autoencoder

April 19, 2020

Video 13.1 https://www.youtube.com/watch?v=kIGHE7Cfe1s
Video 13.2 https://www.youtube.com/watch?v=Rm9bJcDd1KU
Video 13.3 https://youtu.be/6HjZk-3LsjE

```
In [33]: from keras.callbacks import TensorBoard
         from keras.layers import Input, Dense
         from keras.models import Model
         from keras.datasets import mnist
         import numpy as np
         import keras

         (xtrain, ytrain), (xtest, ytest) = mnist.load_data()

         xtrain = xtrain.astype('float32') / 255.
         xtest = xtest.astype('float32') / 255.
         xtrain = xtrain.reshape((len(xtrain), np.prod(xtrain.shape[1:])))
         xtest = xtest.reshape((len(xtest), np.prod(xtest.shape[1:])))
         xtrain.shape, xtest.shape
```

```
Out[33]: ((60000, 784), (10000, 784))
```

```
In [13]: import matplotlib.pyplot as plt
         %matplotlib inline
```

```
In [6]: # this is the size of our encoded representations
        encoding_dim = 4  # 32 floats -> compression of factor 24.5, assuming the input is 784

        # this is our input placeholder
        x = input_img = Input(shape=(784,))
        # "encoded" is the encoded representation of the input
        x = Dense(256, activation='relu')(x)
        x = Dense(128, activation='relu')(x)
        encoded = Dense(encoding_dim, activation='relu')(x)


        # "decoded" is the lossy reconstruction of the input
        x = Dense(128, activation='relu')(encoded)
        x = Dense(256, activation='relu')(x)
```

```
decoded = Dense(784, activation='sigmoid')(x)

# this model maps an input to its reconstruction
autoencoder = Model(input_img, decoded)

encoder = Model(input_img, encoded)

# create a placeholder for an encoded (32-dimensional) input
encoded_input = Input(shape=(encoding_dim,))
# retrieve the last layer of the autoencoder model
dcd1 = autoencoder.layers[-1]
dcd2 = autoencoder.layers[-2]
dcd3 = autoencoder.layers[-3]

# create the decoder model
decoder = Model(encoded_input, dcd1(dcd2(dcd3(encoded_input))))
```

In [7]:
```
autoencoder.compile(optimizer='adadelta', loss='binary_crossentropy')
```

