Influence of Regularization / Code Part I

In [ ]:

```
import tensorflow as tf
import tensorflow_datasets as tfds
import matplotlib.pyplot as plt
from sklearn.model_selection import train_test_split
import keras
from tensorflow.keras.utils import to_categorical
from tensorflow.python.keras import Sequential
from tensorflow.python.keras.layers import Dense, Conv2D, Flatten, MaxPooling2D
import time
from tensorflow.python.keras.layers import *
from tensorflow.python.keras import Sequential
from tensorflow.python.keras.layers import Dense, Conv2D, Flatten, MaxPooling2D
from keras import regularizers
```

In [ ]:

```
# Enable GPU: "Runtime"-->"Change Runtime"-->"Hardware Accelerator"
#Check if GPU is enabled
tf.test.gpu_device_name()
```

Out[ ]:

```
''
```

In [ ]:

```
#2. Import dataset
data = tf.keras.datasets.fashion_mnist

(x_train, y_train), (x_test, y_test) = data.load_data()
#assert x_rem.shape == (60000, 28, 28)
assert x_test.shape == (10000, 28, 28)
#assert y_rem.shape == (60000,)
assert y_test.shape == (10000,)
#x_train, x_valid, y_train, y_valid = train_test_split(x_rem, y_rem, test_size=0.15)
assert x_train.shape == (60000, 28, 28)
#assert x_valid.shape == (9000, 28, 28)
assert y_train.shape == (60000,)
#assert y_valid.shape == (9000,)
```

In [ ]:

```
#Data pre-processing

# reshape data to fit the model
x_train = x_train.reshape(x_train.shape[0], 28, 28, 1)
x_test = x_test.reshape(x_test.shape[0], 28, 28, 1)
#x_valid = x_valid.reshape(x_valid.shape[0], 28, 28, 1)

y_train = to_categorical(y_train)
y_test = to_categorical(y_test)
#y_valid = to_categorical(y_valid)

# Inspect what the one-hot encoding looks like for the first value
y_train[0]
```

Out[ ]:

```
array([0., 0., 0., 0., 0., 0., 1., 0., 0., 0.], dtype=float32)
```

EXPERIMENTS

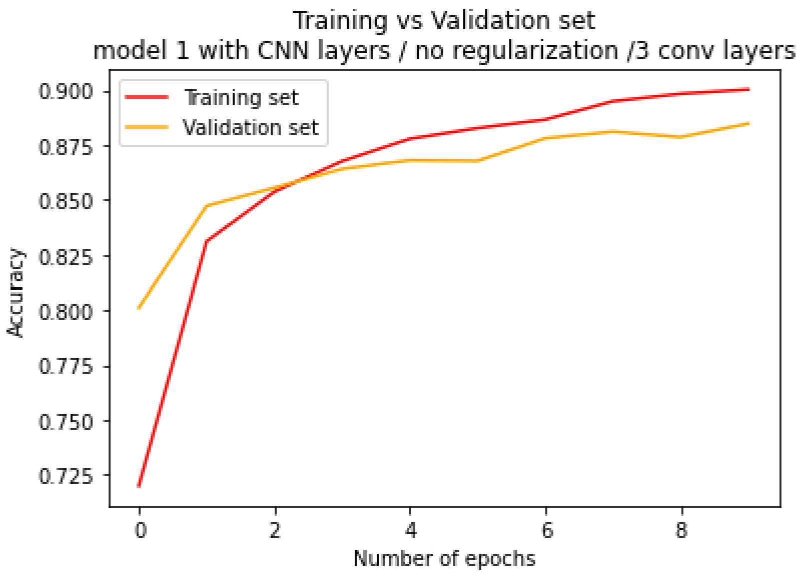
In [ ]:

```
from tensorflow.python.ops.gen_batch_ops import batch
# Set all the hyperparameters to the same for each model

num_iter = 2000
opt = 'adam'
num_filters = 32
kernel_size=3
pool_size = (2,2)
strides= (2,2)
activation = 'relu'
padding = 'SAME'
loss = "categorical_crossentropy"
epochs = 10
batch_size = 128
```

In [ ]:

```
# Create model 1 with CNN layers / no regularization /3 conv layers
title = 'model 1 with CNN layers / no regularization /3 conv layers'

model = Sequential()

# add a conv layer with "same" zero padding
model.add(Conv2D(num_filters, kernel_size = kernel_size, activation = activation, padd

# Add a pooling layer
model.add(MaxPooling2D(pool_size= pool_size))

# Add a second conv layer with a stride of 2x2
model.add(Conv2D(num_filters, kernel_size = kernel_size, activation = activation, padd

# Add a pooling layer
model.add(MaxPooling2D(pool_size = pool_size))

# Add a third conv layer with a stride of 2x2
model.add(Conv2D(num_filters, kernel_size = kernel_size, activation = activation, padd

# Add a pooling layer
model.add(MaxPooling2D(pool_size = pool_size))

# Flatten the input
model.add(Flatten())

# Regular FC layer with output size 10 (for the 10 digits)
model.add(Dense(10, activation = "softmax"))

# Print the summary of the model to view the shape and number of parameters
model.summary()



# Specify the optimizer
model.compile(optimizer = opt, loss = loss, metrics = ['accuracy'])



# Time how fast the model train
start = time.time()

# Train using adam
model1 = model.fit(x_train, y_train, validation_split=0.15,batch_size = batch_size, ep
end = time.time()

num_mins = (end-start)/60
print("Total training time: "  + str(num_mins) + " minutes.")




# Evaluate the model
score = model.evaluate(x_test, y_test, verbose = 0)
print("Test loss: %.4f" % score[0])
print("Accuracy: %.2f" % (score[1] * 100.0))




# Plot accuracy (val vs test)
from matplotlib import pyplot as plt

plt.plot(model1.history["accuracy"], color = "red", label = "Training set")
plt.plot(model1.history["val_accuracy"], color = "orange", label = "Validation set")

plt.title("Training vs Validation set\n"+title)
plt.ylabel("Accuracy")
plt.xlabel("Number of epochs")
plt.legend()
plt.show()
```

```
Model: "sequential_3"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_9 (Conv2D)            (None, 28, 28, 32)        320
_________________________________________________________________
max_pooling2d_9 (MaxPooling2 (None, 14, 14, 32)        0
_________________________________________________________________
conv2d_10 (Conv2D)           (None, 7, 7, 32)          9248
_________________________________________________________________
max_pooling2d_10 (MaxPooling (None, 3, 3, 32)          0
_________________________________________________________________
conv2d_11 (Conv2D)           (None, 2, 2, 32)          9248
_________________________________________________________________
max_pooling2d_11 (MaxPooling (None, 1, 1, 32)          0
_________________________________________________________________
flatten_3 (Flatten)          (None, 32)                0
_________________________________________________________________
dense_3 (Dense)              (None, 10)                330
=================================================================
Total params: 19,146
Trainable params: 19,146
Non-trainable params: 0
_________________________________________________________________
Epoch 1/10
339/339 [==============================] - 26s 75ms/step - loss: 1.0358 - accuracy:
0.7199 - val_loss: 0.5741 - val_accuracy: 0.8010
Epoch 2/10
339/339 [==============================] - 34s 100ms/step - loss: 0.4844 - accuracy:
0.8310 - val_loss: 0.4556 - val_accuracy: 0.8472
Epoch 3/10
339/339 [==============================] - 37s 109ms/step - loss: 0.4129 - accuracy:
0.8536 - val_loss: 0.4143 - val_accuracy: 0.8554
Epoch 4/10
339/339 [==============================] - 44s 129ms/step - loss: 0.3715 - accuracy:
0.8676 - val_loss: 0.4050 - val_accuracy: 0.8641
Epoch 5/10
339/339 [==============================] - 26s 76ms/step - loss: 0.3441 - accuracy:
0.8778 - val_loss: 0.3880 - val_accuracy: 0.8680
Epoch 6/10
339/339 [==============================] - 25s 73ms/step - loss: 0.3240 - accuracy:
0.8827 - val_loss: 0.3825 - val_accuracy: 0.8677
Epoch 7/10
339/339 [==============================] - 25s 73ms/step - loss: 0.3116 - accuracy:
0.8866 - val_loss: 0.3555 - val_accuracy: 0.8780
Epoch 8/10
339/339 [==============================] - 26s 78ms/step - loss: 0.2907 - accuracy:
0.8949 - val_loss: 0.3540 - val_accuracy: 0.8810
Epoch 9/10
339/339 [==============================] - 27s 79ms/step - loss: 0.2796 - accuracy:
0.8983 - val_loss: 0.3509 - val_accuracy: 0.8786
Epoch 10/10
339/339 [==============================] - 33s 99ms/step - loss: 0.2696 - accuracy:
0.9003 - val_loss: 0.3479 - val_accuracy: 0.8847
Total training time: 5.033408737182617 minutes.
Test loss: 0.3669
Accuracy: 87.84
```

