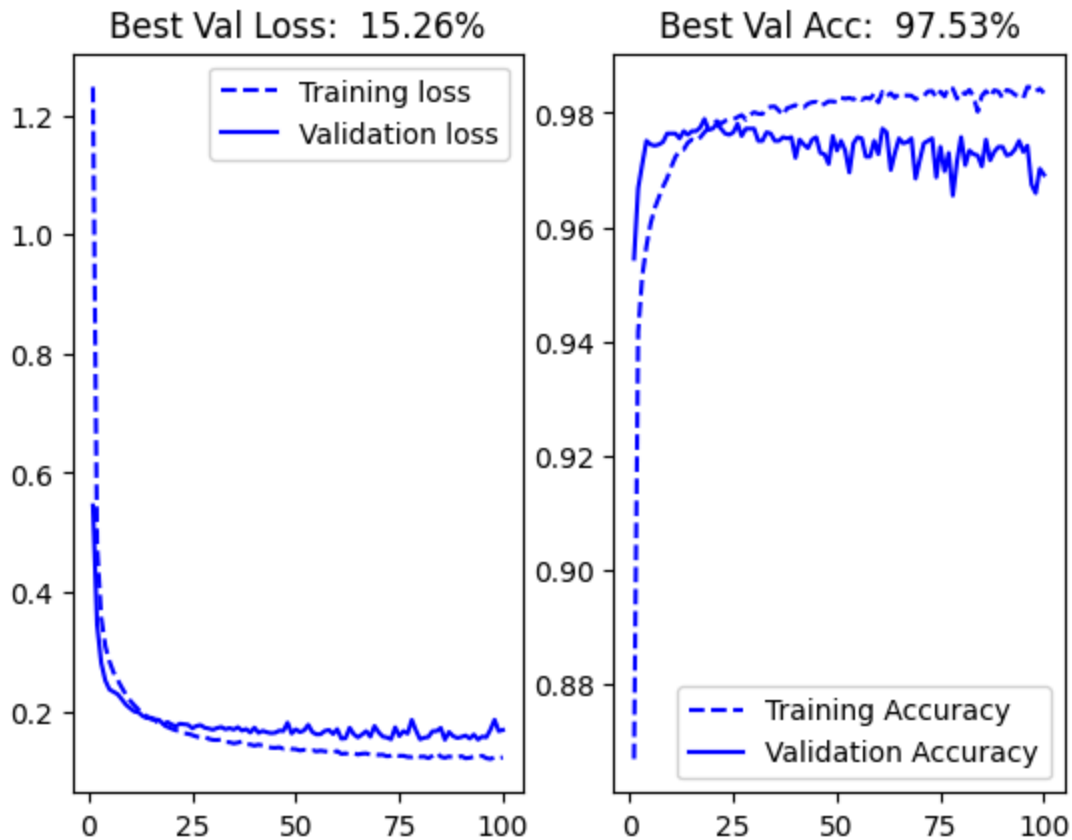
54/54  1s 18ms/step - accuracy: 0.9849 - loss: 0.1198 - val\_accuracy: 0.9675 - val\_loss: 0.1694  
Epoch 98/100

54/54  1s 18ms/step - accuracy: 0.9836 - loss: 0.1234 - val\_accuracy: 0.9660 - val\_loss: 0.1861  
Epoch 99/100

54/54  1s 17ms/step - accuracy: 0.9834 - loss: 0.1232 - val\_accuracy: 0.9702 - val\_loss: 0.1670  
Epoch 100/100

54/54  1s 18ms/step - accuracy: 0.9843 - loss: 0.1204 - val\_accuracy: 0.9692 - val\_loss: 0.1690

5/5  0s 7ms/step - accuracy: 0.9728 - loss: 0.1521



```
In [10]: tf.keras.backend.clear_session()
         case_number = 5
         filename = f"models/lecture10_case{case_number}.keras"

         #rebuild the model so the weights are randomly initialized
         n_hidden1 = 512
         n_hidden2 = 128
```

```

lam = 0.002
L2_regularizer = regularizers.l2(lam)

inputs = keras.Input(shape=(28*28,))
x = layers.Dense(n_hidden1, activation="relu",
                  kernel_regularizer= L2_regularizer,
                  )(inputs)
x = layers.Dense(n_hidden2, activation="relu",
                  kernel_regularizer = L2_regularizer,
                  )(x)

outputs = layers.Dense(10, activation="softmax")(x)
model = keras.Model(inputs=inputs, outputs=outputs)

model.summary()

#recompile model with rmsprop optimizer

adam = optimizers.Adam(
    learning_rate = 0.001,
    beta_1 = 0.9,
    beta_2 = 0.999,
    epsilon = 1e-7,
    amsgrad = False,
    weight_decay = None,
    ema_momentum = 0.99
)

model.compile(optimizer=adam,
              loss = "sparse_categorical_crossentropy",
              metrics = ["accuracy"])

#create a callback to save the best model with respect to validation loss

callbacks = [
    keras.callbacks.ModelCheckpoint(
        filepath = filename,
        save_best_only = True,
        monitor = "val_loss")]

```

**Model: "functional"**

Layer (type)	Output Shape	Par
input_layer ( <a href="#">InputLayer</a> )	(None, 784)	
dense ( <a href="#">Dense</a> )	(None, 512)	401
dense_1 ( <a href="#">Dense</a> )	(None, 128)	65
dense_2 ( <a href="#">Dense</a> )	(None, 10)	1

**Total params:** 468,874 (1.79 MB)




















**Trainable params:** 468,874 (1.79 MB)



















**Non-trainable params:** 0 (0.00 B)


```
In [11]: #train model with ptraining data, and use val_ds for validation
         number_epochs = 100


         history = model.fit(ptrain_ds, epochs = number_epochs,
                             validation_data = val_ds,
                             callbacks = callbacks)


         #evaluate
         fit_evaluation(history, filename, val_ds)
```


Epoch 1/100  
54/54  1s 18ms/step - accuracy: 0.7247 - loss: 2.3172 -  
val\_accuracy: 0.9441 - val\_loss: 0.9478  
Epoch 2/100  
54/54  1s 18ms/step - accuracy: 0.9291 - loss: 0.9121 -  
val\_accuracy: 0.9615 - val\_loss: 0.6494  
Epoch 3/100  
54/54  1s 17ms/step - accuracy: 0.9440 - loss: 0.6549 -  
val\_accuracy: 0.9662 - val\_loss: 0.5074  
Epoch 4/100  
54/54  1s 17ms/step - accuracy: 0.9528 - loss: 0.5191 -  
val\_accuracy: 0.9692 - val\_loss: 0.4196  
Epoch 5/100  
54/54  1s 16ms/step - accuracy: 0.9583 - loss: 0.4336 -  
val\_accuracy: 0.9719 - val\_loss: 0.3613  
Epoch 6/100  
54/54  1s 17ms/step - accuracy: 0.9624 - loss: 0.3762 -  
val\_accuracy: 0.9743 - val\_loss: 0.3211  
Epoch 7/100  
54/54  1s 18ms/step - accuracy: 0.9657 - loss: 0.3359 -  
val\_accuracy: 0.9760 - val\_loss: 0.2921  
Epoch 8/100  
54/54  1s 17ms/step - accuracy: 0.9680 - loss: 0.3062 -  
val\_accuracy: 0.9760 - val\_loss: 0.2713  
Epoch 9/100  
54/54  1s 17ms/step - accuracy: 0.9700 - loss: 0.2844 -  
val\_accuracy: 0.9770 - val\_loss: 0.2557  
Epoch 10/100  
54/54  1s 16ms/step - accuracy: 0.9710 - loss: 0.2679 -  
val\_accuracy: 0.9781 - val\_loss: 0.2438  
Epoch 11/100  
54/54  1s 16ms/step - accuracy: 0.9724 - loss: 0.2549 -  
val\_accuracy: 0.9781 - val\_loss: 0.2347  
Epoch 12/100  
54/54  1s 16ms/step - accuracy: 0.9732 - loss: 0.2445 -  
val\_accuracy: 0.9790 - val\_loss: 0.2275  
Epoch 13/100  
54/54  1s 16ms/step - accuracy: 0.9744 - loss: 0.2362 -  
val\_accuracy: 0.9796 - val\_loss: 0.2217  
Epoch 14/100  
54/54  1s 16ms/step - accuracy: 0.9752 - loss: 0.2293 -  
val\_accuracy: 0.9809 - val\_loss: 0.2163  
Epoch 15/100  
54/54  1s 16ms/step - accuracy: 0.9758 - loss: 0.2231 -  
val\_accuracy: 0.9807 - val\_loss: 0.2120  
Epoch 16/100  
54/54  1s 17ms/step - accuracy: 0.9765 - loss: 0.2178 -  
val\_accuracy: 0.9802 - val\_loss: 0.2085  
Epoch 17/100  
54/54  1s 16ms/step - accuracy: 0.9769 - loss: 0.2133 -  
val\_accuracy: 0.9804 - val\_loss: 0.2052  
Epoch 18/100  
54/54  1s 15ms/step - accuracy: 0.9773 - loss: 0.2092 -  
val\_accuracy: 0.9794 - val\_loss: 0.2024  
Epoch 19/100  
54/54  1s 17ms/step - accuracy: 0.9781 - loss: 0.2055 -


```
val_accuracy: 0.9794 - val_loss: 0.1996
Epoch 20/100
54/54  1s 16ms/step - accuracy: 0.9785 - loss: 0.2023 -
val_accuracy: 0.9798 - val_loss: 0.1972
Epoch 21/100
54/54  1s 17ms/step - accuracy: 0.9789 - loss: 0.1992 -
val_accuracy: 0.9796 - val_loss: 0.1948
Epoch 22/100
54/54  1s 16ms/step - accuracy: 0.9792 - loss: 0.1963 -
val_accuracy: 0.9790 - val_loss: 0.1934
Epoch 23/100
54/54  1s 17ms/step - accuracy: 0.9793 - loss: 0.1939 -
val_accuracy: 0.9792 - val_loss: 0.1914
Epoch 24/100
54/54  1s 17ms/step - accuracy: 0.9796 - loss: 0.1915 -
val_accuracy: 0.9790 - val_loss: 0.1901
Epoch 25/100
54/54  1s 16ms/step - accuracy: 0.9799 - loss: 0.1893 -
val_accuracy: 0.9792 - val_loss: 0.1885
Epoch 26/100
54/54  1s 16ms/step - accuracy: 0.9800 - loss: 0.1871 -
val_accuracy: 0.9794 - val_loss: 0.1868
Epoch 27/100
54/54  1s 16ms/step - accuracy: 0.9801 - loss: 0.1850 -
val_accuracy: 0.9790 - val_loss: 0.1852
Epoch 28/100
54/54  1s 17ms/step - accuracy: 0.9805 - loss: 0.1831 -
val_accuracy: 0.9792 - val_loss: 0.1842
Epoch 29/100
54/54  1s 17ms/step - accuracy: 0.9807 - loss: 0.1811 -
val_accuracy: 0.9798 - val_loss: 0.1825
Epoch 30/100
54/54  1s 16ms/step - accuracy: 0.9809 - loss: 0.1790 -
val_accuracy: 0.9800 - val_loss: 0.1808
Epoch 31/100
54/54  1s 16ms/step - accuracy: 0.9812 - loss: 0.1770 -
val_accuracy: 0.9802 - val_loss: 0.1797
Epoch 32/100
54/54  1s 16ms/step - accuracy: 0.9816 - loss: 0.1749 -
val_accuracy: 0.9809 - val_loss: 0.1785
Epoch 33/100
54/54  1s 17ms/step - accuracy: 0.9819 - loss: 0.1731 -
val_accuracy: 0.9811 - val_loss: 0.1775
Epoch 34/100
54/54  1s 16ms/step - accuracy: 0.9822 - loss: 0.1710 -
val_accuracy: 0.9811 - val_loss: 0.1763
Epoch 35/100
54/54  1s 16ms/step - accuracy: 0.9822 - loss: 0.1694 -
val_accuracy: 0.9815 - val_loss: 0.1758
Epoch 36/100
54/54  1s 16ms/step - accuracy: 0.9825 - loss: 0.1677 -
val_accuracy: 0.9815 - val_loss: 0.1751
Epoch 37/100
54/54  1s 16ms/step - accuracy: 0.9827 - loss: 0.1663 -
val_accuracy: 0.9813 - val_loss: 0.1738
Epoch 38/100
```