In [8]:
```
autoencoder.fit(xtrain, xtrain,
                epochs=100,
                batch_size=256,
                shuffle=True,
                validation_data=(xtest, xtest))
                #callbacks=[TensorBoard(log_dir='/tmp/autoencoder')])                 )
```

```
WARNING:tensorflow:From /Users/Broth/anaconda3/lib/python3.7/site-packages/tensorflow/python/o
Instructions for updating:
Use tf.cast instead.
Train on 60000 samples, validate on 10000 samples
Epoch 1/100
60000/60000 [==============================] - 4s 61us/step - loss: 0.3692 - val_loss: 0.2648
Epoch 2/100
60000/60000 [==============================] - 3s 55us/step - loss: 0.2593 - val_loss: 0.2556
Epoch 3/100
60000/60000 [==============================] - 3s 57us/step - loss: 0.2477 - val_loss: 0.2420
Epoch 4/100
60000/60000 [==============================] - 3s 56us/step - loss: 0.2388 - val_loss: 0.2361
Epoch 5/100
60000/60000 [==============================] - 3s 56us/step - loss: 0.2349 - val_loss: 0.2329
Epoch 6/100
60000/60000 [==============================] - 3s 55us/step - loss: 0.2324 - val_loss: 0.2307
Epoch 7/100
60000/60000 [==============================] - 3s 53us/step - loss: 0.2307 - val_loss: 0.2293
Epoch 8/100
60000/60000 [==============================] - 3s 53us/step - loss: 0.2293 - val_loss: 0.2278
Epoch 9/100
60000/60000 [==============================] - 3s 53us/step - loss: 0.2281 - val_loss: 0.2270
```

```
Epoch 10/100
60000/60000 [==============================] - 3s 54us/step - loss: 0.2270 - val_loss: 0.2263
Epoch 11/100
60000/60000 [==============================] - 3s 53us/step - loss: 0.2258 - val_loss: 0.2253
Epoch 12/100
60000/60000 [==============================] - 3s 53us/step - loss: 0.2246 - val_loss: 0.2232
Epoch 13/100
60000/60000 [==============================] - 3s 54us/step - loss: 0.2235 - val_loss: 0.2231
Epoch 14/100
60000/60000 [==============================] - 3s 54us/step - loss: 0.2224 - val_loss: 0.2210
Epoch 15/100
60000/60000 [==============================] - 3s 55us/step - loss: 0.2214 - val_loss: 0.2198
Epoch 16/100
60000/60000 [==============================] - 3s 55us/step - loss: 0.2203 - val_loss: 0.2197
Epoch 17/100
60000/60000 [==============================] - 3s 56us/step - loss: 0.2194 - val_loss: 0.2180
Epoch 18/100
60000/60000 [==============================] - 3s 57us/step - loss: 0.2187 - val_loss: 0.2178
Epoch 19/100
60000/60000 [==============================] - 3s 57us/step - loss: 0.2178 - val_loss: 0.2178
Epoch 20/100
60000/60000 [==============================] - 3s 57us/step - loss: 0.2172 - val_loss: 0.2165
Epoch 21/100
60000/60000 [==============================] - 3s 56us/step - loss: 0.2164 - val_loss: 0.2159
Epoch 22/100
60000/60000 [==============================] - 3s 57us/step - loss: 0.2159 - val_loss: 0.2150
Epoch 23/100
60000/60000 [==============================] - 3s 57us/step - loss: 0.2152 - val_loss: 0.2147
Epoch 24/100
60000/60000 [==============================] - 3s 57us/step - loss: 0.2147 - val_loss: 0.2146
Epoch 25/100
60000/60000 [==============================] - 3s 57us/step - loss: 0.2141 - val_loss: 0.2143
Epoch 26/100
60000/60000 [==============================] - 3s 58us/step - loss: 0.2135 - val_loss: 0.2137
Epoch 27/100
60000/60000 [==============================] - 3s 57us/step - loss: 0.2130 - val_loss: 0.2144
Epoch 28/100
60000/60000 [==============================] - 3s 58us/step - loss: 0.2125 - val_loss: 0.2114
Epoch 29/100
60000/60000 [==============================] - 3s 58us/step - loss: 0.2120 - val_loss: 0.2119
Epoch 30/100
60000/60000 [==============================] - 3s 57us/step - loss: 0.2116 - val_loss: 0.2115
Epoch 31/100
60000/60000 [==============================] - 3s 56us/step - loss: 0.2110 - val_loss: 0.2119
Epoch 32/100
60000/60000 [==============================] - 3s 57us/step - loss: 0.2106 - val_loss: 0.2104
Epoch 33/100
60000/60000 [==============================] - 3s 56us/step - loss: 0.2100 - val_loss: 0.2097
```

```
Epoch 34/100
60000/60000 [==============================] - 3s 56us/step - loss: 0.2096 - val_loss: 0.2093
Epoch 35/100
60000/60000 [==============================] - 3s 56us/step - loss: 0.2092 - val_loss: 0.2091
Epoch 36/100
60000/60000 [==============================] - 3s 58us/step - loss: 0.2088 - val_loss: 0.2087
Epoch 37/100
60000/60000 [==============================] - 3s 56us/step - loss: 0.2082 - val_loss: 0.2079
Epoch 38/100
60000/60000 [==============================] - 3s 56us/step - loss: 0.2078 - val_loss: 0.2079
Epoch 39/100
60000/60000 [==============================] - 3s 58us/step - loss: 0.2075 - val_loss: 0.2078
Epoch 40/100
60000/60000 [==============================] - 3s 56us/step - loss: 0.2070 - val_loss: 0.2070
Epoch 41/100
60000/60000 [==============================] - 3s 58us/step - loss: 0.2067 - val_loss: 0.2073
Epoch 42/100
60000/60000 [==============================] - 3s 57us/step - loss: 0.2062 - val_loss: 0.2062
Epoch 43/100
60000/60000 [==============================] - 3s 57us/step - loss: 0.2057 - val_loss: 0.2059
Epoch 44/100
60000/60000 [==============================] - 3s 57us/step - loss: 0.2054 - val_loss: 0.2057
Epoch 45/100
60000/60000 [==============================] - 3s 57us/step - loss: 0.2049 - val_loss: 0.2064
Epoch 46/100
60000/60000 [==============================] - 3s 56us/step - loss: 0.2045 - val_loss: 0.2047
Epoch 47/100
60000/60000 [==============================] - 3s 56us/step - loss: 0.2042 - val_loss: 0.2044
Epoch 48/100
60000/60000 [==============================] - 3s 57us/step - loss: 0.2037 - val_loss: 0.2052
Epoch 49/100
60000/60000 [==============================] - 3s 57us/step - loss: 0.2034 - val_loss: 0.2037
Epoch 50/100
60000/60000 [==============================] - 3s 57us/step - loss: 0.2030 - val_loss: 0.2034
Epoch 51/100
60000/60000 [==============================] - 3s 57us/step - loss: 0.2025 - val_loss: 0.2028
Epoch 52/100
60000/60000 [==============================] - 3s 58us/step - loss: 0.2022 - val_loss: 0.2031
Epoch 53/100
60000/60000 [==============================] - 3s 57us/step - loss: 0.2020 - val_loss: 0.2024
Epoch 54/100
60000/60000 [==============================] - 3s 57us/step - loss: 0.2015 - val_loss: 0.2022
Epoch 55/100
60000/60000 [==============================] - 3s 57us/step - loss: 0.2012 - val_loss: 0.2014
Epoch 56/100
60000/60000 [==============================] - 3s 57us/step - loss: 0.2008 - val_loss: 0.2016
Epoch 57/100
60000/60000 [==============================] - 3s 57us/step - loss: 0.2005 - val_loss: 0.2009
```

```
Epoch 58/100
60000/60000 [==============================] - 3s 57us/step - loss: 0.2001 - val_loss: 0.2003
Epoch 59/100
60000/60000 [==============================] - 3s 57us/step - loss: 0.1997 - val_loss: 0.1999
Epoch 60/100
60000/60000 [==============================] - 3s 58us/step - loss: 0.1994 - val_loss: 0.2000
Epoch 61/100
60000/60000 [==============================] - 3s 57us/step - loss: 0.1991 - val_loss: 0.1995
Epoch 62/100
60000/60000 [==============================] - 3s 57us/step - loss: 0.1988 - val_loss: 0.1987
Epoch 63/100
60000/60000 [==============================] - 3s 57us/step - loss: 0.1985 - val_loss: 0.1983
Epoch 64/100
60000/60000 [==============================] - 3s 57us/step - loss: 0.1981 - val_loss: 0.1987
Epoch 65/100
60000/60000 [==============================] - 3s 58us/step - loss: 0.1978 - val_loss: 0.1979
Epoch 66/100
60000/60000 [==============================] - 3s 57us/step - loss: 0.1975 - val_loss: 0.1975
Epoch 67/100
60000/60000 [==============================] - 3s 57us/step - loss: 0.1972 - val_loss: 0.1971
Epoch 68/100
60000/60000 [==============================] - 3s 58us/step - loss: 0.1968 - val_loss: 0.1979
Epoch 69/100
60000/60000 [==============================] - 3s 58us/step - loss: 0.1967 - val_loss: 0.1971
Epoch 70/100
60000/60000 [==============================] - 3s 57us/step - loss: 0.1963 - val_loss: 0.1977
Epoch 71/100
60000/60000 [==============================] - 4s 59us/step - loss: 0.1959 - val_loss: 0.1956
Epoch 72/100
60000/60000 [==============================] - 3s 57us/step - loss: 0.1957 - val_loss: 0.1963
Epoch 73/100
60000/60000 [==============================] - 3s 58us/step - loss: 0.1955 - val_loss: 0.1960
Epoch 74/100
60000/60000 [==============================] - 3s 58us/step - loss: 0.1951 - val_loss: 0.1953
Epoch 75/100
60000/60000 [==============================] - 3s 58us/step - loss: 0.1950 - val_loss: 0.1951
Epoch 76/100
60000/60000 [==============================] - 3s 58us/step - loss: 0.1947 - val_loss: 0.1948
Epoch 77/100
60000/60000 [==============================] - 3s 58us/step - loss: 0.1944 - val_loss: 0.1960
Epoch 78/100
60000/60000 [==============================] - 3s 58us/step - loss: 0.1940 - val_loss: 0.1944
Epoch 79/100
60000/60000 [==============================] - 3s 57us/step - loss: 0.1938 - val_loss: 0.1932
Epoch 80/100
60000/60000 [==============================] - 4s 59us/step - loss: 0.1934 - val_loss: 0.1939
Epoch 81/100
60000/60000 [==============================] - 3s 58us/step - loss: 0.1929 - val_loss: 0.1937
```

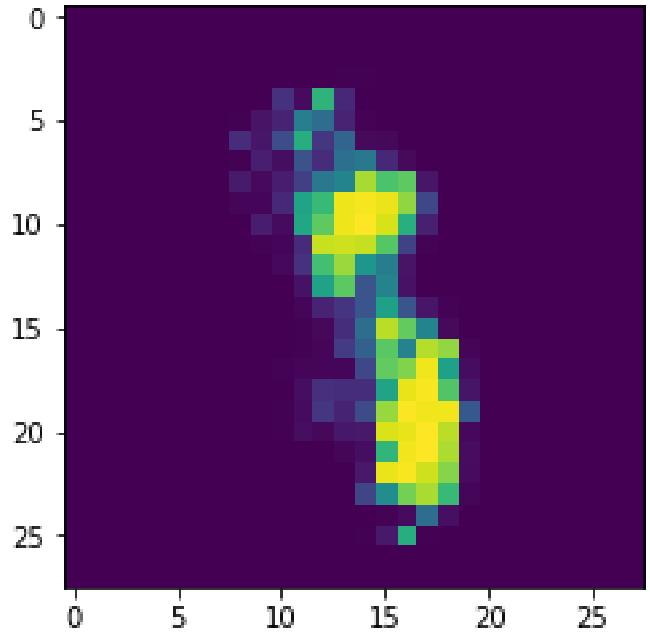
```
Epoch 82/100
60000/60000 [==============================] - 3s 58us/step - loss: 0.1920 - val_loss: 0.1929
Epoch 83/100
60000/60000 [==============================] - 4s 59us/step - loss: 0.1909 - val_loss: 0.1906
Epoch 84/100
60000/60000 [==============================] - 3s 58us/step - loss: 0.1898 - val_loss: 0.1909
Epoch 85/100
60000/60000 [==============================] - 3s 58us/step - loss: 0.1887 - val_loss: 0.1876
Epoch 86/100
60000/60000 [==============================] - 4s 59us/step - loss: 0.1870 - val_loss: 0.1860
Epoch 87/100
60000/60000 [==============================] - 3s 58us/step - loss: 0.1858 - val_loss: 0.1855
Epoch 88/100
60000/60000 [==============================] - 4s 58us/step - loss: 0.1843 - val_loss: 0.1848
Epoch 89/100
60000/60000 [==============================] - 4s 59us/step - loss: 0.1833 - val_loss: 0.1831
Epoch 90/100
60000/60000 [==============================] - 3s 58us/step - loss: 0.1822 - val_loss: 0.1820
Epoch 91/100
60000/60000 [==============================] - 4s 62us/step - loss: 0.1813 - val_loss: 0.1819
Epoch 92/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1809 - val_loss: 0.1833
Epoch 93/100
60000/60000 [==============================] - 4s 63us/step - loss: 0.1799 - val_loss: 0.1833
Epoch 94/100
60000/60000 [==============================] - 4s 60us/step - loss: 0.1793 - val_loss: 0.1798
Epoch 95/100
60000/60000 [==============================] - 4s 60us/step - loss: 0.1788 - val_loss: 0.1792
Epoch 96/100
60000/60000 [==============================] - 4s 60us/step - loss: 0.1781 - val_loss: 0.1786
Epoch 97/100
60000/60000 [==============================] - 4s 61us/step - loss: 0.1771 - val_loss: 0.1771
Epoch 98/100
60000/60000 [==============================] - 4s 60us/step - loss: 0.1762 - val_loss: 0.1755
Epoch 99/100
60000/60000 [==============================] - 4s 60us/step - loss: 0.1752 - val_loss: 0.1748
Epoch 100/100
60000/60000 [==============================] - 4s 60us/step - loss: 0.1744 - val_loss: 0.1742
```