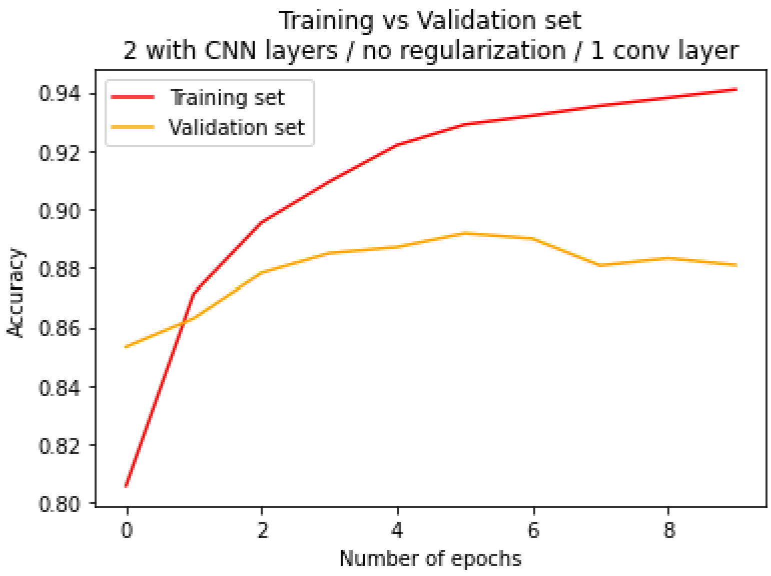


In [ ]:

```
# Create model 2 with CNN layers / no regularization / 1 conv layer

title = '2 with CNN layers / no regularization / 1 conv layer'

model = Sequential()

# add a conv layer with "same" zero padding
model.add(Conv2D(num_filters, kernel_size = kernel_size, activation = activation, padd

# Add a pooling layer
model.add(MaxPooling2D(pool_size = pool_size))

# Flatten the input
model.add(Flatten())

# Regular FC layer with output size 10 (for the 10 digits)
model.add(Dense(10, activation = "softmax"))

# Print the summary of the model to view the shape and number of parameters
model.summary()



# Specify the optimizer
model.compile(optimizer = opt, loss = loss, metrics = ['accuracy'])



# Time how fast the model train
start = time.time()

# Train using adam
model1 = model.fit(x_train, y_train, validation_split=0.15,batch_size = batch_size, ep

end = time.time()

num_mins = (end-start)/60
print("Total training time: "  + str(num_mins) + " minutes.")
```

```
# Evaluate the model
#score = model.evaluate(x_test, y_test, verbose = 0)
#print("Test loss: %.4f" % score[0])
#print("Accuracy: %.2f" % (score[1] * 100.0))




# Plot loss function (val vs test)
from matplotlib import pyplot as plt

plt.plot(model1.history["accuracy"], color = "red", label = "Training set")
plt.plot(model1.history["val_accuracy"], color = "orange", label = "Validation set")

plt.title("Training vs Validation set\n"+title)
plt.ylabel("Accuracy")
plt.xlabel("Number of epochs")
plt.legend()
plt.show()
```

```
Model: "sequential_5"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_13 (Conv2D)           (None, 28, 28, 32)        320
_________________________________________________________________
max_pooling2d_13 (MaxPooling (None, 14, 14, 32)        0
_________________________________________________________________
flatten_5 (Flatten)          (None, 6272)              0
_________________________________________________________________
dense_5 (Dense)              (None, 10)                62730
=================================================================
Total params: 63,050
Trainable params: 63,050
Non-trainable params: 0
_________________________________________________________________
Epoch 1/10
339/339 [==============================] - 21s 61ms/step - loss: 2.7215 - accuracy:
0.8058 - val_loss: 0.7411 - val_accuracy: 0.8533
Epoch 2/10
339/339 [==============================] - 25s 74ms/step - loss: 0.5239 - accuracy:
0.8714 - val_loss: 0.5791 - val_accuracy: 0.8630
Epoch 3/10
339/339 [==============================] - 21s 62ms/step - loss: 0.3330 - accuracy:
0.8955 - val_loss: 0.4412 - val_accuracy: 0.8783
Epoch 4/10
339/339 [==============================] - 24s 70ms/step - loss: 0.2638 - accuracy:
0.9094 - val_loss: 0.4021 - val_accuracy: 0.8850
Epoch 5/10
339/339 [==============================] - 24s 71ms/step - loss: 0.2213 - accuracy:
0.9219 - val_loss: 0.3911 - val_accuracy: 0.8871
Epoch 6/10
339/339 [==============================] - 29s 86ms/step - loss: 0.2028 - accuracy:
0.9289 - val_loss: 0.3992 - val_accuracy: 0.8918
Epoch 7/10
339/339 [==============================] - 20s 59ms/step - loss: 0.1877 - accuracy:
0.9319 - val_loss: 0.3853 - val_accuracy: 0.8899
Epoch 8/10
339/339 [==============================] - 20s 59ms/step - loss: 0.1763 - accuracy:
0.9353 - val_loss: 0.4459 - val_accuracy: 0.8808
Epoch 9/10
339/339 [==============================] - 20s 59ms/step - loss: 0.1715 - accuracy:
0.9380 - val_loss: 0.4318 - val_accuracy: 0.8833
Epoch 10/10
339/339 [==============================] - 20s 58ms/step - loss: 0.1638 - accuracy:
0.9409 - val_loss: 0.4402 - val_accuracy: 0.8809
Total training time: 4.377323408921559 minutes.
```