54/54  1s 16ms/step - accuracy: 0.9829 - loss: 0.1646 -  
val\_accuracy: 0.9815 - val\_loss: 0.1726  
Epoch 39/100


54/54  1s 16ms/step - accuracy: 0.9829 - loss: 0.1629 -  
val\_accuracy: 0.9815 - val\_loss: 0.1713  
Epoch 40/100


54/54  1s 16ms/step - accuracy: 0.9835 - loss: 0.1615 -  
val\_accuracy: 0.9815 - val\_loss: 0.1698  
Epoch 41/100


54/54  1s 16ms/step - accuracy: 0.9838 - loss: 0.1603 -  
val\_accuracy: 0.9815 - val\_loss: 0.1692  
Epoch 42/100


54/54  1s 16ms/step - accuracy: 0.9840 - loss: 0.1590 -  
val\_accuracy: 0.9819 - val\_loss: 0.1677  
Epoch 43/100


54/54  1s 17ms/step - accuracy: 0.9842 - loss: 0.1573 -  
val\_accuracy: 0.9817 - val\_loss: 0.1670  
Epoch 44/100


54/54  1s 16ms/step - accuracy: 0.9846 - loss: 0.1561 -  
val\_accuracy: 0.9821 - val\_loss: 0.1661  
Epoch 45/100


54/54  1s 16ms/step - accuracy: 0.9848 - loss: 0.1546 -  
val\_accuracy: 0.9821 - val\_loss: 0.1652  
Epoch 46/100


54/54  1s 17ms/step - accuracy: 0.9851 - loss: 0.1531 -  
val\_accuracy: 0.9826 - val\_loss: 0.1643  
Epoch 47/100


54/54  1s 15ms/step - accuracy: 0.9852 - loss: 0.1518 -  
val\_accuracy: 0.9824 - val\_loss: 0.1635  
Epoch 48/100


54/54  1s 17ms/step - accuracy: 0.9857 - loss: 0.1507 -  
val\_accuracy: 0.9817 - val\_loss: 0.1625  
Epoch 49/100


54/54  1s 17ms/step - accuracy: 0.9858 - loss: 0.1493 -  
val\_accuracy: 0.9826 - val\_loss: 0.1614  
Epoch 50/100


54/54  1s 17ms/step - accuracy: 0.9860 - loss: 0.1481 -  
val\_accuracy: 0.9828 - val\_loss: 0.1605  
Epoch 51/100


54/54  1s 17ms/step - accuracy: 0.9863 - loss: 0.1471 -  
val\_accuracy: 0.9824 - val\_loss: 0.1604  
Epoch 52/100




















54/54  1s 16ms/step - accuracy: 0.9864 - loss: 0.1461 -  
val\_accuracy: 0.9826 - val\_loss: 0.1595  
Epoch 53/100



















54/54  1s 16ms/step - accuracy: 0.9866 - loss: 0.1451 -  
val\_accuracy: 0.9813 - val\_loss: 0.1596  
Epoch 54/100

54/54  1s 15ms/step - accuracy: 0.9868 - loss: 0.1441 -  
val\_accuracy: 0.9809 - val\_loss: 0.1591  
Epoch 55/100


54/54  1s 17ms/step - accuracy: 0.9868 - loss: 0.1432 -  
val\_accuracy: 0.9815 - val\_loss: 0.1589  
Epoch 56/100


54/54  1s 16ms/step - accuracy: 0.9871 - loss: 0.1425 -  
val\_accuracy: 0.9809 - val\_loss: 0.1585