Out[8]: <keras.callbacks.callbacks.History at 0xb37a3dfd0>

In [10]:
```
noise = np.random.normal(20,4, (4,4))
noise_preds = decoder.predict(noise)
```

In [14]:
```
plt.imshow(noise_preds[1].reshape(28,28))
```

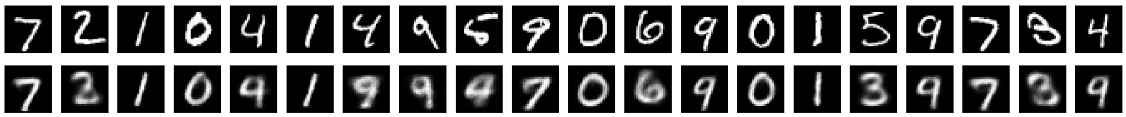
Out[14]: <matplotlib.image.AxesImage at 0xb26d6f6d8>



In [16]:
```
encoded_imgs = encoder.predict(xtest)

np.max(encoded_imgs)
```

Out[16]: 50.756348

In [17]:
```
encoded_imgs = encoder.predict(xtest)
decoded_imgs = decoder.predict(encoded_imgs)
import matplotlib.pyplot as plt

n = 20  # how many digits we will display
plt.figure(figsize=(40, 4))
for i in range(n):
    # display original
    ax = plt.subplot(2, n, i + 1)
    plt.imshow(xtest[i].reshape(28, 28))
    plt.gray()
    ax.get_xaxis().set_visible(False)
    ax.get_yaxis().set_visible(False)

    # display reconstruction
    ax = plt.subplot(2, n, i + 1 + n)
    plt.imshow(decoded_imgs[i].reshape(28, 28))
    plt.gray()
    ax.get_xaxis().set_visible(False)
    ax.get_yaxis().set_visible(False)
plt.show()
```

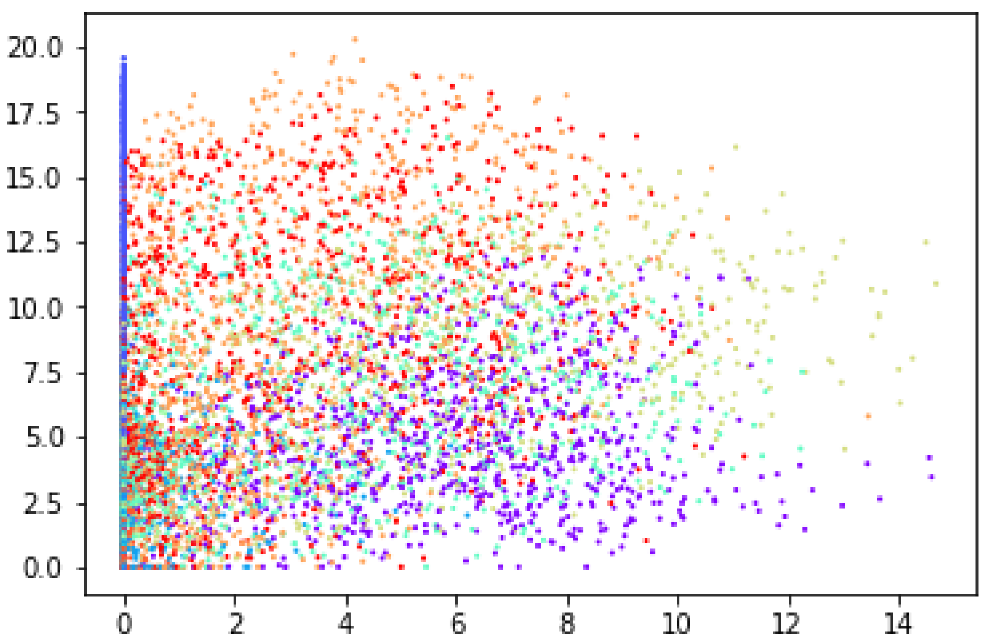


In [18]:
```
encoded_imgs
```

Out[18]:
```
array([[10.915931 ,  2.977148 , 27.044727 , 28.091213 ],
       [ 4.960381 ,  0.       ,  4.912587 ,  3.227916 ],
       [12.855605 ,  0.       , 45.800533 , 19.69311  ],
       ...,
       [ 4.016479 ,  0.       , 14.599002 , 12.466936 ],
       [ 3.1431332,  0.       , 13.0110035,  1.9472578],
       [ 3.577699 ,  6.4040346,  5.6094666, 13.719032 ]], dtype=float32)
```

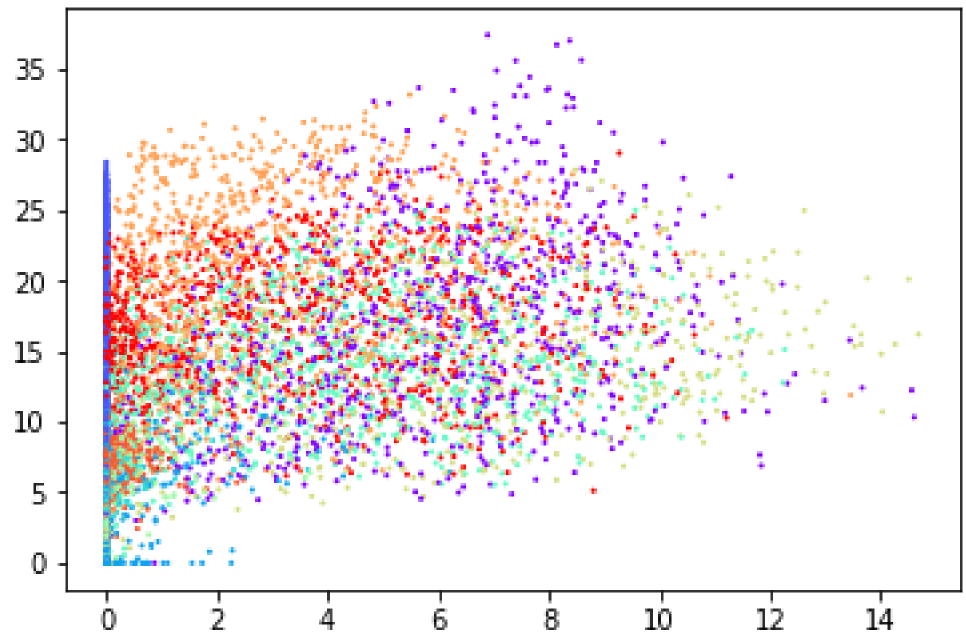
In [19]:
```
plt.scatter(encoded_imgs[:,1], encoded_imgs[:,0], s=1, c=ytest, cmap='rainbow')
# plt.show()
```