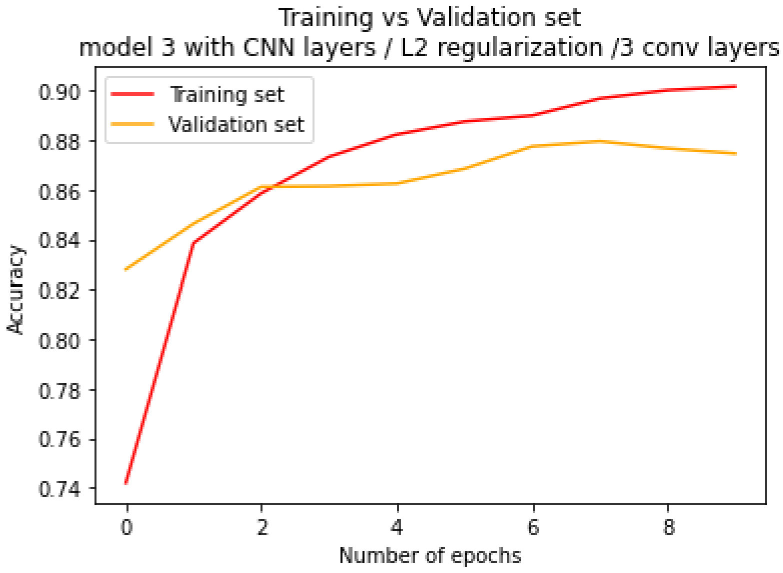


In [ ]:

```
from tensorflow.python.keras import Sequential
from tensorflow.python.keras.layers import Dense, Conv2D, Flatten, MaxPooling2D
from keras import regularizers

# Create model 3 with CNN layers / L2 regularization /3 conv layers
title = 'model 3 with CNN layers / L2 regularization /3 conv layers'

model = Sequential()

# add a conv layer with "same" zero padding
model.add(Conv2D(num_filters, kernel_size = kernel_size, activation = activation, padd

# Add a pooling layer
model.add(MaxPooling2D(pool_size= pool_size))

# Add a second conv layer with a stride of 2x2
model.add(Conv2D(num_filters, kernel_size = kernel_size, activation = activation, padd

# Add a pooling layer
model.add(MaxPooling2D(pool_size = pool_size))

# Add a third conv layer with a stride of 2x2
model.add(Conv2D(num_filters, kernel_size = kernel_size, activation = activation, padd

# Add a pooling layer
model.add(MaxPooling2D(pool_size = pool_size))

# Flatten the input
model.add(Flatten())

# Add L2 metod
model.add(Dense(100, activation = activation, kernel_regularizer=regularizers.l2(0.000

# Regular FC layer with output size 10 (for the 10 digits)
model.add(Dense(10, activation = "softmax"))

# Print the summary of the model to view the shape and number of parameters
model.summary()
```

```
# Specify the optimizer
model.compile(optimizer = opt, loss = loss, metrics = ['accuracy'])



# Time how fast the model train
start = time.time()

# Train using adam
model1 = model.fit(x_train, y_train, validation_split=0.15,batch_size = batch_size, ep

end = time.time()

num_mins = (end-start)/60
print("Total training time: "  + str(num_mins) + " minutes.")





# Evaluate the model
#score = model.evaluate(x_test, y_test, verbose = 0)
#print("Test loss: %.4f" % score[0])
#print("Accuracy: %.2f" % (score[1] * 100.0))





# Plot loss function (val vs test)
from matplotlib import pyplot as plt

plt.plot(model1.history["accuracy"], color = "red", label = "Training set")
plt.plot(model1.history["val_accuracy"], color = "orange", label = "Validation set")

plt.title("Training vs Validation set\n"+title)
plt.ylabel("Accuracy")
plt.xlabel("Number of epochs")
plt.legend()
plt.show()
```

```
Model: "sequential_6"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_14 (Conv2D)           (None, 28, 28, 32)        320
_________________________________________________________________
max_pooling2d_14 (MaxPooling (None, 14, 14, 32)        0
_________________________________________________________________
conv2d_15 (Conv2D)           (None, 7, 7, 32)          9248
_________________________________________________________________
max_pooling2d_15 (MaxPooling (None, 3, 3, 32)          0
_________________________________________________________________
conv2d_16 (Conv2D)           (None, 2, 2, 32)          9248
_________________________________________________________________
max_pooling2d_16 (MaxPooling (None, 1, 1, 32)          0
_________________________________________________________________
flatten_6 (Flatten)          (None, 32)                0
_________________________________________________________________
dense_6 (Dense)              (None, 100)               3300
_________________________________________________________________
dense_7 (Dense)              (None, 10)                1010
=================================================================
Total params: 23,126
Trainable params: 23,126
Non-trainable params: 0
_________________________________________________________________
Epoch 1/10
339/339 [==============================] - 33s 95ms/step - loss: 0.7773 - accuracy:
0.7419 - val_loss: 0.4916 - val_accuracy: 0.8278
Epoch 2/10
339/339 [==============================] - 35s 103ms/step - loss: 0.4438 - accuracy:
0.8384 - val_loss: 0.4320 - val_accuracy: 0.8463
Epoch 3/10
339/339 [==============================] - 30s 90ms/step - loss: 0.3899 - accuracy:
0.8585 - val_loss: 0.4034 - val_accuracy: 0.8612
Epoch 4/10
339/339 [==============================] - 27s 79ms/step - loss: 0.3516 - accuracy:
0.8733 - val_loss: 0.4043 - val_accuracy: 0.8614
Epoch 5/10
339/339 [==============================] - 26s 78ms/step - loss: 0.3257 - accuracy:
0.8823 - val_loss: 0.3916 - val_accuracy: 0.8625
Epoch 6/10
339/339 [==============================] - 26s 75ms/step - loss: 0.3095 - accuracy:
0.8876 - val_loss: 0.3787 - val_accuracy: 0.8685
Epoch 7/10
339/339 [==============================] - 25s 75ms/step - loss: 0.2976 - accuracy:
0.8900 - val_loss: 0.3535 - val_accuracy: 0.8775
Epoch 8/10
339/339 [==============================] - 25s 75ms/step - loss: 0.2807 - accuracy:
0.8969 - val_loss: 0.3550 - val_accuracy: 0.8796
Epoch 9/10
339/339 [==============================] - 27s 80ms/step - loss: 0.2702 - accuracy:
0.9002 - val_loss: 0.3546 - val_accuracy: 0.8767
Epoch 10/10
339/339 [==============================] - 25s 74ms/step - loss: 0.2602 - accuracy:
0.9017 - val_loss: 0.3679 - val_accuracy: 0.8746
Total training time: 5.384840627511342 minutes.
```

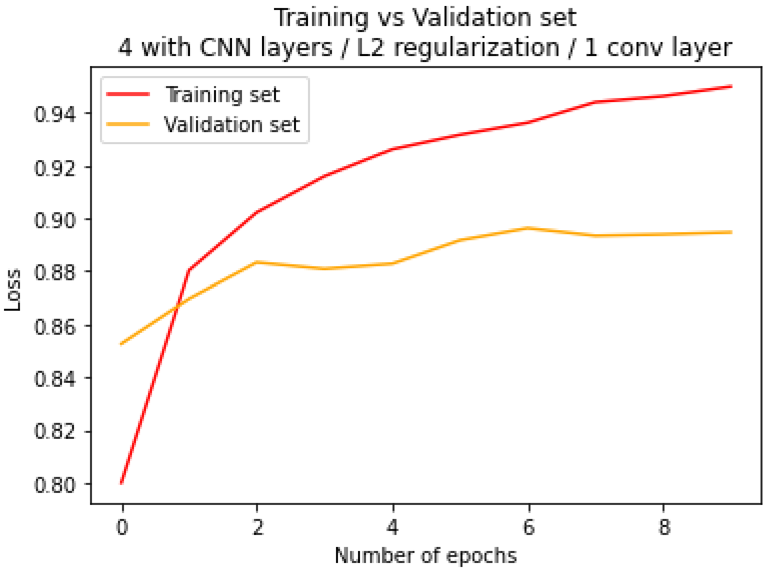


In [ ]:

```
# Create model 4 with CNN layers / L2 regularization / 1 conv layer

title = '4 with CNN layers / L2 regularization / 1 conv layer'

model = Sequential()

# add a conv layer with "same" zero padding
model.add(Conv2D(num_filters, kernel_size = kernel_size, activation = activation, padd

# Add a pooling layer
model.add(MaxPooling2D(pool_size = pool_size))

# Flatten the input
model.add(Flatten())

# Add L2 metod
model.add(Dense(100, activation = activation, kernel_regularizer=regularizers.l2(0.000

# Regular FC layer with output size 10 (for the 10 digits)
model.add(Dense(10, activation = "softmax"))

# Print the summary of the model to view the shape and number of parameters
model.summary()



# Specify the optimizer
model.compile(optimizer = opt, loss = loss, metrics = ['accuracy'])



# Time how fast the model train
start = time.time()

# Train using adam
model1 = model.fit(x_train, y_train, validation_split=0.15,batch_size = batch_size, ep

end = time.time()

num_mins = (end-start)/60
print("Total training time: "  + str(num_mins) + " minutes.")
```

```
# Evaluate the model
#score = model.evaluate(x_test, y_test, verbose = 0)
#print("Test loss: %.4f" % score[0])
#print("Accuracy: %.2f" % (score[1] * 100.0))




# Plot loss function (val vs test)
from matplotlib import pyplot as plt

plt.plot(model1.history["accuracy"], color = "red", label = "Training set")
plt.plot(model1.history["val_accuracy"], color = "orange", label = "Validation set")

plt.title("Training vs Validation set\n"+title)
plt.ylabel("Loss")
plt.xlabel("Number of epochs")
plt.legend()
plt.show()
```

```
Model: "sequential_7"
_________________________________________________________________
Layer (type)                Output Shape              Param #
=================================================================
conv2d_17 (Conv2D)          (None, 28, 28, 32)        320

_________________________________________________________________
max_pooling2d_17 (MaxPooling (None, 14, 14, 32)       0

_________________________________________________________________
flatten_7 (Flatten)         (None, 6272)              0

_________________________________________________________________
dense_8 (Dense)             (None, 100)               627300

_________________________________________________________________
dense_9 (Dense)             (None, 10)                1010
=================================================================
Total params: 628,630
Trainable params: 628,630
Non-trainable params: 0
_________________________________________________________________
Epoch 1/10
339/339 [==============================] - 25s 73ms/step - loss: 2.0214 - accuracy:
0.8000 - val_loss: 0.4934 - val_accuracy: 0.8527
Epoch 2/10
339/339 [==============================] - 24s 72ms/step - loss: 0.3656 - accuracy:
0.8804 - val_loss: 0.3947 - val_accuracy: 0.8697
Epoch 3/10
339/339 [==============================] - 24s 72ms/step - loss: 0.2847 - accuracy:
0.9023 - val_loss: 0.3697 - val_accuracy: 0.8834
Epoch 4/10
339/339 [==============================] - 24s 72ms/step - loss: 0.2411 - accuracy:
0.9160 - val_loss: 0.3753 - val_accuracy: 0.8809
Epoch 5/10
339/339 [==============================] - 24s 71ms/step - loss: 0.2086 - accuracy:
0.9263 - val_loss: 0.3771 - val_accuracy: 0.8829
Epoch 6/10
339/339 [==============================] - 26s 75ms/step - loss: 0.1914 - accuracy:
0.9318 - val_loss: 0.3487 - val_accuracy: 0.8918
Epoch 7/10
339/339 [==============================] - 24s 72ms/step - loss: 0.1746 - accuracy:
0.9363 - val_loss: 0.3496 - val_accuracy: 0.8963
Epoch 8/10
339/339 [==============================] - 25s 73ms/step - loss: 0.1578 - accuracy:
0.9441 - val_loss: 0.3585 - val_accuracy: 0.8935
Epoch 9/10
339/339 [==============================] - 25s 73ms/step - loss: 0.1454 - accuracy:
0.9464 - val_loss: 0.3798 - val_accuracy: 0.8940
Epoch 10/10
339/339 [==============================] - 25s 72ms/step - loss: 0.1360 - accuracy:
0.9500 - val_loss: 0.4102 - val_accuracy: 0.8948
Total training time: 4.374269696076711 minutes.
```