Epoch 57/100  
54/54  1s 18ms/step - accuracy: 0.9875 - loss: 0.1415 -  
val\_accuracy: 0.9804 - val\_loss: 0.1577  
Epoch 58/100  
54/54  1s 17ms/step - accuracy: 0.9873 - loss: 0.1407 -  
val\_accuracy: 0.9798 - val\_loss: 0.1577  
Epoch 59/100  
54/54  1s 18ms/step - accuracy: 0.9875 - loss: 0.1398 -  
val\_accuracy: 0.9811 - val\_loss: 0.1569  
Epoch 60/100  
54/54  1s 18ms/step - accuracy: 0.9877 - loss: 0.1387 -  
val\_accuracy: 0.9817 - val\_loss: 0.1562  
Epoch 61/100  
54/54  1s 18ms/step - accuracy: 0.9877 - loss: 0.1381 -  
val\_accuracy: 0.9813 - val\_loss: 0.1552  
Epoch 62/100  
54/54  1s 17ms/step - accuracy: 0.9880 - loss: 0.1373 -  
val\_accuracy: 0.9811 - val\_loss: 0.1546  
Epoch 63/100  
54/54  1s 19ms/step - accuracy: 0.9880 - loss: 0.1368 -  
val\_accuracy: 0.9807 - val\_loss: 0.1543  
Epoch 64/100  
54/54  1s 18ms/step - accuracy: 0.9879 - loss: 0.1363 -  
val\_accuracy: 0.9809 - val\_loss: 0.1544  
Epoch 65/100  
54/54  1s 17ms/step - accuracy: 0.9880 - loss: 0.1359 -  
val\_accuracy: 0.9811 - val\_loss: 0.1543  
Epoch 66/100  
54/54  1s 17ms/step - accuracy: 0.9876 - loss: 0.1354 -  
val\_accuracy: 0.9802 - val\_loss: 0.1551  
Epoch 67/100  
54/54  1s 16ms/step - accuracy: 0.9870 - loss: 0.1360 -  
val\_accuracy: 0.9781 - val\_loss: 0.1572  
Epoch 68/100  
54/54  1s 16ms/step - accuracy: 0.9865 - loss: 0.1363 -  
val\_accuracy: 0.9783 - val\_loss: 0.1582  
Epoch 69/100  
54/54  1s 16ms/step - accuracy: 0.9861 - loss: 0.1373 -  
val\_accuracy: 0.9792 - val\_loss: 0.1565  
Epoch 70/100  
54/54  1s 16ms/step - accuracy: 0.9862 - loss: 0.1372 -  
val\_accuracy: 0.9790 - val\_loss: 0.1562  
Epoch 71/100  
54/54  1s 18ms/step - accuracy: 0.9864 - loss: 0.1357 -  
val\_accuracy: 0.9787 - val\_loss: 0.1532  
Epoch 72/100  
54/54  1s 17ms/step - accuracy: 0.9875 - loss: 0.1328 -  
val\_accuracy: 0.9800 - val\_loss: 0.1499  
Epoch 73/100  
54/54  1s 17ms/step - accuracy: 0.9881 - loss: 0.1300 -  
val\_accuracy: 0.9813 - val\_loss: 0.1473  
Epoch 74/100  
54/54  1s 17ms/step - accuracy: 0.9887 - loss: 0.1277 -  
val\_accuracy: 0.9817 - val\_loss: 0.1448  
Epoch 75/100  
54/54  1s 17ms/step - accuracy: 0.9892 - loss: 0.1263 -


```
val_accuracy: 0.9830 - val_loss: 0.1439
Epoch 76/100
54/54  1s 19ms/step - accuracy: 0.9897 - loss: 0.1249 -
val_accuracy: 0.9828 - val_loss: 0.1438
Epoch 77/100
54/54  1s 17ms/step - accuracy: 0.9898 - loss: 0.1246 -
val_accuracy: 0.9830 - val_loss: 0.1433
Epoch 78/100
54/54  1s 18ms/step - accuracy: 0.9898 - loss: 0.1237 -
val_accuracy: 0.9834 - val_loss: 0.1428
Epoch 79/100
54/54  1s 19ms/step - accuracy: 0.9901 - loss: 0.1234 -
val_accuracy: 0.9836 - val_loss: 0.1433
Epoch 80/100
54/54  1s 17ms/step - accuracy: 0.9899 - loss: 0.1232 -
val_accuracy: 0.9841 - val_loss: 0.1432
Epoch 81/100
54/54  1s 16ms/step - accuracy: 0.9901 - loss: 0.1227 -
val_accuracy: 0.9836 - val_loss: 0.1427
Epoch 82/100
54/54  1s 16ms/step - accuracy: 0.9901 - loss: 0.1222 -
val_accuracy: 0.9834 - val_loss: 0.1428
Epoch 83/100
54/54  1s 17ms/step - accuracy: 0.9900 - loss: 0.1220 -
val_accuracy: 0.9830 - val_loss: 0.1429
Epoch 84/100
54/54  1s 17ms/step - accuracy: 0.9901 - loss: 0.1214 -
val_accuracy: 0.9834 - val_loss: 0.1426
Epoch 85/100
54/54  1s 17ms/step - accuracy: 0.9903 - loss: 0.1207 -
val_accuracy: 0.9830 - val_loss: 0.1435
Epoch 86/100
54/54  1s 17ms/step - accuracy: 0.9907 - loss: 0.1199 -
val_accuracy: 0.9821 - val_loss: 0.1428
Epoch 87/100
54/54  1s 16ms/step - accuracy: 0.9910 - loss: 0.1187 -
val_accuracy: 0.9824 - val_loss: 0.1429
Epoch 88/100
54/54  1s 17ms/step - accuracy: 0.9911 - loss: 0.1177 -
val_accuracy: 0.9824 - val_loss: 0.1421
Epoch 89/100
54/54  1s 17ms/step - accuracy: 0.9912 - loss: 0.1168 -
val_accuracy: 0.9828 - val_loss: 0.1410
Epoch 90/100
54/54  1s 17ms/step - accuracy: 0.9914 - loss: 0.1158 -
val_accuracy: 0.9830 - val_loss: 0.1402
Epoch 91/100
54/54  1s 17ms/step - accuracy: 0.9915 - loss: 0.1148 -
val_accuracy: 0.9824 - val_loss: 0.1394
Epoch 92/100
54/54  1s 17ms/step - accuracy: 0.9916 - loss: 0.1138 -
val_accuracy: 0.9828 - val_loss: 0.1385
Epoch 93/100
54/54  1s 17ms/step - accuracy: 0.9913 - loss: 0.1130 -
val_accuracy: 0.9828 - val_loss: 0.1380
Epoch 94/100
```





54/54  1s 17ms/step - accuracy: 0.9916 - loss: 0.1126 -  
 val\_accuracy: 0.9838 - val\_loss: 0.1366  
 Epoch 95/100


54/54  1s 18ms/step - accuracy: 0.9916 - loss: 0.1117 -  
 val\_accuracy: 0.9838 - val\_loss: 0.1365  
 Epoch 96/100


54/54  1s 17ms/step - accuracy: 0.9918 - loss: 0.1113 -  
 val\_accuracy: 0.9843 - val\_loss: 0.1363  
 Epoch 97/100

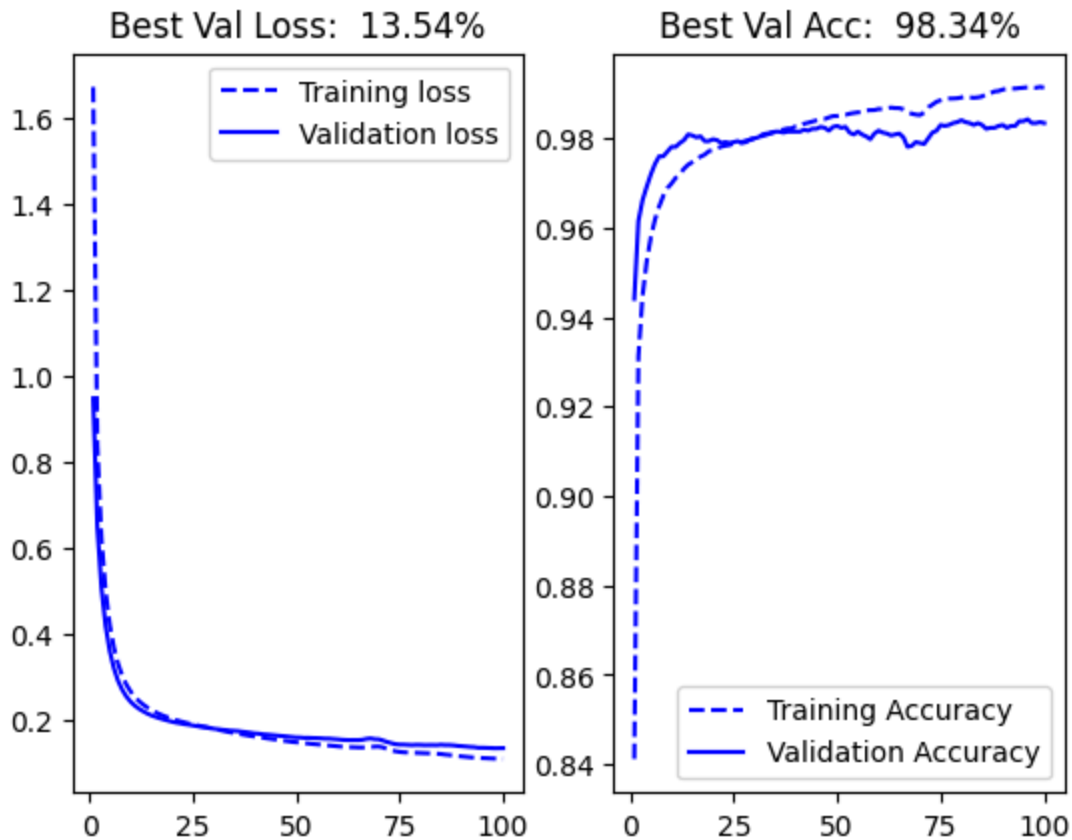
54/54  1s 17ms/step - accuracy: 0.9919 - loss: 0.1108 -  
 val\_accuracy: 0.9834 - val\_loss: 0.1359  
 Epoch 98/100

54/54  1s 17ms/step - accuracy: 0.9919 - loss: 0.1103 -  
 val\_accuracy: 0.9834 - val\_loss: 0.1354  
 Epoch 99/100

54/54  1s 17ms/step - accuracy: 0.9921 - loss: 0.1096 -  
 val\_accuracy: 0.9836 - val\_loss: 0.1356  
 Epoch 100/100

54/54  1s 17ms/step - accuracy: 0.9919 - loss: 0.1095 -  
 val\_accuracy: 0.9834 - val\_loss: 0.1357

5/5  0s 7ms/step - accuracy: 0.9830 - loss: 0.1331



In [4]: `batch_size = 1024`

```
train_x = train_x.reshape(n_train_samples,28,28,1).astype("float64")/255
test_x = test_x.reshape(n_test_samples,28,28,1).astype("float64")/255
#create training data set - batch size = 1024
```

```

train_ds = Dataset.from_tensor_slices((train_x, train_y)).batch(batch_size)
test_ds = Dataset.from_tensor_slices((test_x, test_y)).batch(batch_size)
test_2d_1024_ds = test_ds

#create ptraining, validation, and testing datasets
val_split = 0.10
train_ds_size = len(list(train_ds))
val_ds_size = int(val_split*train_ds_size)
ptrain_ds_size = train_ds_size-val_ds_size
print(f"training batches = {train_ds_size}, validation batches = {val_ds_size}")

ptrain_ds = train_ds.take(ptrain_ds_size)
val_ds = train_ds.skip(ptrain_ds_size).take(val_ds_size)

```

training batches = 59, validation batches = 5, ptraining batches = 54

```

In [5]: case_number = 6
filename = f"models/lecture10_case{case_number}.keras"

tf.keras.backend.clear_session()

lam = 0.002
L2_regularizer = regularizers.l2(lam)

inputs = keras.Input(shape=(28,28,1))
x = layers.Conv2D(filters=32, kernel_size=3, activation="relu",
                  kernel_regularizer = None,)(inputs)
x = layers.MaxPooling2D(pool_size=2)(x)
x = layers.Conv2D(filters=64, kernel_size=3, activation="relu",
                  kernel_regularizer = None,
                  )(x)
x = layers.MaxPooling2D(pool_size=2)(x)
x = layers.Flatten()(x)

outputs = layers.Dense(10, activation="softmax")(x)
model = keras.Model(inputs=inputs, outputs=outputs)

model.summary()

#recompile model with rmsprop optimizer

adam = optimizers.Adam(
    learning_rate = 0.001,
    beta_1 = 0.9,
    beta_2 = 0.999,
    epsilon = 1e-7,
    amsgrad = False,
    weight_decay = None,
    ema_momentum = 0.99
)

model.compile(optimizer=adam,
              loss = "sparse_categorical_crossentropy",
              metrics = ["accuracy"])