Out[19]:
```
<matplotlib.collections.PathCollection at 0xb282f84a8>
```



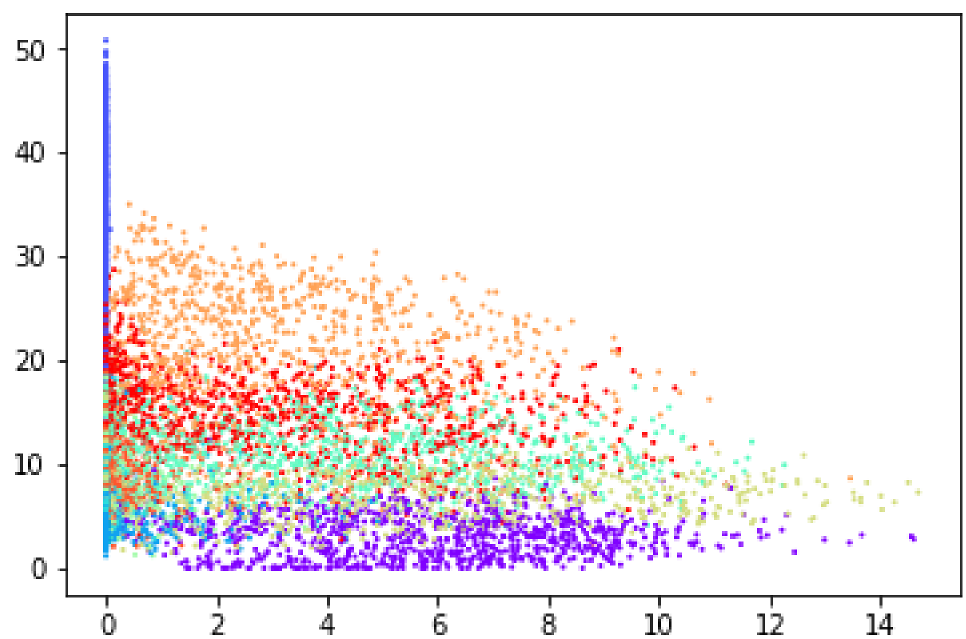
In [20]:
```
plt.scatter(encoded_imgs[:,1], encoded_imgs[:,3], s=1, c=ytest, cmap='rainbow')
# plt.show()
```

Out[20]:
```
<matplotlib.collections.PathCollection at 0xb28623128>
```



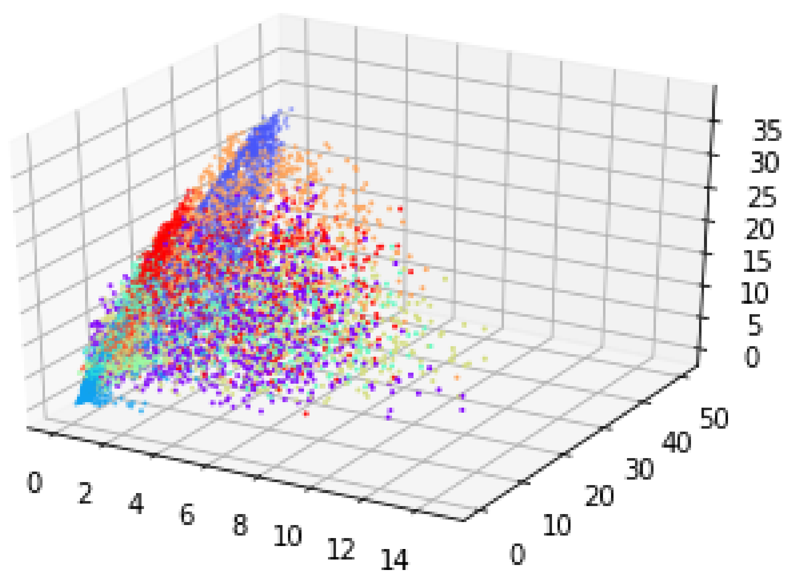

```
In [21]: plt.scatter(encoded_imgs[:,1], encoded_imgs[:,2], s=1, c=ytest, cmap='rainbow')
         # plt.show()
```

Out[21]: <matplotlib.collections.PathCollection at 0xb286d1f98>



In [22]:
```
from mpl_toolkits.mplot3d import Axes3D
fig = plt.figure()
ax = fig.add_subplot(111, projection='3d')
ax.scatter(encoded_imgs[:,1], encoded_imgs[:,2], encoded_imgs[:,3], c=ytest, cmap='ra
```

Out[22]: <mpl_toolkits.mplot3d.art3d.Path3DCollection at 0xb289a6e10>



In [ ]:

1 Assignment

1.0.1 1. Change the `encoding_dim` through various values (`range(2,18,2)` and store or keep track of the best loss you can get. Plot the 8 pairs of dimensions vs loss on a scatter plot