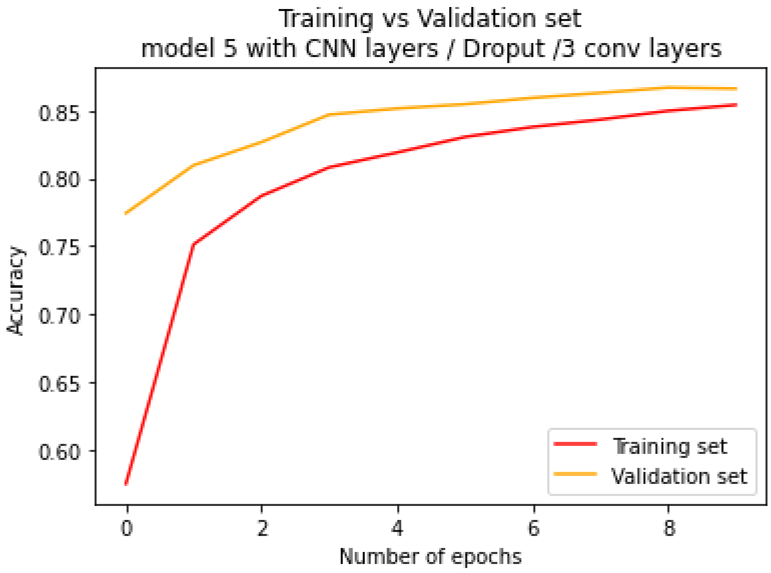
In [ ]:

```
from tensorflow.python.keras import Sequential
from tensorflow.python.keras.layers import Dense, Conv2D, Flatten, MaxPooling2D
from tensorflow.keras.layers import Dropout

# Create model 5 with CNN layers / Dropout /3 conv layers
title = 'model 5 with CNN layers / Droput /3 conv layers'

model = Sequential()

# add a conv layer with "same" zero padding
model.add(Conv2D(num_filters, kernel_size = kernel_size, activation = activation, padd

# Add a pooling layer
model.add(MaxPooling2D(pool_size= pool_size))

#Dropout
model.add(Dropout(0.1))

# Add a second conv layer with a stride of 2x2
model.add(Conv2D(num_filters, kernel_size = kernel_size, activation = activation, padd

# Add a pooling layer
model.add(MaxPooling2D(pool_size = pool_size))

#Dropout
model.add(Dropout(0.1))

# Add a third conv layer with a stride of 2x2
model.add(Conv2D(num_filters, kernel_size = kernel_size, activation = activation, padd

# Add a pooling layer
model.add(MaxPooling2D(pool_size = pool_size))

#Dropout
model.add(Dropout(0.1))

# Flatten the input
model.add(Flatten())

# Regular FC layer with output size 10 (for the 10 digits)
model.add(Dense(10, activation = "softmax"))
```

```
# Print the summary of the model to view the shape and number of parameters
model.summary()



# Specify the optimizer
model.compile(optimizer = opt, loss = loss, metrics = ['accuracy'])



# Time how fast the model train
start = time.time()

# Train using adam
model1 = model.fit(x_train, y_train, validation_split=0.15,batch_size = batch_size, ep

end = time.time()

num_mins = (end-start)/60
print("Total training time: "  + str(num_mins) + " minutes.")




# Evaluate the model
#score = model.evaluate(x_test, y_test, verbose = 0)
#print("Test loss: %.4f" % score[0])
#print("Accuracy: %.2f" % (score[1] * 100.0))




# Plot loss function (val vs test)
from matplotlib import pyplot as plt

plt.plot(model1.history["accuracy"], color = "red", label = "Training set")
plt.plot(model1.history["val_accuracy"], color = "orange", label = "Validation set")

plt.title("Training vs Validation set\n"+title)
plt.ylabel("Accuracy")
plt.xlabel("Number of epochs")
plt.legend()
plt.show()
```

```
Model: "sequential_8"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_18 (Conv2D)           (None, 28, 28, 32)        320

_________________________________________________________________
max_pooling2d_18 (MaxPooling (None, 14, 14, 32)        0

_________________________________________________________________
module_wrapper (ModuleWrappe (None, 14, 14, 32)        0

_________________________________________________________________
conv2d_19 (Conv2D)           (None, 7, 7, 32)          9248

_________________________________________________________________
max_pooling2d_19 (MaxPooling (None, 3, 3, 32)          0

_________________________________________________________________
module_wrapper_1 (ModuleWrap (None, 3, 3, 32)          0

_________________________________________________________________
conv2d_20 (Conv2D)           (None, 2, 2, 32)          9248

_________________________________________________________________
max_pooling2d_20 (MaxPooling (None, 1, 1, 32)          0

_________________________________________________________________
module_wrapper_2 (ModuleWrap (None, 1, 1, 32)          0

_________________________________________________________________
flatten_8 (Flatten)          (None, 32)                0

_________________________________________________________________
dense_10 (Dense)             (None, 10)                330
=================================================================
Total params: 19,146
Trainable params: 19,146
Non-trainable params: 0

_________________________________________________________________
Epoch 1/10
339/339 [==============================] - 29s 85ms/step - loss: 1.7987 - accuracy:
0.5753 - val_loss: 0.6391 - val_accuracy: 0.7744
Epoch 2/10
339/339 [==============================] - 30s 88ms/step - loss: 0.6951 - accuracy:
0.7513 - val_loss: 0.5282 - val_accuracy: 0.8097
Epoch 3/10
339/339 [==============================] - 29s 84ms/step - loss: 0.5919 - accuracy:
0.7870 - val_loss: 0.4809 - val_accuracy: 0.8267
Epoch 4/10
339/339 [==============================] - 29s 84ms/step - loss: 0.5269 - accuracy:
0.8081 - val_loss: 0.4348 - val_accuracy: 0.8469
Epoch 5/10
339/339 [==============================] - 29s 85ms/step - loss: 0.4933 - accuracy:
0.8191 - val_loss: 0.4129 - val_accuracy: 0.8515
Epoch 6/10
339/339 [==============================] - 29s 84ms/step - loss: 0.4634 - accuracy:
0.8305 - val_loss: 0.4007 - val_accuracy: 0.8546
Epoch 7/10
339/339 [==============================] - 29s 85ms/step - loss: 0.4410 - accuracy:
0.8379 - val_loss: 0.3862 - val_accuracy: 0.8593
Epoch 8/10
339/339 [==============================] - 30s 88ms/step - loss: 0.4201 - accuracy:
0.8433 - val_loss: 0.3763 - val_accuracy: 0.8630
Epoch 9/10
339/339 [==============================] - 29s 84ms/step - loss: 0.4048 - accuracy:
0.8497 - val_loss: 0.3620 - val_accuracy: 0.8669
Epoch 10/10
339/339 [==============================] - 29s 84ms/step - loss: 0.3923 - accuracy:
```

```
0.8541 - val_loss: 0.3609 - val_accuracy: 0.8661
Total training time: 4.822744429111481 minutes.
```

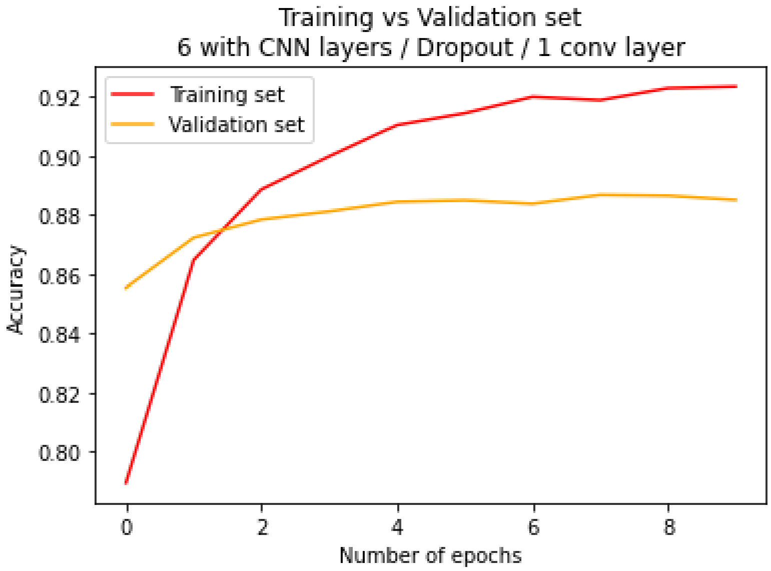


In [ ]:

```
# Create model 6 with CNN layers / Dropout / 1 conv layer

title = '6 with CNN layers / Dropout / 1 conv layer'

model = Sequential()

# add a conv layer with "same" zero padding
model.add(Conv2D(num_filters, kernel_size = kernel_size, activation = activation, padd

# Add a pooling layer
model.add(MaxPooling2D(pool_size = pool_size))

#Dropout
model.add(Dropout(0.1))

# Flatten the input
model.add(Flatten())

# Regular FC layer with output size 10 (for the 10 digits)
model.add(Dense(10, activation = "softmax"))

# Print the summary of the model to view the shape and number of parameters
model.summary()



# Specify the optimizer
model.compile(optimizer = opt, loss = loss, metrics = ['accuracy'])



# Time how fast the model train
start = time.time()

# Train using adam
model1 = model.fit(x_train, y_train, validation_split=0.15,batch_size = batch_size, ep

end = time.time()
```

```
num_mins = (end-start)/60
print("Total training time: "  + str(num_mins) + " minutes.")




# Evaluate the model
#score = model.evaluate(x_test, y_test, verbose = 0)
#print("Test loss: %.4f" % score[0])
#print("Accuracy: %.2f" % (score[1] * 100.0))




# Plot loss function (val vs test)
from matplotlib import pyplot as plt

plt.plot(model1.history["accuracy"], color = "red", label = "Training set")
plt.plot(model1.history["val_accuracy"], color = "orange", label = "Validation set")

plt.title("Training vs Validation set\n"+title)
plt.ylabel("Accuracy")
plt.xlabel("Number of epochs")
plt.legend()
plt.show()
```