```

```

#create a callback to save the best model with respect to validation loss

callbacks = [
    keras.callbacks.ModelCheckpoint(
        filepath = filename,
        save_best_only = True,
        monitor = "val_loss")]

#train model with ptraining data, and use val_ds for validation
number_epochs = 100

history = model.fit(ptrain_ds, epochs = number_epochs,
                    validation_data = val_ds,
                    callbacks = callbacks)

#evaluate
fit_evaluation(history, filename, val_ds)

```


### Model: "functional"


Layer (type)	Output Shape	Par
input_layer (InputLayer)	(None, 28, 28, 1)	
conv2d (Conv2D)	(None, 26, 26, 32)	
max_pooling2d (MaxPooling2D)	(None, 13, 13, 32)	
conv2d_1 (Conv2D)	(None, 11, 11, 64)	18
max_pooling2d_1 (MaxPooling2D)	(None, 5, 5, 64)	
flatten (Flatten)	(None, 1600)	
dense (Dense)	(None, 10)	16


**Total params:** 34,826 (136.04 KB)


**Trainable params:** 34,826 (136.04 KB)


**Non-trainable params:** 0 (0.00 B)


Epoch 1/100  
54/54  7s 123ms/step - accuracy: 0.1168 - loss: 2.3000 - val\_accuracy: 0.4307 - val\_loss: 2.2713


Epoch 2/100  
54/54  6s 115ms/step - accuracy: 0.4202 - loss: 2.2043 - val\_accuracy: 0.6879 - val\_loss: 1.7385


Epoch 3/100  
54/54  6s 118ms/step - accuracy: 0.6977 - loss: 1.5221 - val\_accuracy: 0.8229 - val\_loss: 0.8647


Epoch 4/100  
54/54  7s 123ms/step - accuracy: 0.7849 - loss: 0.8389 - val\_accuracy: 0.8631 - val\_loss: 0.5659


Epoch 5/100  
54/54  7s 120ms/step - accuracy: 0.8249 - loss: 0.6190 - val\_accuracy: 0.8816 - val\_loss: 0.4666


Epoch 6/100  
54/54  6s 117ms/step - accuracy: 0.8456 - loss: 0.5322 - val\_accuracy: 0.8946 - val\_loss: 0.4090


Epoch 7/100  
54/54  6s 118ms/step - accuracy: 0.8596 - loss: 0.4806 - val\_accuracy: 0.9026 - val\_loss: 0.3650


Epoch 8/100  
54/54  7s 121ms/step - accuracy: 0.8688 - loss: 0.4443 - val\_accuracy: 0.9092 - val\_loss: 0.3396


Epoch 9/100  
54/54  6s 115ms/step - accuracy: 0.8767 - loss: 0.4190 - val\_accuracy: 0.9126 - val\_loss: 0.3172


Epoch 10/100  
54/54  6s 118ms/step - accuracy: 0.8827 - loss: 0.3976 - val\_accuracy: 0.9177 - val\_loss: 0.2990


Epoch 11/100  
54/54  6s 118ms/step - accuracy: 0.8886 - loss: 0.3792 - val\_accuracy: 0.9211 - val\_loss: 0.2844


Epoch 12/100  
54/54  6s 118ms/step - accuracy: 0.8930 - loss: 0.3632 - val\_accuracy: 0.9233 - val\_loss: 0.2715


Epoch 13/100  
54/54  6s 119ms/step - accuracy: 0.8966 - loss: 0.3487 - val\_accuracy: 0.9262 - val\_loss: 0.2598


Epoch 14/100  
54/54  6s 115ms/step - accuracy: 0.9003 - loss: 0.3351 - val\_accuracy: 0.9294 - val\_loss: 0.2489








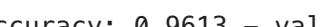
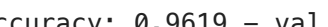









Epoch 15/100  
54/54  6s 117ms/step - accuracy: 0.9046 - loss: 0.3222 - val\_accuracy: 0.9328 - val\_loss: 0.2387


Epoch 16/100  
54/54  6s 116ms/step - accuracy: 0.9093 - loss: 0.3099 - val\_accuracy: 0.9358 - val\_loss: 0.2291


Epoch 17/100  
54/54  6s 116ms/step - accuracy: 0.9127 - loss: 0.2980 - val\_accuracy: 0.9392 - val\_loss: 0.2201


Epoch 18/100  
54/54  6s 116ms/step - accuracy: 0.9153 - loss: 0.2867 - val\_accuracy: 0.9420 - val\_loss: 0.2116


Epoch 19/100  
54/54  6s 115ms/step - accuracy: 0.9188 - loss: 0.2758 -


```
val_accuracy: 0.9430 - val_loss: 0.2035
Epoch 20/100
54/54  6s 118ms/step - accuracy: 0.9223 - loss: 0.2653 -
val_accuracy: 0.9477 - val_loss: 0.1959
Epoch 21/100
54/54  6s 115ms/step - accuracy: 0.9253 - loss: 0.2553 -
val_accuracy: 0.9503 - val_loss: 0.1887
Epoch 22/100
54/54  6s 116ms/step - accuracy: 0.9286 - loss: 0.2456 -
val_accuracy: 0.9511 - val_loss: 0.1819
Epoch 23/100
54/54  6s 116ms/step - accuracy: 0.9313 - loss: 0.2364 -
val_accuracy: 0.9537 - val_loss: 0.1755
Epoch 24/100
54/54  6s 116ms/step - accuracy: 0.9338 - loss: 0.2276 -
val_accuracy: 0.9562 - val_loss: 0.1694
Epoch 25/100
54/54  6s 117ms/step - accuracy: 0.9367 - loss: 0.2193 -
val_accuracy: 0.9583 - val_loss: 0.1638
Epoch 26/100
54/54  6s 116ms/step - accuracy: 0.9389 - loss: 0.2114 -
val_accuracy: 0.9596 - val_loss: 0.1585
Epoch 27/100
54/54  6s 117ms/step - accuracy: 0.9413 - loss: 0.2038 -
val_accuracy: 0.9613 - val_loss: 0.1533
Epoch 28/100
54/54  6s 116ms/step - accuracy: 0.9432 - loss: 0.1967 -
val_accuracy: 0.9619 - val_loss: 0.1487
Epoch 29/100
54/54  6s 115ms/step - accuracy: 0.9449 - loss: 0.1900 -
val_accuracy: 0.9643 - val_loss: 0.1443
Epoch 30/100
54/54  6s 118ms/step - accuracy: 0.9467 - loss: 0.1837 -
val_accuracy: 0.9649 - val_loss: 0.1402
Epoch 31/100
54/54  6s 116ms/step - accuracy: 0.9486 - loss: 0.1777 -
val_accuracy: 0.9649 - val_loss: 0.1364
Epoch 32/100
54/54  6s 117ms/step - accuracy: 0.9501 - loss: 0.1721 -
val_accuracy: 0.9656 - val_loss: 0.1328
Epoch 33/100
54/54  6s 116ms/step - accuracy: 0.9516 - loss: 0.1668 -
val_accuracy: 0.9666 - val_loss: 0.1295
Epoch 34/100
54/54  6s 116ms/step - accuracy: 0.9533 - loss: 0.1619 -
val_accuracy: 0.9679 - val_loss: 0.1264
Epoch 35/100
54/54  6s 116ms/step - accuracy: 0.9548 - loss: 0.1572 -
val_accuracy: 0.9694 - val_loss: 0.1235
Epoch 36/100
54/54  7s 125ms/step - accuracy: 0.9558 - loss: 0.1528 -
val_accuracy: 0.9702 - val_loss: 0.1208
Epoch 37/100
54/54  7s 121ms/step - accuracy: 0.9571 - loss: 0.1487 -
val_accuracy: 0.9705 - val_loss: 0.1183
Epoch 38/100
```


54/54  7s 125ms/step - accuracy: 0.9581 - loss: 0.1448 -  
val\_accuracy: 0.9707 - val\_loss: 0.1159  
Epoch 39/100


54/54  6s 118ms/step - accuracy: 0.9593 - loss: 0.1411 -  
val\_accuracy: 0.9707 - val\_loss: 0.1136  
Epoch 40/100


54/54  6s 117ms/step - accuracy: 0.9603 - loss: 0.1376 -  
val\_accuracy: 0.9715 - val\_loss: 0.1116  
Epoch 41/100


54/54  6s 119ms/step - accuracy: 0.9610 - loss: 0.1344 -  
val\_accuracy: 0.9715 - val\_loss: 0.1096  
Epoch 42/100


54/54  6s 117ms/step - accuracy: 0.9618 - loss: 0.1314 -  
val\_accuracy: 0.9717 - val\_loss: 0.1078  
Epoch 43/100


54/54  6s 117ms/step - accuracy: 0.9629 - loss: 0.1284 -  
val\_accuracy: 0.9719 - val\_loss: 0.1061  
Epoch 44/100


54/54  6s 119ms/step - accuracy: 0.9636 - loss: 0.1257 -  
val\_accuracy: 0.9726 - val\_loss: 0.1045  
Epoch 45/100


54/54  6s 117ms/step - accuracy: 0.9644 - loss: 0.1231 -  
val\_accuracy: 0.9728 - val\_loss: 0.1031  
Epoch 46/100