In [50]:
```
dims = list(range(2,18,2))

losses = []
for dim in dims:
    encoding_dim = dim  # 32 floats -> compression of factor 24.5, assuming the input

    # this is our input placeholder
    x = input_img = Input(shape=(784,))
    # "encoded" is the encoded representation of the input
    x = Dense(256, activation='relu')(x)
    x = Dense(128, activation='relu')(x)
    encoded = Dense(encoding_dim, activation='relu')(x)
```

```python
            # "decoded" is the lossy reconstruction of the input
            x = Dense(128, activation='relu')(encoded)
            x = Dense(256, activation='relu')(x)
            decoded = Dense(784, activation='sigmoid')(x)

            # this model maps an input to its reconstruction
            autoencoder = Model(input_img, decoded)

            encoder = Model(input_img, encoded)

            # create a placeholder for an encoded (32-dimensional) input
            encoded_input = Input(shape=(encoding_dim,))
            # retrieve the last layer of the autoencoder model
            dcd1 = autoencoder.layers[-1]
            dcd2 = autoencoder.layers[-2]
            dcd3 = autoencoder.layers[-3]

            # create the decoder model
            decoder = Model(encoded_input, dcd1(dcd2(dcd3(encoded_input))))

            autoencoder.compile(optimizer='adadelta', loss='binary_crossentropy')

            history = autoencoder.fit(xtrain, xtrain,
                        epochs=100,
                        batch_size=256,
                        shuffle=True,
                        validation_data=(xtest, xtest))
                        #callbacks=[TensorBoard(log_dir='/tmp/autoencoder')])


            losses.append(history.history['val_loss'][-1])
```

```
Train on 60000 samples, validate on 10000 samples
Epoch 1/100
60000/60000 [==============================] - 5s 84us/step - loss: 0.3540 - val_loss: 0.2644
Epoch 2/100
60000/60000 [==============================] - 4s 59us/step - loss: 0.2595 - val_loss: 0.2560
Epoch 3/100
60000/60000 [==============================] - 4s 60us/step - loss: 0.2537 - val_loss: 0.2530
Epoch 4/100
60000/60000 [==============================] - 4s 59us/step - loss: 0.2517 - val_loss: 0.2517
Epoch 5/100
60000/60000 [==============================] - 4s 63us/step - loss: 0.2508 - val_loss: 0.2511
Epoch 6/100
60000/60000 [==============================] - 4s 60us/step - loss: 0.2502 - val_loss: 0.2512
Epoch 7/100
60000/60000 [==============================] - 4s 61us/step - loss: 0.2497 - val_loss: 0.2499
```

```
Epoch 8/100
60000/60000 [==============================] - 4s 61us/step - loss: 0.2491 - val_loss: 0.2493
Epoch 9/100
60000/60000 [==============================] - 4s 62us/step - loss: 0.2484 - val_loss: 0.2490
Epoch 10/100
60000/60000 [==============================] - 4s 62us/step - loss: 0.2477 - val_loss: 0.2475
Epoch 11/100
60000/60000 [==============================] - 4s 63us/step - loss: 0.2466 - val_loss: 0.2466
Epoch 12/100
60000/60000 [==============================] - 4s 63us/step - loss: 0.2455 - val_loss: 0.2453
Epoch 13/100
60000/60000 [==============================] - 4s 63us/step - loss: 0.2446 - val_loss: 0.2443
Epoch 14/100
60000/60000 [==============================] - 4s 69us/step - loss: 0.2437 - val_loss: 0.2433
Epoch 15/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.2431 - val_loss: 0.2430
Epoch 16/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.2425 - val_loss: 0.2427
Epoch 17/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.2418 - val_loss: 0.2427
Epoch 18/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.2397 - val_loss: 0.2388
Epoch 19/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.2360 - val_loss: 0.2332
Epoch 20/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.2318 - val_loss: 0.2292
Epoch 21/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.2286 - val_loss: 0.2259
Epoch 22/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.2264 - val_loss: 0.2258
Epoch 23/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.2250 - val_loss: 0.2231
Epoch 24/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.2237 - val_loss: 0.2218
Epoch 25/100
60000/60000 [==============================] - 4s 69us/step - loss: 0.2222 - val_loss: 0.2208
Epoch 26/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.2212 - val_loss: 0.2202
Epoch 27/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.2201 - val_loss: 0.2187
Epoch 28/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.2191 - val_loss: 0.2176
Epoch 29/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.2179 - val_loss: 0.2169
Epoch 30/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.2170 - val_loss: 0.2162
Epoch 31/100
60000/60000 [==============================] - 4s 69us/step - loss: 0.2160 - val_loss: 0.2152
```

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Epoch 32/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.2149 - val_loss: 0.2143
Epoch 33/100
60000/60000 [==============================] - 4s 69us/step - loss: 0.2140 - val_loss: 0.2137
Epoch 34/100
60000/60000 [==============================] - 4s 71us/step - loss: 0.2130 - val_loss: 0.2127
Epoch 35/100
60000/60000 [==============================] - 4s 71us/step - loss: 0.2122 - val_loss: 0.2113
Epoch 36/100
60000/60000 [==============================] - 4s 69us/step - loss: 0.2113 - val_loss: 0.2112
Epoch 37/100
60000/60000 [==============================] - 4s 69us/step - loss: 0.2107 - val_loss: 0.2110
Epoch 38/100
60000/60000 [==============================] - 4s 69us/step - loss: 0.2101 - val_loss: 0.2102
Epoch 39/100
60000/60000 [==============================] - 4s 70us/step - loss: 0.2094 - val_loss: 0.2094
Epoch 40/100
60000/60000 [==============================] - 4s 69us/step - loss: 0.2088 - val_loss: 0.2086
Epoch 41/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.2083 - val_loss: 0.2077
Epoch 42/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.2077 - val_loss: 0.2078
Epoch 43/100
60000/60000 [==============================] - 4s 74us/step - loss: 0.2072 - val_loss: 0.2070
Epoch 44/100
60000/60000 [==============================] - 4s 70us/step - loss: 0.2067 - val_loss: 0.2067
Epoch 45/100
60000/60000 [==============================] - 4s 70us/step - loss: 0.2062 - val_loss: 0.2060
Epoch 46/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.2057 - val_loss: 0.2053
Epoch 47/100
60000/60000 [==============================] - 4s 69us/step - loss: 0.2052 - val_loss: 0.2052
Epoch 48/100
60000/60000 [==============================] - 4s 71us/step - loss: 0.2048 - val_loss: 0.2060
Epoch 49/100
60000/60000 [==============================] - 4s 69us/step - loss: 0.2043 - val_loss: 0.2046
Epoch 50/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.2039 - val_loss: 0.2042
Epoch 51/100
60000/60000 [==============================] - 4s 69us/step - loss: 0.2034 - val_loss: 0.2035
Epoch 52/100
60000/60000 [==============================] - 4s 69us/step - loss: 0.2030 - val_loss: 0.2038
Epoch 53/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.2027 - val_loss: 0.2027
Epoch 54/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.2023 - val_loss: 0.2024
Epoch 55/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.2018 - val_loss: 0.2019
```

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Epoch 56/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.2015 - val_loss: 0.2020
Epoch 57/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.2011 - val_loss: 0.2015
Epoch 58/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.2007 - val_loss: 0.2008
Epoch 59/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.2004 - val_loss: 0.2012
Epoch 60/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.2001 - val_loss: 0.2003
Epoch 61/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1998 - val_loss: 0.2004
Epoch 62/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1994 - val_loss: 0.2006
Epoch 63/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.1991 - val_loss: 0.2002
Epoch 64/100
60000/60000 [==============================] - 4s 69us/step - loss: 0.1988 - val_loss: 0.1990
Epoch 65/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1985 - val_loss: 0.1993
Epoch 66/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1983 - val_loss: 0.1991
Epoch 67/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.1979 - val_loss: 0.1984
Epoch 68/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.1977 - val_loss: 0.1975
Epoch 69/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1973 - val_loss: 0.1976
Epoch 70/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1971 - val_loss: 0.1976
Epoch 71/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1967 - val_loss: 0.1984
Epoch 72/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.1964 - val_loss: 0.1968
Epoch 73/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1962 - val_loss: 0.1974
Epoch 74/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1959 - val_loss: 0.1962
Epoch 75/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1957 - val_loss: 0.1964
Epoch 76/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1953 - val_loss: 0.1964
Epoch 77/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1950 - val_loss: 0.1954
Epoch 78/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1949 - val_loss: 0.1954
Epoch 79/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1947 - val_loss: 0.1951
```