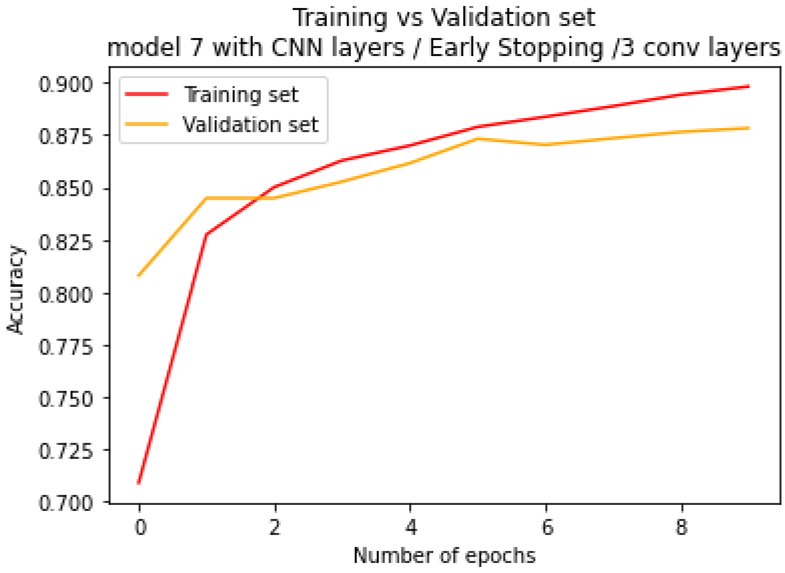
```
Model: "sequential_9"
_________________________________________________________________
Layer (type)                 Output Shape              Param #   
=================================================================
conv2d_21 (Conv2D)           (None, 28, 28, 32)        320       
_________________________________________________________________
max_pooling2d_21 (MaxPooling (None, 14, 14, 32)        0         
_________________________________________________________________
module_wrapper_3 (ModuleWrap (None, 14, 14, 32)        0         
_________________________________________________________________
flatten_9 (Flatten)          (None, 6272)              0         
_________________________________________________________________
dense_11 (Dense)             (None, 10)                62730     
=================================================================
Total params: 63,050
Trainable params: 63,050
Non-trainable params: 0
_________________________________________________________________
Epoch 1/10
339/339 [==============================] - 24s 69ms/step - loss: 3.4073 - accuracy:
0.7894 - val_loss: 0.6530 - val_accuracy: 0.8554
Epoch 2/10
339/339 [==============================] - 23s 68ms/step - loss: 0.4798 - accuracy:
0.8647 - val_loss: 0.4044 - val_accuracy: 0.8723
Epoch 3/10
339/339 [==============================] - 23s 68ms/step - loss: 0.3209 - accuracy:
0.8887 - val_loss: 0.3799 - val_accuracy: 0.8784
Epoch 4/10
339/339 [==============================] - 23s 68ms/step - loss: 0.2754 - accuracy:
0.8998 - val_loss: 0.3644 - val_accuracy: 0.8812
Epoch 5/10
339/339 [==============================] - 24s 72ms/step - loss: 0.2489 - accuracy:
0.9105 - val_loss: 0.3534 - val_accuracy: 0.8844
Epoch 6/10
339/339 [==============================] - 23s 68ms/step - loss: 0.2334 - accuracy:
0.9145 - val_loss: 0.3548 - val_accuracy: 0.8850
Epoch 7/10
339/339 [==============================] - 23s 68ms/step - loss: 0.2204 - accuracy:
0.9200 - val_loss: 0.3645 - val_accuracy: 0.8838
Epoch 8/10
339/339 [==============================] - 23s 68ms/step - loss: 0.2188 - accuracy:
0.9189 - val_loss: 0.3634 - val_accuracy: 0.8868
Epoch 9/10
339/339 [==============================] - 23s 68ms/step - loss: 0.2083 - accuracy:
0.9230 - val_loss: 0.3694 - val_accuracy: 0.8865
Epoch 10/10
339/339 [==============================] - 23s 68ms/step - loss: 0.2033 - accuracy:
0.9235 - val_loss: 0.3752 - val_accuracy: 0.8851
Total training time: 4.373109606901805 minutes.
```



In [ ]:

```
# Create model 7 with CNN layers / Early Stopping /3 conv layers

from tensorflow.python.keras.callbacks import EarlyStopping, ModelCheckpoint

title = 'model 7 with CNN layers / Early Stopping /3 conv layers'

model = Sequential()

# add a conv layer with "same" zero padding
model.add(Conv2D(num_filters, kernel_size = kernel_size, activation = activation, padd

# Add a pooling layer
model.add(MaxPooling2D(pool_size= pool_size))

# Add a second conv layer with a stride of 2x2
model.add(Conv2D(num_filters, kernel_size = kernel_size, activation = activation, padd

# Add a pooling layer
model.add(MaxPooling2D(pool_size = pool_size))

# Add a third conv layer with a stride of 2x2
model.add(Conv2D(num_filters, kernel_size = kernel_size, activation = activation, padd

# Add a pooling layer
model.add(MaxPooling2D(pool_size = pool_size))

# Flatten the input
model.add(Flatten())

# Regular FC layer with output size 10 (for the 10 digits)
model.add(Dense(10, activation = "softmax"))

# Print the summary of the model to view the shape and number of parameters
model.summary()


#Early Stopping

es = EarlyStopping(monitor = "val_loss", mode = "min", verbose = 1, restore_best_weigh
mc = ModelCheckpoint("best_model_tutorial", monitor = "val_loss", save_best_only = Tru
# Specify the optimizer
model.compile(optimizer = opt, loss = loss, metrics = ['accuracy'])



# Time how fast the model train
start = time.time()

# Train using adam
model1 = model.fit(x_train, y_train, validation_split=0.15,batch_size = batch_size, ep

end = time.time()

num_mins = (end-start)/60
print("Total training time: "  + str(num_mins) + " minutes.")





# Evaluate the model
#score = model.evaluate(x_test, y_test, verbose = 0)
#print("Test loss: %.4f" % score[0])
#print("Accuracy: %.2f" % (score[1] * 100.0))




# Plot loss function (val vs test)
from matplotlib import pyplot as plt

plt.plot(model1.history["accuracy"], color = "red", label = "Training set")
plt.plot(model1.history["val_accuracy"], color = "orange", label = "Validation set")

plt.title("Training vs Validation set\n"+title)
plt.ylabel("Accuracy")
plt.xlabel("Number of epochs")
plt.legend()
plt.show()
```

```
Model: "sequential_2"
_________________________________________________________________
Layer (type)                 Output Shape              Param #   
=================================================================
conv2d (Conv2D)              (None, 28, 28, 32)        320       
_________________________________________________________________
max_pooling2d (MaxPooling2D) (None, 14, 14, 32)        0         
_________________________________________________________________
conv2d_1 (Conv2D)            (None, 7, 7, 32)          9248      
_________________________________________________________________
max_pooling2d_1 (MaxPooling2 (None, 3, 3, 32)          0         
_________________________________________________________________
conv2d_2 (Conv2D)            (None, 2, 2, 32)          9248      
_________________________________________________________________
max_pooling2d_2 (MaxPooling2 (None, 1, 1, 32)          0         
_________________________________________________________________
flatten (Flatten)            (None, 32)                0         
_________________________________________________________________
dense (Dense)                (None, 10)                330       
=================================================================
Total params: 19,146
Trainable params: 19,146
Non-trainable params: 0
_________________________________________________________________
Epoch 1/10
339/339 [==============================] - 27s 77ms/step - loss: 1.3704 - accuracy:
0.7090 - val_loss: 0.5477 - val_accuracy: 0.8078
Epoch 2/10
339/339 [==============================] - 26s 75ms/step - loss: 0.4892 - accuracy:
0.8274 - val_loss: 0.4477 - val_accuracy: 0.8448
Epoch 3/10
339/339 [==============================] - 25s 73ms/step - loss: 0.4236 - accuracy:
0.8501 - val_loss: 0.4377 - val_accuracy: 0.8448
Epoch 4/10
339/339 [==============================] - 25s 73ms/step - loss: 0.3851 - accuracy:
0.8628 - val_loss: 0.4094 - val_accuracy: 0.8527
Epoch 5/10
339/339 [==============================] - 25s 73ms/step - loss: 0.3625 - accuracy:
0.8700 - val_loss: 0.3941 - val_accuracy: 0.8616
Epoch 6/10
339/339 [==============================] - 25s 72ms/step - loss: 0.3376 - accuracy:
0.8789 - val_loss: 0.3653 - val_accuracy: 0.8732
Epoch 7/10
339/339 [==============================] - 24s 72ms/step - loss: 0.3236 - accuracy:
0.8837 - val_loss: 0.3699 - val_accuracy: 0.8703
Epoch 8/10
339/339 [==============================] - 24s 72ms/step - loss: 0.3045 - accuracy:
0.8888 - val_loss: 0.3665 - val_accuracy: 0.8735
Epoch 9/10
339/339 [==============================] - 24s 72ms/step - loss: 0.2911 - accuracy:
0.8943 - val_loss: 0.3514 - val_accuracy: 0.8765
Epoch 10/10
339/339 [==============================] - 24s 72ms/step - loss: 0.2775 - accuracy:
0.8982 - val_loss: 0.3600 - val_accuracy: 0.8783
Total training time: 4.378224221865336 minutes.
```