54/54  6s 119ms/step - accuracy: 0.9651 - loss: 0.1207 -  
val\_accuracy: 0.9730 - val\_loss: 0.1016  
Epoch 47/100


54/54  6s 117ms/step - accuracy: 0.9657 - loss: 0.1183 -  
val\_accuracy: 0.9730 - val\_loss: 0.1003  
Epoch 48/100


54/54  6s 118ms/step - accuracy: 0.9663 - loss: 0.1161 -  
val\_accuracy: 0.9736 - val\_loss: 0.0990  
Epoch 49/100


54/54  6s 116ms/step - accuracy: 0.9668 - loss: 0.1139 -  
val\_accuracy: 0.9743 - val\_loss: 0.0978  
Epoch 50/100


54/54  6s 117ms/step - accuracy: 0.9673 - loss: 0.1119 -  
val\_accuracy: 0.9749 - val\_loss: 0.0967  
Epoch 51/100


54/54  6s 119ms/step - accuracy: 0.9678 - loss: 0.1099 -  
val\_accuracy: 0.9751 - val\_loss: 0.0956  
Epoch 52/100




















54/54  6s 117ms/step - accuracy: 0.9684 - loss: 0.1080 -  
val\_accuracy: 0.9753 - val\_loss: 0.0945  
Epoch 53/100



















54/54  6s 119ms/step - accuracy: 0.9688 - loss: 0.1062 -  
val\_accuracy: 0.9758 - val\_loss: 0.0935  
Epoch 54/100

54/54  6s 117ms/step - accuracy: 0.9693 - loss: 0.1045 -  
val\_accuracy: 0.9758 - val\_loss: 0.0926  
Epoch 55/100

54/54  6s 119ms/step - accuracy: 0.9700 - loss: 0.1028 -  
val\_accuracy: 0.9762 - val\_loss: 0.0916  
Epoch 56/100

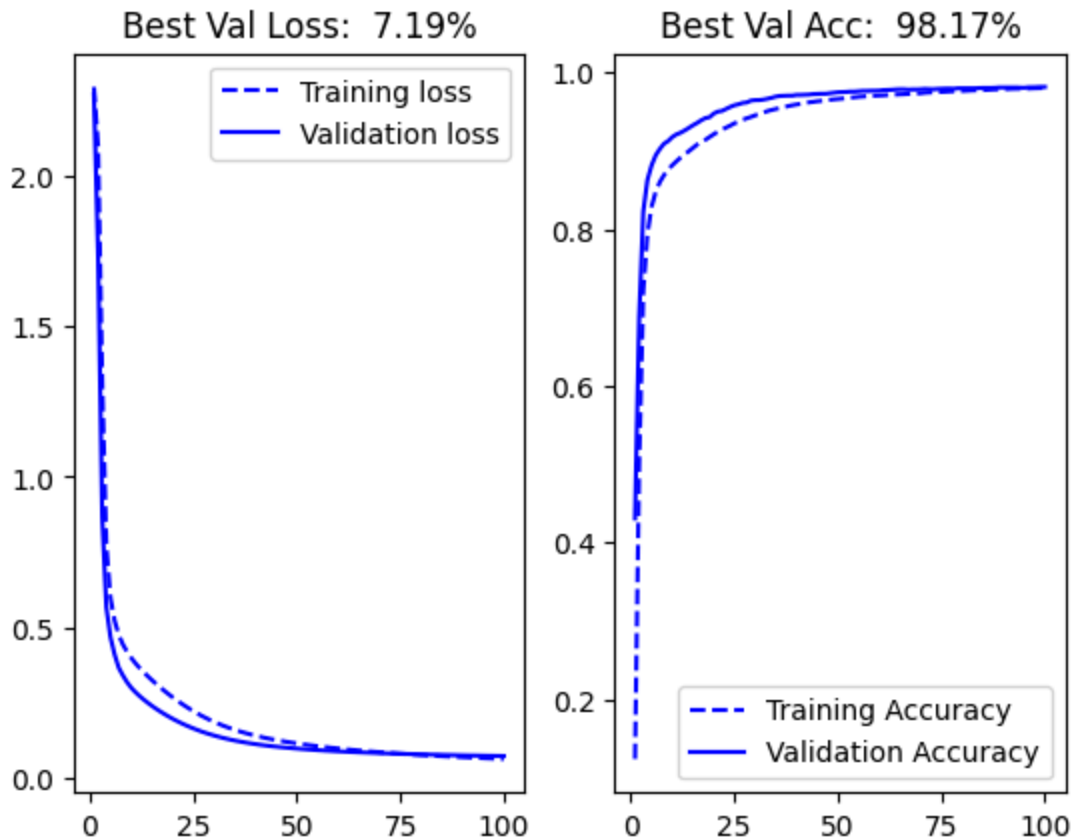
54/54  6s 117ms/step - accuracy: 0.9702 - loss: 0.1012 -  
val\_accuracy: 0.9766 - val\_loss: 0.0908

Epoch 57/100  
54/54  6s 117ms/step - accuracy: 0.9706 - loss: 0.0996 - val\_accuracy: 0.9766 - val\_loss: 0.0899  
Epoch 58/100  
54/54  7s 122ms/step - accuracy: 0.9709 - loss: 0.0981 - val\_accuracy: 0.9768 - val\_loss: 0.0891  
Epoch 59/100  
54/54  7s 128ms/step - accuracy: 0.9711 - loss: 0.0966 - val\_accuracy: 0.9768 - val\_loss: 0.0884  
Epoch 60/100  
54/54  7s 124ms/step - accuracy: 0.9713 - loss: 0.0953 - val\_accuracy: 0.9770 - val\_loss: 0.0876  
Epoch 61/100  
54/54  6s 119ms/step - accuracy: 0.9717 - loss: 0.0939 - val\_accuracy: 0.9777 - val\_loss: 0.0870  
Epoch 62/100  
54/54  7s 121ms/step - accuracy: 0.9721 - loss: 0.0926 - val\_accuracy: 0.9779 - val\_loss: 0.0863  
Epoch 63/100  
54/54  6s 119ms/step - accuracy: 0.9722 - loss: 0.0913 - val\_accuracy: 0.9781 - val\_loss: 0.0856  
Epoch 64/100  
54/54  6s 118ms/step - accuracy: 0.9727 - loss: 0.0900 - val\_accuracy: 0.9785 - val\_loss: 0.0850  
Epoch 65/100  
54/54  7s 121ms/step - accuracy: 0.9728 - loss: 0.0888 - val\_accuracy: 0.9787 - val\_loss: 0.0844  
Epoch 66/100  
54/54  7s 123ms/step - accuracy: 0.9730 - loss: 0.0877 - val\_accuracy: 0.9787 - val\_loss: 0.0839  
Epoch 67/100  
54/54  7s 121ms/step - accuracy: 0.9734 - loss: 0.0865 - val\_accuracy: 0.9783 - val\_loss: 0.0833  
Epoch 68/100  
54/54  6s 118ms/step - accuracy: 0.9736 - loss: 0.0854 - val\_accuracy: 0.9785 - val\_loss: 0.0828  
Epoch 69/100  
54/54  6s 119ms/step - accuracy: 0.9738 - loss: 0.0843 - val\_accuracy: 0.9785 - val\_loss: 0.0823  
Epoch 70/100  
54/54  6s 117ms/step - accuracy: 0.9740 - loss: 0.0833 - val\_accuracy: 0.9787 - val\_loss: 0.0817  
Epoch 71/100  
54/54  6s 117ms/step - accuracy: 0.9747 - loss: 0.0823 - val\_accuracy: 0.9792 - val\_loss: 0.0812  
Epoch 72/100  
54/54  6s 119ms/step - accuracy: 0.9750 - loss: 0.0813 - val\_accuracy: 0.9790 - val\_loss: 0.0808  
Epoch 73/100  
54/54  6s 116ms/step - accuracy: 0.9754 - loss: 0.0804 - val\_accuracy: 0.9787 - val\_loss: 0.0803  
Epoch 74/100  
54/54  6s 118ms/step - accuracy: 0.9758 - loss: 0.0795 - val\_accuracy: 0.9792 - val\_loss: 0.0799  
Epoch 75/100  
54/54  6s 116ms/step - accuracy: 0.9758 - loss: 0.0785 -

```
val_accuracy: 0.9794 - val_loss: 0.0795
Epoch 76/100
54/54  6s 118ms/step - accuracy: 0.9761 - loss: 0.0777 -
val_accuracy: 0.9796 - val_loss: 0.0790
Epoch 77/100
54/54  6s 118ms/step - accuracy: 0.9764 - loss: 0.0768 -
val_accuracy: 0.9796 - val_loss: 0.0786
Epoch 78/100
54/54  10s 117ms/step - accuracy: 0.9767 - loss: 0.0760
- val_accuracy: 0.9794 - val_loss: 0.0782
Epoch 79/100
54/54  6s 117ms/step - accuracy: 0.9768 - loss: 0.0752 -
val_accuracy: 0.9800 - val_loss: 0.0778
Epoch 80/100
54/54  6s 117ms/step - accuracy: 0.9771 - loss: 0.0744 -
val_accuracy: 0.9800 - val_loss: 0.0774
Epoch 81/100
54/54  6s 119ms/step - accuracy: 0.9773 - loss: 0.0736 -
val_accuracy: 0.9800 - val_loss: 0.0771
Epoch 82/100
54/54  6s 118ms/step - accuracy: 0.9777 - loss: 0.0728 -
val_accuracy: 0.9800 - val_loss: 0.0767
Epoch 83/100
54/54  6s 119ms/step - accuracy: 0.9779 - loss: 0.0721 -
val_accuracy: 0.9800 - val_loss: 0.0764
Epoch 84/100
54/54  6s 117ms/step - accuracy: 0.9782 - loss: 0.0714 -
val_accuracy: 0.9802 - val_loss: 0.0761
Epoch 85/100
54/54  6s 120ms/step - accuracy: 0.9783 - loss: 0.0707 -
val_accuracy: 0.9804 - val_loss: 0.0758
Epoch 86/100
54/54  6s 118ms/step - accuracy: 0.9785 - loss: 0.0700 -
val_accuracy: 0.9804 - val_loss: 0.0754
Epoch 87/100
54/54  6s 117ms/step - accuracy: 0.9789 - loss: 0.0693 -
val_accuracy: 0.9804 - val_loss: 0.0751
Epoch 88/100
54/54  6s 119ms/step - accuracy: 0.9791 - loss: 0.0686 -
val_accuracy: 0.9807 - val_loss: 0.0748
Epoch 89/100
54/54  6s 118ms/step - accuracy: 0.9792 - loss: 0.0680 -
val_accuracy: 0.9811 - val_loss: 0.0745
Epoch 90/100
54/54  6s 119ms/step - accuracy: 0.9794 - loss: 0.0674 -
val_accuracy: 0.9811 - val_loss: 0.0743
Epoch 91/100
54/54  6s 118ms/step - accuracy: 0.9797 - loss: 0.0667 -
val_accuracy: 0.9811 - val_loss: 0.0740
Epoch 92/100
54/54  6s 119ms/step - accuracy: 0.9801 - loss: 0.0661 -
val_accuracy: 0.9811 - val_loss: 0.0737
Epoch 93/100
54/54  6s 118ms/step - accuracy: 0.9802 - loss: 0.0655 -
val_accuracy: 0.9811 - val_loss: 0.0735
Epoch 94/100
```