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Epoch 80/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1943 - val_loss: 0.1949
Epoch 81/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1940 - val_loss: 0.1945
Epoch 82/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1937 - val_loss: 0.1938
Epoch 83/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1936 - val_loss: 0.1948
Epoch 84/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1933 - val_loss: 0.1941
Epoch 85/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1931 - val_loss: 0.1936
Epoch 86/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1928 - val_loss: 0.1937
Epoch 87/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1927 - val_loss: 0.1932
Epoch 88/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1923 - val_loss: 0.1937
Epoch 89/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1922 - val_loss: 0.1925
Epoch 90/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1920 - val_loss: 0.1942
Epoch 91/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1917 - val_loss: 0.1938
Epoch 92/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1915 - val_loss: 0.1932
Epoch 93/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1914 - val_loss: 0.1923
Epoch 94/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1910 - val_loss: 0.1923
Epoch 95/100
60000/60000 [==============================] - 4s 64us/step - loss: 0.1910 - val_loss: 0.1922
Epoch 96/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1906 - val_loss: 0.1914
Epoch 97/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1904 - val_loss: 0.1915
Epoch 98/100
60000/60000 [==============================] - 4s 64us/step - loss: 0.1903 - val_loss: 0.1914
Epoch 99/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1900 - val_loss: 0.1909
Epoch 100/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1899 - val_loss: 0.1913
Train on 60000 samples, validate on 10000 samples
Epoch 1/100
60000/60000 [==============================] - 5s 82us/step - loss: 0.3710 - val_loss: 0.2644
Epoch 2/100
60000/60000 [==============================] - 4s 61us/step - loss: 0.2594 - val_loss: 0.2570
Epoch 3/100
```

```
60000/60000 [==============================] - 4s 67us/step - loss: 0.2534 - val_loss: 0.2525
Epoch 4/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.2484 - val_loss: 0.2441
Epoch 5/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.2406 - val_loss: 0.2383
Epoch 6/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.2370 - val_loss: 0.2364
Epoch 7/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.2347 - val_loss: 0.2330
Epoch 8/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.2275 - val_loss: 0.2218
Epoch 9/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.2203 - val_loss: 0.2176
Epoch 10/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.2174 - val_loss: 0.2151
Epoch 11/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.2152 - val_loss: 0.2131
Epoch 12/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.2130 - val_loss: 0.2111
Epoch 13/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.2107 - val_loss: 0.2093
Epoch 14/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.2088 - val_loss: 0.2073
Epoch 15/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.2070 - val_loss: 0.2062
Epoch 16/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.2053 - val_loss: 0.2040
Epoch 17/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.2039 - val_loss: 0.2031
Epoch 18/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.2024 - val_loss: 0.2012
Epoch 19/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.2012 - val_loss: 0.2019
Epoch 20/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.2000 - val_loss: 0.2005
Epoch 21/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1989 - val_loss: 0.1972
Epoch 22/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1977 - val_loss: 0.1966
Epoch 23/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1966 - val_loss: 0.1964
Epoch 24/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1957 - val_loss: 0.1950
Epoch 25/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1948 - val_loss: 0.1954
Epoch 26/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1940 - val_loss: 0.1937
Epoch 27/100
```

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60000/60000 [==============================] - 4s 66us/step - loss: 0.1930 - val_loss: 0.1924
Epoch 28/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1921 - val_loss: 0.1919
Epoch 29/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1913 - val_loss: 0.1924
Epoch 30/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1905 - val_loss: 0.1917
Epoch 31/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1898 - val_loss: 0.1889
Epoch 32/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1891 - val_loss: 0.1879
Epoch 33/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1882 - val_loss: 0.1871
Epoch 34/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1877 - val_loss: 0.1869
Epoch 35/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1867 - val_loss: 0.1871
Epoch 36/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1863 - val_loss: 0.1862
Epoch 37/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1856 - val_loss: 0.1862
Epoch 38/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1850 - val_loss: 0.1857
Epoch 39/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1844 - val_loss: 0.1842
Epoch 40/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1837 - val_loss: 0.1843
Epoch 41/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1831 - val_loss: 0.1842
Epoch 42/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1825 - val_loss: 0.1825
Epoch 43/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1817 - val_loss: 0.1805
Epoch 44/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1803 - val_loss: 0.1792
Epoch 45/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1781 - val_loss: 0.1766
Epoch 46/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1761 - val_loss: 0.1752
Epoch 47/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1748 - val_loss: 0.1768
Epoch 48/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1739 - val_loss: 0.1727
Epoch 49/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1730 - val_loss: 0.1732
Epoch 50/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1719 - val_loss: 0.1714
Epoch 51/100
```

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60000/60000 [==============================] - 4s 65us/step - loss: 0.1712 - val_loss: 0.1705
Epoch 52/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1704 - val_loss: 0.1701
Epoch 53/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1697 - val_loss: 0.1692
Epoch 54/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1689 - val_loss: 0.1694
Epoch 55/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1685 - val_loss: 0.1674
Epoch 56/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1678 - val_loss: 0.1673
Epoch 57/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1674 - val_loss: 0.1674
Epoch 58/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1666 - val_loss: 0.1667
Epoch 59/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1663 - val_loss: 0.1665
Epoch 60/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1657 - val_loss: 0.1662
Epoch 61/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1651 - val_loss: 0.1661
Epoch 62/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1648 - val_loss: 0.1649
Epoch 63/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1641 - val_loss: 0.1637
Epoch 64/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1639 - val_loss: 0.1636
Epoch 65/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1632 - val_loss: 0.1633
Epoch 66/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1631 - val_loss: 0.1621
Epoch 67/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1625 - val_loss: 0.1634
Epoch 68/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1622 - val_loss: 0.1625
Epoch 69/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1618 - val_loss: 0.1611
Epoch 70/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1614 - val_loss: 0.1609
Epoch 71/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1610 - val_loss: 0.1605
Epoch 72/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1608 - val_loss: 0.1608
Epoch 73/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1604 - val_loss: 0.1612
Epoch 74/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1601 - val_loss: 0.1615
Epoch 75/100
```

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60000/60000 [==============================] - 4s 65us/step - loss: 0.1597 - val_loss: 0.1590
Epoch 76/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1595 - val_loss: 0.1601
Epoch 77/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1592 - val_loss: 0.1597
Epoch 78/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1590 - val_loss: 0.1589
Epoch 79/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1588 - val_loss: 0.1592
Epoch 80/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1584 - val_loss: 0.1600
Epoch 81/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1582 - val_loss: 0.1597
Epoch 82/100
60000/60000 [==============================] - 4s 64us/step - loss: 0.1580 - val_loss: 0.1600
Epoch 83/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1578 - val_loss: 0.1584
Epoch 84/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1575 - val_loss: 0.1574
Epoch 85/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1574 - val_loss: 0.1579
Epoch 86/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1570 - val_loss: 0.1572
Epoch 87/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1569 - val_loss: 0.1573
Epoch 88/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1567 - val_loss: 0.1567
Epoch 89/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1565 - val_loss: 0.1572
Epoch 90/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1562 - val_loss: 0.1565
Epoch 91/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1561 - val_loss: 0.1568
Epoch 92/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1559 - val_loss: 0.1560
Epoch 93/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1558 - val_loss: 0.1566
Epoch 94/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.1556 - val_loss: 0.1557
Epoch 95/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1553 - val_loss: 0.1560
Epoch 96/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1553 - val_loss: 0.1570
Epoch 97/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1552 - val_loss: 0.1564
Epoch 98/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1549 - val_loss: 0.1552
Epoch 99/100
```

```
60000/60000 [==============================] - 4s 67us/step - loss: 0.1548 - val_loss: 0.1559
Epoch 100/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1546 - val_loss: 0.1547
Train on 60000 samples, validate on 10000 samples
Epoch 1/100
60000/60000 [==============================] - 5s 83us/step - loss: 0.3554 - val_loss: 0.2644
Epoch 2/100
60000/60000 [==============================] - 4s 61us/step - loss: 0.2581 - val_loss: 0.2531
Epoch 3/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.2443 - val_loss: 0.2363
Epoch 4/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.2297 - val_loss: 0.2244
Epoch 5/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.2236 - val_loss: 0.2204
Epoch 6/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.2172 - val_loss: 0.2093
Epoch 7/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.2074 - val_loss: 0.2041
Epoch 8/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.2019 - val_loss: 0.1976
Epoch 9/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1962 - val_loss: 0.1922
Epoch 10/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1900 - val_loss: 0.1867
Epoch 11/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1851 - val_loss: 0.1833
Epoch 12/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1818 - val_loss: 0.1799
Epoch 13/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1792 - val_loss: 0.1768
Epoch 14/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1773 - val_loss: 0.1762
Epoch 15/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1754 - val_loss: 0.1746
Epoch 16/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1738 - val_loss: 0.1719
Epoch 17/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1722 - val_loss: 0.1715
Epoch 18/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1710 - val_loss: 0.1707
Epoch 19/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1697 - val_loss: 0.1685
Epoch 20/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1684 - val_loss: 0.1680
Epoch 21/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1674 - val_loss: 0.1674
Epoch 22/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1665 - val_loss: 0.1658
```

```
Epoch 23/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1654 - val_loss: 0.1648
Epoch 24/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1645 - val_loss: 0.1637
Epoch 25/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1639 - val_loss: 0.1638
Epoch 26/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1630 - val_loss: 0.1631
Epoch 27/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1622 - val_loss: 0.1629
Epoch 28/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1615 - val_loss: 0.1606
Epoch 29/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1611 - val_loss: 0.1611
Epoch 30/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1603 - val_loss: 0.1605
Epoch 31/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1597 - val_loss: 0.1585
Epoch 32/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1591 - val_loss: 0.1589
Epoch 33/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1585 - val_loss: 0.1582
Epoch 34/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1579 - val_loss: 0.1579
Epoch 35/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1576 - val_loss: 0.1574
Epoch 36/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1569 - val_loss: 0.1568
Epoch 37/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1565 - val_loss: 0.1559
Epoch 38/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1559 - val_loss: 0.1549
Epoch 39/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1555 - val_loss: 0.1552
Epoch 40/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1552 - val_loss: 0.1569
Epoch 41/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1547 - val_loss: 0.1558
Epoch 42/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1543 - val_loss: 0.1541
Epoch 43/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1539 - val_loss: 0.1536
Epoch 44/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1536 - val_loss: 0.1542
Epoch 45/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1533 - val_loss: 0.1541
Epoch 46/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1530 - val_loss: 0.1527
```