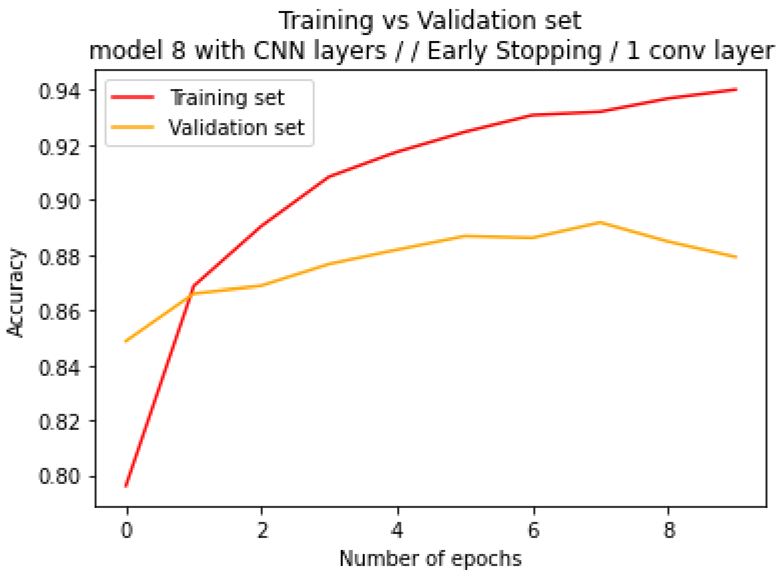


In [ ]:

```
# Create model 8 with CNN layers / / Early Stopping / 1 conv layer

title = 'model 8 with CNN layers / / Early Stopping / 1 conv layer'

model = Sequential()

# add a conv layer with "same" zero padding
model.add(Conv2D(num_filters, kernel_size = kernel_size, activation = activation, padd

# Add a pooling layer
model.add(MaxPooling2D(pool_size = pool_size))

# Flatten the input
model.add(Flatten())

# Regular FC layer with output size 10 (for the 10 digits)
model.add(Dense(10, activation = "softmax"))

# Print the summary of the model to view the shape and number of parameters
model.summary()


#Early Stopping

es = EarlyStopping(monitor = "val_loss", mode = "min", verbose = 1, restore_best_weigh
mc = ModelCheckpoint("best_model_tutorial", monitor = "val_loss", save_best_only = Tru



# Specify the optimizer
model.compile(optimizer = opt, loss = loss, metrics = ['accuracy'])



# Time how fast the model train
start = time.time()

# Train using adam
model1 = model.fit(x_train, y_train, validation_split=0.15,batch_size = batch_size, ep

end = time.time()
```

```
num_mins = (end-start)/60
print("Total training time: "  + str(num_mins) + " minutes.")




# Evaluate the model
#score = model.evaluate(x_test, y_test, verbose = 0)
#print("Test loss: %.4f" % score[0])
#print("Accuracy: %.2f" % (score[1] * 100.0))




# Plot loss function (val vs test)
from matplotlib import pyplot as plt

plt.plot(model1.history["accuracy"], color = "red", label = "Training set")
plt.plot(model1.history["val_accuracy"], color = "orange", label = "Validation set")

plt.title("Training vs Validation set\n"+title)
plt.ylabel("Accuracy")
plt.xlabel("Number of epochs")
plt.legend()
plt.show()
```

```
Model: "sequential_3"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_3 (Conv2D)            (None, 28, 28, 32)        320
_________________________________________________________________
max_pooling2d_3 (MaxPooling2 (None, 14, 14, 32)        0
_________________________________________________________________
flatten_1 (Flatten)          (None, 6272)              0
_________________________________________________________________
dense_1 (Dense)              (None, 10)                62730
=================================================================
Total params: 63,050
Trainable params: 63,050
Non-trainable params: 0
_________________________________________________________________
Epoch 1/10
339/339 [==============================] - 20s 58ms/step - loss: 4.0163 - accuracy:
0.7961 - val_loss: 0.9317 - val_accuracy: 0.8488
Epoch 2/10
339/339 [==============================] - 19s 57ms/step - loss: 0.5709 - accuracy:
0.8686 - val_loss: 0.5362 - val_accuracy: 0.8660
Epoch 3/10
339/339 [==============================] - 19s 57ms/step - loss: 0.3604 - accuracy:
0.8904 - val_loss: 0.4838 - val_accuracy: 0.8688
Epoch 4/10
339/339 [==============================] - 19s 57ms/step - loss: 0.2782 - accuracy:
0.9084 - val_loss: 0.4454 - val_accuracy: 0.8766
Epoch 5/10
339/339 [==============================] - 19s 57ms/step - loss: 0.2397 - accuracy:
0.9174 - val_loss: 0.4185 - val_accuracy: 0.8818
Epoch 6/10
339/339 [==============================] - 19s 57ms/step - loss: 0.2139 - accuracy:
0.9247 - val_loss: 0.4197 - val_accuracy: 0.8868
Epoch 7/10
339/339 [==============================] - 19s 56ms/step - loss: 0.1941 - accuracy:
0.9308 - val_loss: 0.4116 - val_accuracy: 0.8861
Epoch 8/10
339/339 [==============================] - 19s 57ms/step - loss: 0.1895 - accuracy:
0.9320 - val_loss: 0.4002 - val_accuracy: 0.8918
Epoch 9/10
339/339 [==============================] - 19s 57ms/step - loss: 0.1761 - accuracy:
0.9369 - val_loss: 0.4249 - val_accuracy: 0.8848
Epoch 10/10
339/339 [==============================] - 19s 56ms/step - loss: 0.1656 - accuracy:
0.9401 - val_loss: 0.4503 - val_accuracy: 0.8792
Total training time: 3.372301439444224 minutes.
```