54/54 ————— 6s 117ms/step - accuracy: 0.9803 - loss: 0.0649 -  
 val\_accuracy: 0.9809 - val\_loss: 0.0732  
 Epoch 95/100  
 54/54 ————— 6s 120ms/step - accuracy: 0.9804 - loss: 0.0643 -  
 val\_accuracy: 0.9807 - val\_loss: 0.0730  
 Epoch 96/100  
 54/54 ————— 6s 117ms/step - accuracy: 0.9805 - loss: 0.0638 -  
 val\_accuracy: 0.9813 - val\_loss: 0.0728  
 Epoch 97/100  
 54/54 ————— 6s 117ms/step - accuracy: 0.9808 - loss: 0.0632 -  
 val\_accuracy: 0.9813 - val\_loss: 0.0726  
 Epoch 98/100  
 54/54 ————— 6s 117ms/step - accuracy: 0.9809 - loss: 0.0626 -  
 val\_accuracy: 0.9815 - val\_loss: 0.0723  
 Epoch 99/100  
 54/54 ————— 6s 119ms/step - accuracy: 0.9811 - loss: 0.0621 -  
 val\_accuracy: 0.9817 - val\_loss: 0.0722  
 Epoch 100/100  
 54/54 ————— 6s 118ms/step - accuracy: 0.9813 - loss: 0.0616 -  
 val\_accuracy: 0.9817 - val\_loss: 0.0719  
 5/5 ————— 0s 30ms/step - accuracy: 0.9816 - loss: 0.0661



```
In [14]: case_number = 7
filename = f"models/lecture10_case{case_number}.keras"
tf.keras.backend.clear_session()
```

```
inputs = keras.Input(shape=(28,28,1))
x = layers.Conv2D(filters=32, kernel_size=3, activation="relu",
```

```

        kernel_regularizer = None,)(inputs)
x = layers.MaxPooling2D(pool_size=2)(x)
x = layers.Dropout(0.25)(x)
x = layers.Conv2D(filters=64, kernel_size=3, activation="relu",
                  kernel_regularizer = None,
                  )(x)
x = layers.MaxPooling2D(pool_size=2)(x)
x = layers.Dropout(0.25)(x)
x = layers.Flatten()(x)
x = layers.Dense(512, activation = "relu")(x)
x = layers.Dense(128, activation="relu")(x)

outputs = layers.Dense(10, activation="softmax")(x)
model = keras.Model(inputs=inputs, outputs=outputs)

model.summary()

#recompile model with rmsprop optimizer

adam = optimizers.Adam(
    learning_rate = 0.001,
    beta_1 = 0.9,
    beta_2 = 0.999,
    epsilon = 1e-7,
    amsgrad = False,
    weight_decay = None,
    ema_momentum = 0.99
)

model.compile(optimizer=adam,
              loss = "sparse_categorical_crossentropy",
              metrics = ["accuracy"])

#create a callback to save the best model with respect to validation loss

callbacks = [
    keras.callbacks.ModelCheckpoint(
        filepath = filename,
        save_best_only = True,
        monitor = "val_loss")]

#train model with ptraining data, and use val_ds for validation
number_epochs = 100

history = model.fit(ptrain_ds, epochs = number_epochs,
                    validation_data = val_ds,
                    callbacks = callbacks)

#evaluate
fit_evaluation(history, filename, val_ds)

```


**Model: "functional"**


Layer (type)	Output Shape	Par
input_layer (InputLayer)	(None, 28, 28, 1)	
conv2d (Conv2D)	(None, 26, 26, 32)	
max_pooling2d (MaxPooling2D)	(None, 13, 13, 32)	
dropout (Dropout)	(None, 13, 13, 32)	
conv2d_1 (Conv2D)	(None, 11, 11, 64)	18
max_pooling2d_1 (MaxPooling2D)	(None, 5, 5, 64)	
dropout_1 (Dropout)	(None, 5, 5, 64)	
flatten (Flatten)	(None, 1600)	
dense (Dense)	(None, 512)	819
dense_1 (Dense)	(None, 128)	65
dense_2 (Dense)	(None, 10)	1


**Total params:** 905,482 (3.45 MB)


**Trainable params:** 905,482 (3.45 MB)


**Non-trainable params:** 0 (0.00 B)


Epoch 1/100  
54/54  9s 148ms/step - accuracy: 0.1640 - loss: 2.2502 - val\_accuracy: 0.6120 - val\_loss: 1.3930


Epoch 2/100  
54/54  8s 144ms/step - accuracy: 0.6506 - loss: 1.1066 - val\_accuracy: 0.8361 - val\_loss: 0.5391


Epoch 3/100  
54/54  8s 141ms/step - accuracy: 0.7996 - loss: 0.6171 - val\_accuracy: 0.8912 - val\_loss: 0.3684


Epoch 4/100  
54/54  8s 141ms/step - accuracy: 0.8489 - loss: 0.4823 - val\_accuracy: 0.9177 - val\_loss: 0.2866


Epoch 5/100  
54/54  8s 141ms/step - accuracy: 0.8781 - loss: 0.3952 - val\_accuracy: 0.9341 - val\_loss: 0.2314


Epoch 6/100  
54/54  8s 142ms/step - accuracy: 0.8991 - loss: 0.3281 - val\_accuracy: 0.9490 - val\_loss: 0.1877


Epoch 7/100  
54/54  8s 139ms/step - accuracy: 0.9161 - loss: 0.2774 - val\_accuracy: 0.9581 - val\_loss: 0.1582


Epoch 8/100  
54/54  8s 143ms/step - accuracy: 0.9279 - loss: 0.2331 - val\_accuracy: 0.9660 - val\_loss: 0.1361


Epoch 9/100  
54/54  8s 141ms/step - accuracy: 0.9376 - loss: 0.2021 - val\_accuracy: 0.9692 - val\_loss: 0.1204


Epoch 10/100  
54/54  8s 144ms/step - accuracy: 0.9444 - loss: 0.1799 - val\_accuracy: 0.9728 - val\_loss: 0.1066


Epoch 11/100  
54/54  8s 142ms/step - accuracy: 0.9492 - loss: 0.1640 - val\_accuracy: 0.9734 - val\_loss: 0.0995


Epoch 12/100  
54/54  8s 142ms/step - accuracy: 0.9532 - loss: 0.1492 - val\_accuracy: 0.9743 - val\_loss: 0.0935


Epoch 13/100  
54/54  8s 142ms/step - accuracy: 0.9581 - loss: 0.1371 - val\_accuracy: 0.9777 - val\_loss: 0.0863


Epoch 14/100  
54/54  8s 143ms/step - accuracy: 0.9592 - loss: 0.1327 - val\_accuracy: 0.9773 - val\_loss: 0.0818



















Epoch 15/100  
54/54  8s 142ms/step - accuracy: 0.9618 - loss: 0.1231 - val\_accuracy: 0.9785 - val\_loss: 0.0783


Epoch 16/100  
54/54  8s 143ms/step - accuracy: 0.9633 - loss: 0.1178 - val\_accuracy: 0.9794 - val\_loss: 0.0741


Epoch 17/100  
54/54  8s 142ms/step - accuracy: 0.9658 - loss: 0.1096 - val\_accuracy: 0.9798 - val\_loss: 0.0719


Epoch 18/100  
54/54  8s 142ms/step - accuracy: 0.9671 - loss: 0.1046 - val\_accuracy: 0.9815 - val\_loss: 0.0680