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Epoch 47/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1526 - val_loss: 0.1535
Epoch 48/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1523 - val_loss: 0.1525
Epoch 49/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1519 - val_loss: 0.1518
Epoch 50/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1516 - val_loss: 0.1520
Epoch 51/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1513 - val_loss: 0.1515
Epoch 52/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1510 - val_loss: 0.1517
Epoch 53/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1508 - val_loss: 0.1507
Epoch 54/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1505 - val_loss: 0.1505
Epoch 55/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1502 - val_loss: 0.1501
Epoch 56/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1498 - val_loss: 0.1500
Epoch 57/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1497 - val_loss: 0.1498
Epoch 58/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1494 - val_loss: 0.1492
Epoch 59/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1493 - val_loss: 0.1497
Epoch 60/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1489 - val_loss: 0.1510
Epoch 61/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1487 - val_loss: 0.1482
Epoch 62/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1485 - val_loss: 0.1481
Epoch 63/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1480 - val_loss: 0.1479
Epoch 64/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1477 - val_loss: 0.1479
Epoch 65/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1474 - val_loss: 0.1468
Epoch 66/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1469 - val_loss: 0.1472
Epoch 67/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1463 - val_loss: 0.1461
Epoch 68/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1459 - val_loss: 0.1461
Epoch 69/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1455 - val_loss: 0.1457
Epoch 70/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1450 - val_loss: 0.1452
```

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Epoch 71/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1446 - val_loss: 0.1452
Epoch 72/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1441 - val_loss: 0.1452
Epoch 73/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1438 - val_loss: 0.1431
Epoch 74/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1434 - val_loss: 0.1437
Epoch 75/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1430 - val_loss: 0.1427
Epoch 76/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1426 - val_loss: 0.1435
Epoch 77/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1422 - val_loss: 0.1413
Epoch 78/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1419 - val_loss: 0.1428
Epoch 79/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1415 - val_loss: 0.1404
Epoch 80/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1413 - val_loss: 0.1408
Epoch 81/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1409 - val_loss: 0.1404
Epoch 82/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1407 - val_loss: 0.1406
Epoch 83/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1403 - val_loss: 0.1408
Epoch 84/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1401 - val_loss: 0.1401
Epoch 85/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1398 - val_loss: 0.1402
Epoch 86/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1395 - val_loss: 0.1404
Epoch 87/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1392 - val_loss: 0.1392
Epoch 88/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1390 - val_loss: 0.1389
Epoch 89/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1388 - val_loss: 0.1396
Epoch 90/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1387 - val_loss: 0.1387
Epoch 91/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1384 - val_loss: 0.1383
Epoch 92/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1383 - val_loss: 0.1374
Epoch 93/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1379 - val_loss: 0.1388
Epoch 94/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1378 - val_loss: 0.1375
```

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Epoch 95/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1376 - val_loss: 0.1382
Epoch 96/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1374 - val_loss: 0.1380
Epoch 97/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1373 - val_loss: 0.1365
Epoch 98/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1372 - val_loss: 0.1365
Epoch 99/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1370 - val_loss: 0.1370
Epoch 100/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1367 - val_loss: 0.1389
Train on 60000 samples, validate on 10000 samples
Epoch 1/100
60000/60000 [==============================] - 5s 85us/step - loss: 0.3528 - val_loss: 0.2647
Epoch 2/100
60000/60000 [==============================] - 4s 62us/step - loss: 0.2584 - val_loss: 0.2545
Epoch 3/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.2473 - val_loss: 0.2410
Epoch 4/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.2383 - val_loss: 0.2350
Epoch 5/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.2299 - val_loss: 0.2254
Epoch 6/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.2209 - val_loss: 0.2134
Epoch 7/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.2089 - val_loss: 0.2026
Epoch 8/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1996 - val_loss: 0.1945
Epoch 9/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1922 - val_loss: 0.1896
Epoch 10/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1873 - val_loss: 0.1853
Epoch 11/100
60000/60000 [==============================] - 4s 64us/step - loss: 0.1833 - val_loss: 0.1809
Epoch 12/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1800 - val_loss: 0.1777
Epoch 13/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1773 - val_loss: 0.1755
Epoch 14/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1749 - val_loss: 0.1726
Epoch 15/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1726 - val_loss: 0.1717
Epoch 16/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1703 - val_loss: 0.1677
Epoch 17/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1677 - val_loss: 0.1664
Epoch 18/100
```

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60000/60000 [==============================] - 4s 67us/step - loss: 0.1657 - val_loss: 0.1642
Epoch 19/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1638 - val_loss: 0.1629
Epoch 20/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1626 - val_loss: 0.1631
Epoch 21/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1611 - val_loss: 0.1605
Epoch 22/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1599 - val_loss: 0.1580
Epoch 23/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1585 - val_loss: 0.1568
Epoch 24/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1566 - val_loss: 0.1553
Epoch 25/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1549 - val_loss: 0.1515
Epoch 26/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1529 - val_loss: 0.1520
Epoch 27/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1511 - val_loss: 0.1503
Epoch 28/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1500 - val_loss: 0.1488
Epoch 29/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1488 - val_loss: 0.1469
Epoch 30/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1479 - val_loss: 0.1460
Epoch 31/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1470 - val_loss: 0.1462
Epoch 32/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1461 - val_loss: 0.1440
Epoch 33/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1454 - val_loss: 0.1443
Epoch 34/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1446 - val_loss: 0.1426
Epoch 35/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1439 - val_loss: 0.1430
Epoch 36/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1433 - val_loss: 0.1424
Epoch 37/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1427 - val_loss: 0.1420
Epoch 38/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1422 - val_loss: 0.1410
Epoch 39/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1417 - val_loss: 0.1411
Epoch 40/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1411 - val_loss: 0.1410
Epoch 41/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1407 - val_loss: 0.1406
Epoch 42/100
```