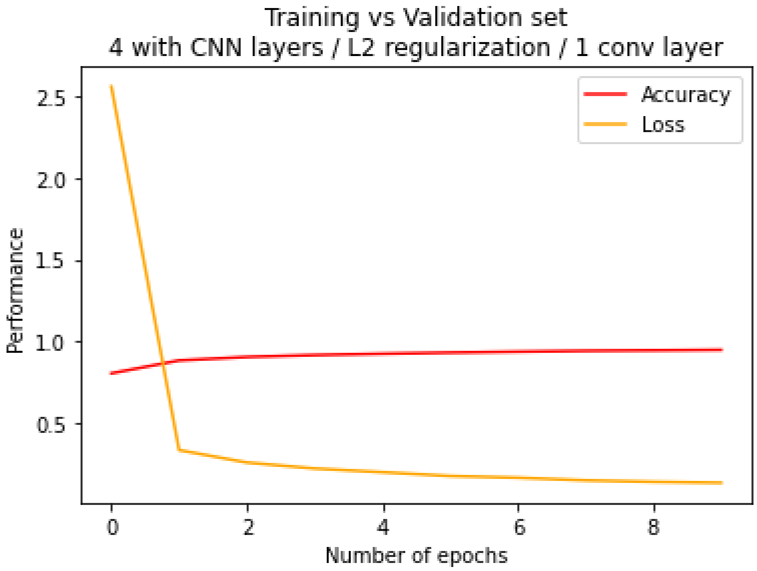
TOP-PERFORMING MODEL

In [ ]:

```
# Training on the whole train dataset on the top performing model from the experiments

# Create model 4 with CNN layers / L2 regularization / 1 conv layer

title = '4 with CNN layers / L2 regularization / 1 conv layer'

model = Sequential()

# add a conv layer with "same" zero padding
model.add(Conv2D(num_filters, kernel_size = kernel_size, activation = activation, padd

# Add a pooling layer
model.add(MaxPooling2D(pool_size = pool_size))

# Flatten the input
model.add(Flatten())

# Add L2 metod
model.add(Dense(100, activation = activation, kernel_regularizer=regularizers.l2(0.000

# Regular FC layer with output size 10 (for the 10 digits)
model.add(Dense(10, activation = "softmax"))

# Print the summary of the model to view the shape and number of parameters
model.summary()



# Specify the optimizer
model.compile(optimizer = opt, loss = loss, metrics = ['accuracy'])



# Time how fast the model train
start = time.time()
```

```
# Train using adam
top_model = model.fit(x_train, y_train, batch_size = batch_size, epochs = epochs, verb

end = time.time()

num_mins = (end-start)/60
print("Total training time: "  + str(num_mins) + " minutes.")




# Evaluate the model
score = model.evaluate(x_test, y_test, verbose = 0)
print("Test loss: %.4f" % score[0])
print("Test accuracy: %.2f" % (score[1] * 100.0))




# Plot loss function (val vs test)
from matplotlib import pyplot as plt

plt.plot(top_model.history["accuracy"], color = "red", label = "Accuracy")
plt.plot(top_model.history["loss"], color = "orange", label = "Loss")

plt.title("Training vs Validation set\n"+title)
plt.ylabel("Performance")
plt.xlabel("Number of epochs")
plt.legend()
plt.show()
```

```
Model: "sequential_7"
_________________________________________________________________
Layer (type)                 Output Shape              Param #   
=================================================================
conv2d_7 (Conv2D)            (None, 28, 28, 32)        320       
_________________________________________________________________
max_pooling2d_7 (MaxPooling2 (None, 14, 14, 32)        0         
_________________________________________________________________
flatten_5 (Flatten)          (None, 6272)              0         
_________________________________________________________________
dense_4 (Dense)              (None, 100)               627300    
_________________________________________________________________
dense_5 (Dense)              (None, 10)                1010      
=================================================================
Total params: 628,630
Trainable params: 628,630
Non-trainable params: 0
_________________________________________________________________
Epoch 1/10
399/399 [==============================] - 28s 70ms/step - loss: 2.5558 - accuracy:
0.8069
Epoch 2/10
399/399 [==============================] - 26s 65ms/step - loss: 0.3379 - accuracy:
0.8857
Epoch 3/10
399/399 [==============================] - 26s 64ms/step - loss: 0.2621 - accuracy:
0.9069
Epoch 4/10
399/399 [==============================] - 28s 69ms/step - loss: 0.2254 - accuracy:
0.9186
Epoch 5/10
399/399 [==============================] - 26s 65ms/step - loss: 0.2028 - accuracy:
0.9266
Epoch 6/10
399/399 [==============================] - 26s 65ms/step - loss: 0.1795 - accuracy:
0.9334
Epoch 7/10
399/399 [==============================] - 26s 65ms/step - loss: 0.1691 - accuracy:
0.9393
Epoch 8/10
399/399 [==============================] - 26s 65ms/step - loss: 0.1529 - accuracy:
0.9445
Epoch 9/10
399/399 [==============================] - 26s 65ms/step - loss: 0.1440 - accuracy:
0.9473
Epoch 10/10
399/399 [==============================] - 26s 66ms/step - loss: 0.1384 - accuracy:
0.9504
Total training time: 5.373602437973022 minutes.
Test loss: 0.3863
Test accuracy: 89.24
```



Interpreting CNN Representations / Code Part II

In [ ]:
```
# Training on the whole train dataset on the top performing model from the experiments
# Creating a new model with the bse of best oerformnig model
# Create new model with CNN layers / L2 regularization / 1 conv layer

title = 'model with CNN layers / L2 regularization / 1 conv layer'

model = Sequential()

# add a conv layer with "same" zero padding
model.add(Conv2D(num_filters, kernel_size = kernel_size, activation = activation, padd

# Add a pooling layer
model.add(MaxPooling2D(pool_size = pool_size))

# add a conv layer with "same" zero padding
model.add(Conv2D(num_filters, kernel_size = kernel_size, activation = activation, padd

# Add a pooling layer
model.add(MaxPooling2D(pool_size = pool_size))

# add a conv layer with "same" zero padding
model.add(Conv2D(num_filters, kernel_size = kernel_size, activation = activation, padd

# Add a pooling layer
model.add(MaxPooling2D(pool_size = pool_size))

# add a conv layer with "same" zero padding
model.add(Conv2D(num_filters, kernel_size = kernel_size, activation = activation, padd

# Add a pooling layer
model.add(MaxPooling2D(pool_size = pool_size))

# Flatten the input
model.add(Flatten())
```

```
# Add L2 metod
model.add(Dense(100, activation = activation, kernel_regularizer=regularizers.l2(0.00

# Regular FC layer with output size 10 (for the 10 digits)
model.add(Dense(10, activation = "softmax"))

# Print the summary of the model to view the shape and number of parameters
model.summary()



# Specify the optimizer
model.compile(optimizer = opt, loss = loss, metrics = ['accuracy'])



# Time how fast the model train
start = time.time()

# Train using adam
history = model.fit(x_train, y_train, batch_size = batch_size, epochs = epochs, verbos

end = time.time()

num_mins = (end-start)/60
print("Total training time: "  + str(num_mins) + " minutes.")
```

```
Model: "sequential_12"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_16 (Conv2D)           (None, 28, 28, 32)        320
_________________________________________________________________
max_pooling2d_16 (MaxPooling (None, 14, 14, 32)        0
_________________________________________________________________
conv2d_17 (Conv2D)           (None, 14, 14, 32)        9248
_________________________________________________________________
max_pooling2d_17 (MaxPooling (None, 7, 7, 32)          0
_________________________________________________________________
conv2d_18 (Conv2D)           (None, 7, 7, 32)          9248
_________________________________________________________________
max_pooling2d_18 (MaxPooling (None, 3, 3, 32)          0
_________________________________________________________________
conv2d_19 (Conv2D)           (None, 3, 3, 32)          9248
_________________________________________________________________
max_pooling2d_19 (MaxPooling (None, 1, 1, 32)          0
_________________________________________________________________
flatten_9 (Flatten)          (None, 32)                0
_________________________________________________________________
dense_12 (Dense)             (None, 100)               3300
_________________________________________________________________
dense_13 (Dense)             (None, 10)                1010
=================================================================
Total params: 32,374
Trainable params: 32,374
Non-trainable params: 0
_________________________________________________________________
Epoch 1/10
399/399 [==============================] - 49s 122ms/step - loss: 0.6694 - accuracy:
0.7729
Epoch 2/10
399/399 [==============================] - 48s 120ms/step - loss: 0.3855 - accuracy:
0.8615
Epoch 3/10
399/399 [==============================] - 48s 120ms/step - loss: 0.3275 - accuracy:
0.8812
Epoch 4/10
399/399 [==============================] - 49s 122ms/step - loss: 0.2959 - accuracy:
0.8922
Epoch 5/10
399/399 [==============================] - 48s 120ms/step - loss: 0.2733 - accuracy:
0.9011
Epoch 6/10
399/399 [==============================] - 48s 120ms/step - loss: 0.2584 - accuracy:
0.9070
Epoch 7/10
399/399 [==============================] - 48s 120ms/step - loss: 0.2394 - accuracy:
0.9123
Epoch 8/10
399/399 [==============================] - 49s 122ms/step - loss: 0.2296 - accuracy:
0.9157
Epoch 9/10
399/399 [==============================] - 48s 120ms/step - loss: 0.2166 - accuracy:
0.9209
Epoch 10/10
399/399 [==============================] - 48s 120ms/step - loss: 0.2104 - accuracy:
```

```
0.9212
Total training time: 8.37537084420522 minutes.
```

Out[ ]:

```
'from matplotlib import pyplot as plt\n\nplt.plot(top_model_visual.history["accurac
y"], color = "red", label = "Accuracy")\nplt.plot(top_model_visual.history["loss"], c
olor = "orange", label = "Loss")\n\nplt.title("Training vs Validation set\n"+title)\n
plt.ylabel("Performance")\nplt.xlabel("Number of epochs")\nplt.legend()\nplt.show()'
```

In [ ]:

```python
# Printing model summary once again

model.summary()
```

```
Model: "sequential_12"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_16 (Conv2D)           (None, 28, 28, 32)        320
_________________________________________________________________
max_pooling2d_16 (MaxPooling (None, 14, 14, 32)        0
_________________________________________________________________
conv2d_17 (Conv2D)           (None, 14, 14, 32)        9248
_________________________________________________________________
max_pooling2d_17 (MaxPooling (None, 7, 7, 32)          0
_________________________________________________________________
conv2d_18 (Conv2D)           (None, 7, 7, 32)          9248
_________________________________________________________________
max_pooling2d_18 (MaxPooling (None, 3, 3, 32)          0
_________________________________________________________________
conv2d_19 (Conv2D)           (None, 3, 3, 32)          9248
_________________________________________________________________
max_pooling2d_19 (MaxPooling (None, 1, 1, 32)          0
_________________________________________________________________
flatten_9 (Flatten)          (None, 32)                0
_________________________________________________________________
dense_12 (Dense)             (None, 100)               3300
_________________________________________________________________
dense_13 (Dense)             (None, 10)                1010
=================================================================
Total params: 32,374
Trainable params: 32,374
Non-trainable params: 0
_________________________________________________________________
```