Epoch 19/100  
54/54  8s 143ms/step - accuracy: 0.9694 - loss: 0.0989 -


```
val_accuracy: 0.9813 - val_loss: 0.0675
Epoch 20/100
54/54  8s 142ms/step - accuracy: 0.9713 - loss: 0.0939 -
val_accuracy: 0.9834 - val_loss: 0.0643
Epoch 21/100
54/54  8s 143ms/step - accuracy: 0.9708 - loss: 0.0933 -
val_accuracy: 0.9826 - val_loss: 0.0638
Epoch 22/100
54/54  8s 141ms/step - accuracy: 0.9724 - loss: 0.0883 -
val_accuracy: 0.9832 - val_loss: 0.0612
Epoch 23/100
54/54  8s 141ms/step - accuracy: 0.9732 - loss: 0.0833 -
val_accuracy: 0.9830 - val_loss: 0.0599
Epoch 24/100
54/54  8s 142ms/step - accuracy: 0.9746 - loss: 0.0820 -
val_accuracy: 0.9838 - val_loss: 0.0591
Epoch 25/100
54/54  8s 142ms/step - accuracy: 0.9752 - loss: 0.0776 -
val_accuracy: 0.9845 - val_loss: 0.0574
Epoch 26/100
54/54  8s 142ms/step - accuracy: 0.9777 - loss: 0.0717 -
val_accuracy: 0.9860 - val_loss: 0.0556
Epoch 27/100
54/54  8s 144ms/step - accuracy: 0.9773 - loss: 0.0729 -
val_accuracy: 0.9864 - val_loss: 0.0552
Epoch 28/100
54/54  8s 142ms/step - accuracy: 0.9771 - loss: 0.0725 -
val_accuracy: 0.9851 - val_loss: 0.0551
Epoch 29/100
54/54  8s 145ms/step - accuracy: 0.9787 - loss: 0.0677 -
val_accuracy: 0.9858 - val_loss: 0.0535
Epoch 30/100
54/54  8s 141ms/step - accuracy: 0.9791 - loss: 0.0657 -
val_accuracy: 0.9858 - val_loss: 0.0542
Epoch 31/100
54/54  8s 144ms/step - accuracy: 0.9800 - loss: 0.0636 -
val_accuracy: 0.9860 - val_loss: 0.0522
Epoch 32/100
54/54  8s 143ms/step - accuracy: 0.9805 - loss: 0.0609 -
val_accuracy: 0.9855 - val_loss: 0.0533
Epoch 33/100
54/54  8s 141ms/step - accuracy: 0.9811 - loss: 0.0598 -
val_accuracy: 0.9864 - val_loss: 0.0518
Epoch 34/100
54/54  8s 142ms/step - accuracy: 0.9817 - loss: 0.0568 -
val_accuracy: 0.9853 - val_loss: 0.0533
Epoch 35/100
54/54  8s 142ms/step - accuracy: 0.9820 - loss: 0.0559 -
val_accuracy: 0.9849 - val_loss: 0.0530
Epoch 36/100
54/54  8s 139ms/step - accuracy: 0.9829 - loss: 0.0538 -
val_accuracy: 0.9866 - val_loss: 0.0507
Epoch 37/100
54/54  8s 144ms/step - accuracy: 0.9833 - loss: 0.0527 -
val_accuracy: 0.9855 - val_loss: 0.0517
Epoch 38/100
```


54/54  8s 140ms/step - accuracy: 0.9823 - loss: 0.0537 -  
val\_accuracy: 0.9868 - val\_loss: 0.0502  
Epoch 39/100


54/54  8s 143ms/step - accuracy: 0.9834 - loss: 0.0504 -  
val\_accuracy: 0.9858 - val\_loss: 0.0497  
Epoch 40/100


54/54  8s 143ms/step - accuracy: 0.9840 - loss: 0.0502 -  
val\_accuracy: 0.9870 - val\_loss: 0.0460  
Epoch 41/100


54/54  8s 144ms/step - accuracy: 0.9845 - loss: 0.0474 -  
val\_accuracy: 0.9872 - val\_loss: 0.0491  
Epoch 42/100


54/54  8s 141ms/step - accuracy: 0.9849 - loss: 0.0482 -  
val\_accuracy: 0.9875 - val\_loss: 0.0465  
Epoch 43/100


54/54  8s 141ms/step - accuracy: 0.9852 - loss: 0.0447 -  
val\_accuracy: 0.9870 - val\_loss: 0.0476  
Epoch 44/100


54/54  8s 139ms/step - accuracy: 0.9856 - loss: 0.0453 -  
val\_accuracy: 0.9889 - val\_loss: 0.0460  
Epoch 45/100


54/54  8s 142ms/step - accuracy: 0.9867 - loss: 0.0423 -  
val\_accuracy: 0.9885 - val\_loss: 0.0470  
Epoch 46/100


54/54  8s 140ms/step - accuracy: 0.9858 - loss: 0.0428 -  
val\_accuracy: 0.9883 - val\_loss: 0.0457  
Epoch 47/100


54/54  8s 146ms/step - accuracy: 0.9870 - loss: 0.0403 -  
val\_accuracy: 0.9889 - val\_loss: 0.0454  
Epoch 48/100


54/54  8s 145ms/step - accuracy: 0.9869 - loss: 0.0396 -  
val\_accuracy: 0.9887 - val\_loss: 0.0440  
Epoch 49/100


54/54  8s 145ms/step - accuracy: 0.9879 - loss: 0.0388 -  
val\_accuracy: 0.9894 - val\_loss: 0.0457  
Epoch 50/100


54/54  8s 139ms/step - accuracy: 0.9881 - loss: 0.0378 -  
val\_accuracy: 0.9881 - val\_loss: 0.0479  
Epoch 51/100


54/54  8s 143ms/step - accuracy: 0.9886 - loss: 0.0354 -  
val\_accuracy: 0.9879 - val\_loss: 0.0470  
Epoch 52/100




















54/54  8s 141ms/step - accuracy: 0.9881 - loss: 0.0371 -  
val\_accuracy: 0.9898 - val\_loss: 0.0435  
Epoch 53/100








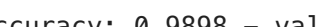
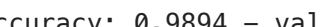









54/54  8s 143ms/step - accuracy: 0.9886 - loss: 0.0343 -  
val\_accuracy: 0.9894 - val\_loss: 0.0442  
Epoch 54/100

54/54  8s 141ms/step - accuracy: 0.9888 - loss: 0.0344 -  
val\_accuracy: 0.9896 - val\_loss: 0.0442  
Epoch 55/100


54/54  8s 141ms/step - accuracy: 0.9898 - loss: 0.0319 -  
val\_accuracy: 0.9892 - val\_loss: 0.0450  
Epoch 56/100


54/54  8s 140ms/step - accuracy: 0.9904 - loss: 0.0305 -  
val\_accuracy: 0.9898 - val\_loss: 0.0433