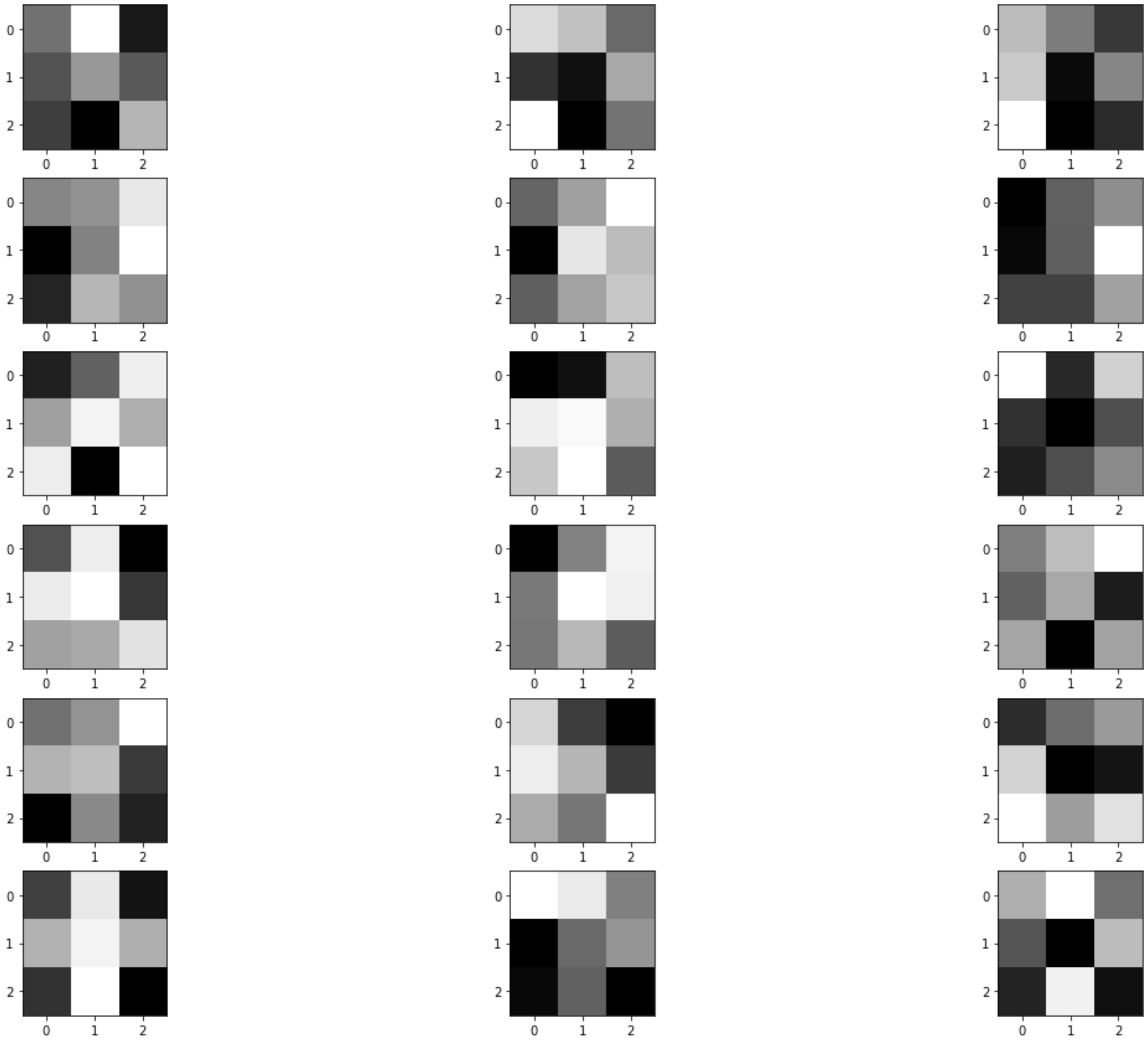
Visualizing Convolutional Layers

In [ ]:

```python
# summarize filter shapes
for layer in model.layers:
        # check for convolutional layer
        if 'conv' not in layer.name:
                continue
        # get filter weights
        filters, biases = layer.get_weights()
        print(layer.name, filters.shape)


 # retrieve weights from the first conv layer
filters , bias = model.layers[2].get_weights()


# normalize filter values to 0-1 so we can visualize them
```

```
f_min, f_max = filters.min(), filters.max()
filters = (filters - f_min) / (f_max - f_min)


n_filters =6
ix=1
fig = plt.figure(figsize=(20,15))
for i in range(n_filters):
    # get the filters
    f = filters[:,:,:,i]
    for j in range(3):
        # subplot for 6 filters and 3 channels
        plt.subplot(n_filters,3,ix)
        plt.imshow(f[:,:,j] ,cmap='gray')
        ix+=1
#plot the filters
plt.show()
```

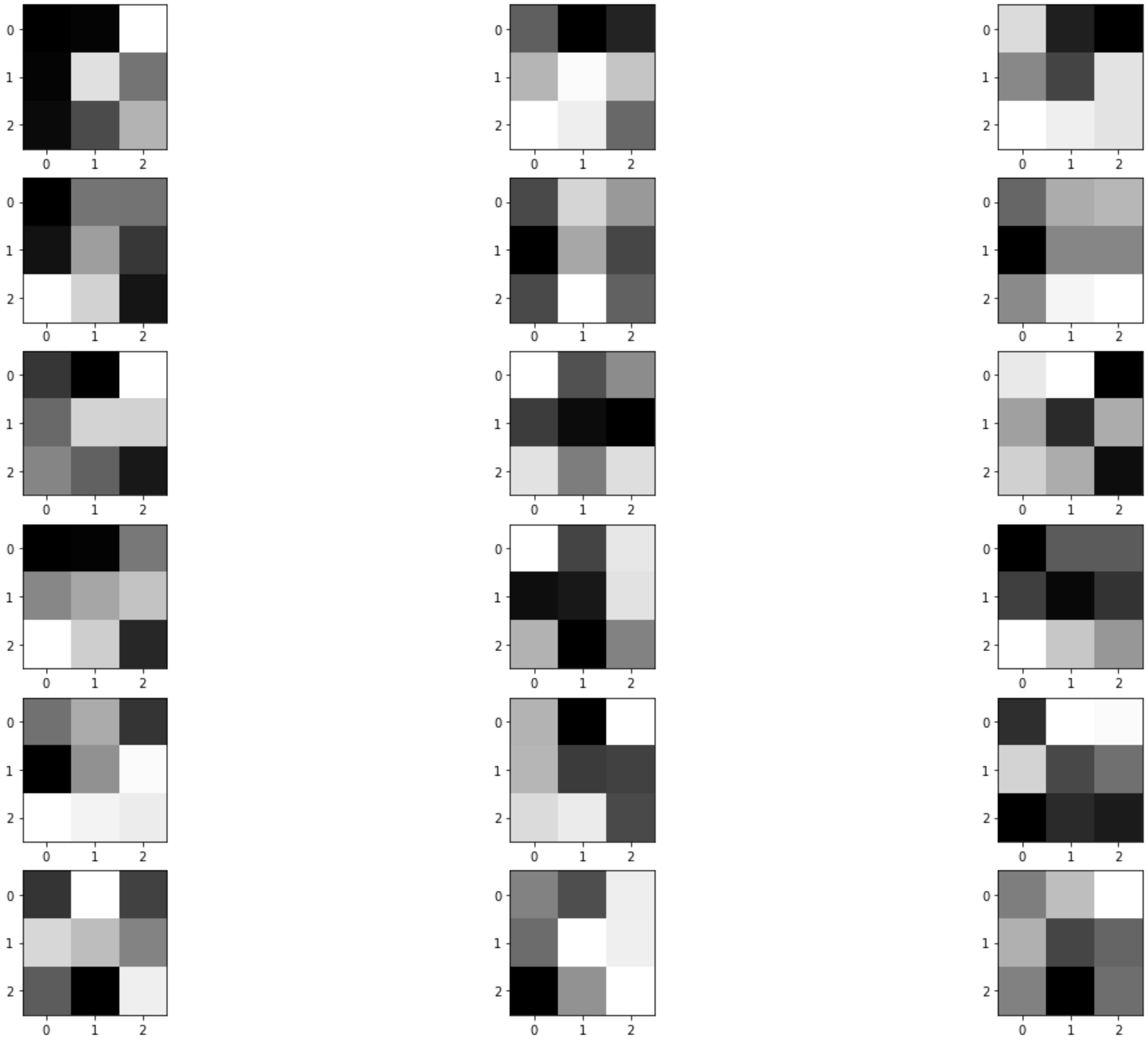
```
conv2d_16 (3, 3, 1, 32)
conv2d_17 (3, 3, 32, 32)
conv2d_18 (3, 3, 32, 32)
conv2d_19 (3, 3, 32, 32)
```



```
In [ ]: # summarize filter shapes
        for layer in model.layers:
```

```
        # check for convolutional layer
        if 'conv' not in layer.name:
                continue
        # get filter weights
        filters, biases = layer.get_weights()
        print(layer.name, filters.shape)


 # retrieve weights from the fourth conv layer
filters , bias = model.layers[6].get_weights()


# normalize filter values to 0-1 so we can visualize them
f_min, f_max = filters.min(), filters.max()
filters = (filters - f_min) / (f_max - f_min)


n_filters =6
ix=1
fig = plt.figure(figsize=(20,15))
for i in range(n_filters):
    # get the filters
    f = filters[:,:,:,i]
    for j in range(3):
        # subplot for 6 filters and 3 channels
        plt.subplot(n_filters,3,ix)
        plt.imshow(f[:,:,j] ,cmap='gray')
        ix+=1
#plot the filters
plt.show()
```

```
conv2d_16 (3, 3, 1, 32)
conv2d_17 (3, 3, 32, 32)
conv2d_18 (3, 3, 32, 32)
conv2d_19 (3, 3, 32, 32)
```


0
1
2
0
1
2