Epoch 57/100  
54/54  8s 144ms/step - accuracy: 0.9902 - loss: 0.0305 - val\_accuracy: 0.9894 - val\_loss: 0.0448  
Epoch 58/100  
54/54  8s 141ms/step - accuracy: 0.9905 - loss: 0.0296 - val\_accuracy: 0.9889 - val\_loss: 0.0449  
Epoch 59/100  
54/54  8s 145ms/step - accuracy: 0.9897 - loss: 0.0314 - val\_accuracy: 0.9902 - val\_loss: 0.0424  
Epoch 60/100  
54/54  8s 156ms/step - accuracy: 0.9911 - loss: 0.0286 - val\_accuracy: 0.9889 - val\_loss: 0.0461  
Epoch 61/100  
54/54  8s 154ms/step - accuracy: 0.9903 - loss: 0.0298 - val\_accuracy: 0.9900 - val\_loss: 0.0408  
Epoch 62/100  
54/54  8s 149ms/step - accuracy: 0.9907 - loss: 0.0286 - val\_accuracy: 0.9875 - val\_loss: 0.0468  
Epoch 63/100  
54/54  8s 145ms/step - accuracy: 0.9905 - loss: 0.0288 - val\_accuracy: 0.9902 - val\_loss: 0.0436  
Epoch 64/100  
54/54  8s 140ms/step - accuracy: 0.9913 - loss: 0.0270 - val\_accuracy: 0.9892 - val\_loss: 0.0466  
Epoch 65/100  
54/54  7s 137ms/step - accuracy: 0.9914 - loss: 0.0256 - val\_accuracy: 0.9892 - val\_loss: 0.0439  
Epoch 66/100  
54/54  7s 138ms/step - accuracy: 0.9913 - loss: 0.0254 - val\_accuracy: 0.9881 - val\_loss: 0.0495  
Epoch 67/100  
54/54  7s 136ms/step - accuracy: 0.9917 - loss: 0.0248 - val\_accuracy: 0.9885 - val\_loss: 0.0440  
Epoch 68/100  
54/54  7s 137ms/step - accuracy: 0.9913 - loss: 0.0256 - val\_accuracy: 0.9896 - val\_loss: 0.0435  
Epoch 69/100  
54/54  7s 136ms/step - accuracy: 0.9921 - loss: 0.0237 - val\_accuracy: 0.9898 - val\_loss: 0.0445  
Epoch 70/100  
54/54  7s 139ms/step - accuracy: 0.9927 - loss: 0.0215 - val\_accuracy: 0.9887 - val\_loss: 0.0459  
Epoch 71/100  
54/54  7s 136ms/step - accuracy: 0.9918 - loss: 0.0237 - val\_accuracy: 0.9892 - val\_loss: 0.0433  
Epoch 72/100  
54/54  7s 137ms/step - accuracy: 0.9932 - loss: 0.0204 - val\_accuracy: 0.9877 - val\_loss: 0.0463  
Epoch 73/100  
54/54  7s 135ms/step - accuracy: 0.9929 - loss: 0.0213 - val\_accuracy: 0.9889 - val\_loss: 0.0443  
Epoch 74/100  
54/54  7s 136ms/step - accuracy: 0.9931 - loss: 0.0208 - val\_accuracy: 0.9896 - val\_loss: 0.0424  
Epoch 75/100  
54/54  7s 135ms/step - accuracy: 0.9937 - loss: 0.0201 -


```
val_accuracy: 0.9902 - val_loss: 0.0431
Epoch 76/100
54/54  7s 136ms/step - accuracy: 0.9940 - loss: 0.0182 -
val_accuracy: 0.9904 - val_loss: 0.0422
Epoch 77/100
54/54  7s 137ms/step - accuracy: 0.9946 - loss: 0.0177 -
val_accuracy: 0.9900 - val_loss: 0.0425
Epoch 78/100
54/54  7s 138ms/step - accuracy: 0.9930 - loss: 0.0198 -
val_accuracy: 0.9902 - val_loss: 0.0424
Epoch 79/100
54/54  7s 137ms/step - accuracy: 0.9942 - loss: 0.0173 -
val_accuracy: 0.9902 - val_loss: 0.0417
Epoch 80/100
54/54  7s 136ms/step - accuracy: 0.9946 - loss: 0.0161 -
val_accuracy: 0.9900 - val_loss: 0.0411
Epoch 81/100
54/54  7s 137ms/step - accuracy: 0.9939 - loss: 0.0178 -
val_accuracy: 0.9913 - val_loss: 0.0416
Epoch 82/100
54/54  7s 138ms/step - accuracy: 0.9946 - loss: 0.0162 -
val_accuracy: 0.9898 - val_loss: 0.0437
Epoch 83/100
54/54  7s 136ms/step - accuracy: 0.9944 - loss: 0.0161 -
val_accuracy: 0.9898 - val_loss: 0.0433
Epoch 84/100
54/54  8s 140ms/step - accuracy: 0.9942 - loss: 0.0176 -
val_accuracy: 0.9894 - val_loss: 0.0435
Epoch 85/100
54/54  8s 140ms/step - accuracy: 0.9947 - loss: 0.0173 -
val_accuracy: 0.9889 - val_loss: 0.0480
Epoch 86/100
54/54  7s 139ms/step - accuracy: 0.9955 - loss: 0.0146 -
val_accuracy: 0.9892 - val_loss: 0.0433
Epoch 87/100
54/54  7s 137ms/step - accuracy: 0.9949 - loss: 0.0147 -
val_accuracy: 0.9911 - val_loss: 0.0406
Epoch 88/100
54/54  8s 141ms/step - accuracy: 0.9955 - loss: 0.0127 -
val_accuracy: 0.9898 - val_loss: 0.0485
Epoch 89/100
54/54  7s 136ms/step - accuracy: 0.9945 - loss: 0.0154 -
val_accuracy: 0.9898 - val_loss: 0.0414
Epoch 90/100
54/54  7s 137ms/step - accuracy: 0.9951 - loss: 0.0144 -
val_accuracy: 0.9909 - val_loss: 0.0388
Epoch 91/100
54/54  7s 138ms/step - accuracy: 0.9950 - loss: 0.0133 -
val_accuracy: 0.9923 - val_loss: 0.0402
Epoch 92/100
54/54  7s 137ms/step - accuracy: 0.9947 - loss: 0.0159 -
val_accuracy: 0.9900 - val_loss: 0.0423
Epoch 93/100
54/54  7s 136ms/step - accuracy: 0.9947 - loss: 0.0146 -
val_accuracy: 0.9900 - val_loss: 0.0402
Epoch 94/100
```





54/54  7s 136ms/step - accuracy: 0.9956 - loss: 0.0134 - val\_accuracy: 0.9913 - val\_loss: 0.0396  
Epoch 95/100


54/54  7s 136ms/step - accuracy: 0.9957 - loss: 0.0136 - val\_accuracy: 0.9902 - val\_loss: 0.0454  
Epoch 96/100


54/54  7s 136ms/step - accuracy: 0.9958 - loss: 0.0125 - val\_accuracy: 0.9923 - val\_loss: 0.0425  
Epoch 97/100

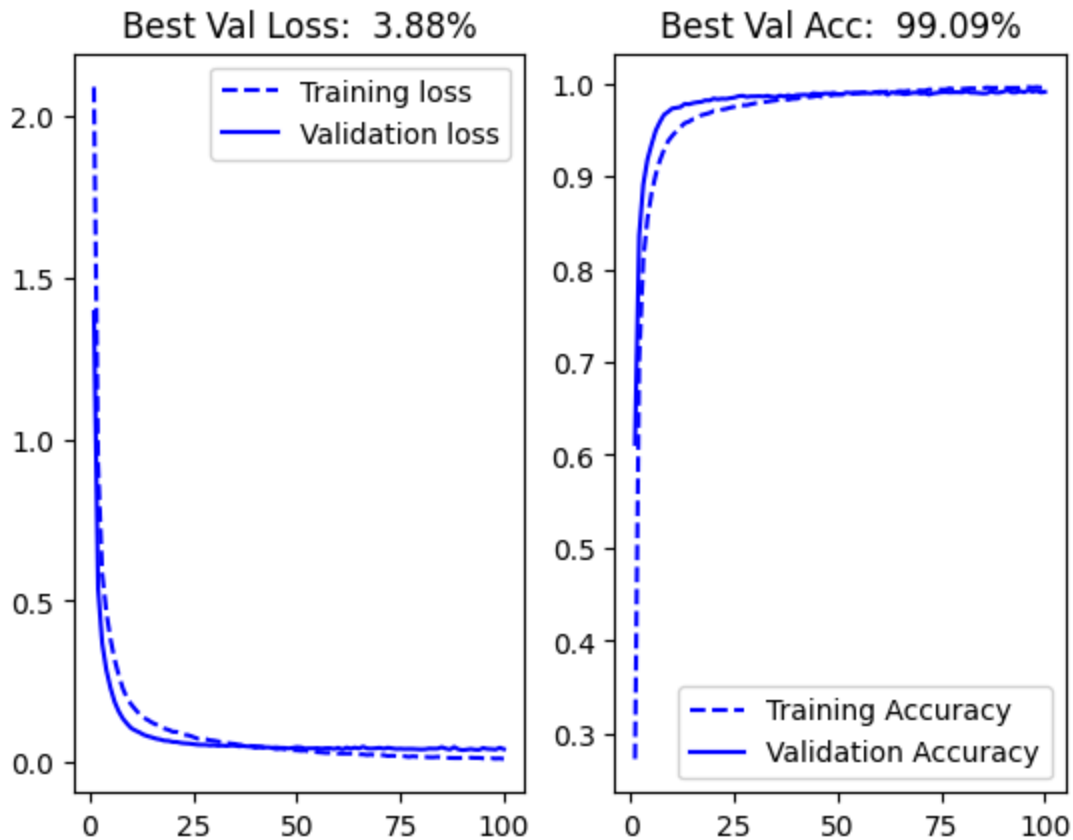
54/54  7s 137ms/step - accuracy: 0.9949 - loss: 0.0139 - val\_accuracy: 0.9906 - val\_loss: 0.0420  
Epoch 98/100

54/54  8s 146ms/step - accuracy: 0.9961 - loss: 0.0110 - val\_accuracy: 0.9917 - val\_loss: 0.0407  
Epoch 99/100

54/54  8s 154ms/step - accuracy: 0.9955 - loss: 0.0121 - val\_accuracy: 0.9900 - val\_loss: 0.0462  
Epoch 100/100

54/54  8s 151ms/step - accuracy: 0.9958 - loss: 0.0115 - val\_accuracy: 0.9906 - val\_loss: 0.0417

5/5  0s 42ms/step - accuracy: 0.9913 - loss: 0.0324



```
In [10]: for case_number in range(1,8):
          filename = f"models/lecture10_case{case_number}.keras"
          case_model = keras.models.load_model(filename)
          if case_number==1:
              test_ds = test_1d_32_ds
          if (case_number>=2) and (case_number <= 5):
              test_ds = test_1d_1024_ds
          if case_number >= 6:
```

```
test_ds = test_2d_1024_ds
```

```
test_loss, test_acc = case_model.evaluate(test_ds)
print(f"CASE {case_number}: TEST LOSS = {test_loss*100:.2f}% \tTEST ACC
```

```
313/313 ----- 1s 1ms/step - accuracy: 0.9547 - loss: 0.1681
CASE 1: TEST LOSS = 15.60%      TEST ACC = 95.93%
10/10 ----- 0s 8ms/step - accuracy: 0.9720 - loss: 0.0930
CASE 2: TEST LOSS = 7.85%      TEST ACC = 97.56%
10/10 ----- 0s 8ms/step - accuracy: 0.9629 - loss: 0.2319
CASE 3: TEST LOSS = 21.24%     TEST ACC = 96.90%
10/10 ----- 0s 7ms/step - accuracy: 0.9711 - loss: 0.1653
CASE 4: TEST LOSS = 15.03%     TEST ACC = 97.54%
10/10 ----- 0s 7ms/step - accuracy: 0.9762 - loss: 0.1509
CASE 5: TEST LOSS = 13.74%     TEST ACC = 98.07%
10/10 ----- 0s 33ms/step - accuracy: 0.9768 - loss: 0.0738
CASE 6: TEST LOSS = 6.29%      TEST ACC = 98.06%
10/10 ----- 0s 37ms/step - accuracy: 0.9887 - loss: 0.0400
CASE 7: TEST LOSS = 3.15%      TEST ACC = 99.08%
```