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60000/60000 [==============================] - 4s 65us/step - loss: 0.1402 - val_loss: 0.1403
Epoch 43/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.1398 - val_loss: 0.1394
Epoch 44/100
60000/60000 [==============================] - 4s 70us/step - loss: 0.1393 - val_loss: 0.1380
Epoch 45/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1390 - val_loss: 0.1390
Epoch 46/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1385 - val_loss: 0.1392
Epoch 47/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1381 - val_loss: 0.1388
Epoch 48/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1378 - val_loss: 0.1399
Epoch 49/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1376 - val_loss: 0.1379
Epoch 50/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1373 - val_loss: 0.1361
Epoch 51/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.1368 - val_loss: 0.1371
Epoch 52/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1365 - val_loss: 0.1357
Epoch 53/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1362 - val_loss: 0.1368
Epoch 54/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1360 - val_loss: 0.1355
Epoch 55/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1356 - val_loss: 0.1353
Epoch 56/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1354 - val_loss: 0.1356
Epoch 57/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1352 - val_loss: 0.1345
Epoch 58/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1348 - val_loss: 0.1338
Epoch 59/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1345 - val_loss: 0.1339
Epoch 60/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1344 - val_loss: 0.1351
Epoch 61/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1341 - val_loss: 0.1329
Epoch 62/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1338 - val_loss: 0.1331
Epoch 63/100
60000/60000 [==============================] - 4s 64us/step - loss: 0.1335 - val_loss: 0.1337
Epoch 64/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1334 - val_loss: 0.1332
Epoch 65/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1331 - val_loss: 0.1337
Epoch 66/100
```

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60000/60000 [==============================] - 4s 65us/step - loss: 0.1329 - val_loss: 0.1331
Epoch 67/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1328 - val_loss: 0.1331
Epoch 68/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1325 - val_loss: 0.1344
Epoch 69/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1323 - val_loss: 0.1329
Epoch 70/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1320 - val_loss: 0.1327
Epoch 71/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1319 - val_loss: 0.1323
Epoch 72/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1317 - val_loss: 0.1314
Epoch 73/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1314 - val_loss: 0.1327
Epoch 74/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1313 - val_loss: 0.1314
Epoch 75/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1312 - val_loss: 0.1309
Epoch 76/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1310 - val_loss: 0.1301
Epoch 77/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1308 - val_loss: 0.1304
Epoch 78/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1306 - val_loss: 0.1310
Epoch 79/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1304 - val_loss: 0.1303
Epoch 80/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1302 - val_loss: 0.1296
Epoch 81/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1302 - val_loss: 0.1312
Epoch 82/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1300 - val_loss: 0.1302
Epoch 83/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1297 - val_loss: 0.1293
Epoch 84/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1297 - val_loss: 0.1300
Epoch 85/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1294 - val_loss: 0.1298
Epoch 86/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1293 - val_loss: 0.1288
Epoch 87/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1291 - val_loss: 0.1290
Epoch 88/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1290 - val_loss: 0.1288
Epoch 89/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1289 - val_loss: 0.1293
Epoch 90/100
```

```
60000/60000 [==============================] - 4s 66us/step - loss: 0.1287 - val_loss: 0.1291
Epoch 91/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1287 - val_loss: 0.1285
Epoch 92/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1284 - val_loss: 0.1289
Epoch 93/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1284 - val_loss: 0.1290
Epoch 94/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1283 - val_loss: 0.1283
Epoch 95/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1281 - val_loss: 0.1289
Epoch 96/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1278 - val_loss: 0.1290
Epoch 97/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1277 - val_loss: 0.1286
Epoch 98/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1277 - val_loss: 0.1281
Epoch 99/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1277 - val_loss: 0.1275
Epoch 100/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1274 - val_loss: 0.1277
Train on 60000 samples, validate on 10000 samples
Epoch 1/100
60000/60000 [==============================] - 5s 85us/step - loss: 0.3406 - val_loss: 0.2641
Epoch 2/100
60000/60000 [==============================] - 4s 61us/step - loss: 0.2588 - val_loss: 0.2541
Epoch 3/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.2466 - val_loss: 0.2398
Epoch 4/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.2356 - val_loss: 0.2307
Epoch 5/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.2252 - val_loss: 0.2153
Epoch 6/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.2062 - val_loss: 0.1955
Epoch 7/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1929 - val_loss: 0.1859
Epoch 8/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1841 - val_loss: 0.1798
Epoch 9/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1771 - val_loss: 0.1728
Epoch 10/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1720 - val_loss: 0.1674
Epoch 11/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1679 - val_loss: 0.1631
Epoch 12/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1644 - val_loss: 0.1631
Epoch 13/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1613 - val_loss: 0.1596
```

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Epoch 14/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1583 - val_loss: 0.1543
Epoch 15/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1552 - val_loss: 0.1548
Epoch 16/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1526 - val_loss: 0.1500
Epoch 17/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1499 - val_loss: 0.1478
Epoch 18/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1477 - val_loss: 0.1459
Epoch 19/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1457 - val_loss: 0.1422
Epoch 20/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1439 - val_loss: 0.1418
Epoch 21/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1422 - val_loss: 0.1394
Epoch 22/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1407 - val_loss: 0.1395
Epoch 23/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1392 - val_loss: 0.1365
Epoch 24/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1379 - val_loss: 0.1352
Epoch 25/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1369 - val_loss: 0.1351
Epoch 26/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1357 - val_loss: 0.1359
Epoch 27/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1348 - val_loss: 0.1326
Epoch 28/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1339 - val_loss: 0.1331
Epoch 29/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1331 - val_loss: 0.1316
Epoch 30/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1323 - val_loss: 0.1300
Epoch 31/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1316 - val_loss: 0.1298
Epoch 32/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1308 - val_loss: 0.1303
Epoch 33/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1303 - val_loss: 0.1291
Epoch 34/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1297 - val_loss: 0.1272
Epoch 35/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1289 - val_loss: 0.1282
Epoch 36/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1284 - val_loss: 0.1265
Epoch 37/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1279 - val_loss: 0.1280
```

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Epoch 38/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1274 - val_loss: 0.1261
Epoch 39/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1268 - val_loss: 0.1250
Epoch 40/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1264 - val_loss: 0.1247
Epoch 41/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1259 - val_loss: 0.1244
Epoch 42/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1253 - val_loss: 0.1241
Epoch 43/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1249 - val_loss: 0.1233
Epoch 44/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1246 - val_loss: 0.1227
Epoch 45/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1241 - val_loss: 0.1236
Epoch 46/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1238 - val_loss: 0.1222
Epoch 47/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1234 - val_loss: 0.1226
Epoch 48/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1230 - val_loss: 0.1219
Epoch 49/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1227 - val_loss: 0.1212
Epoch 50/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1223 - val_loss: 0.1216
Epoch 51/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1219 - val_loss: 0.1207
Epoch 52/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1216 - val_loss: 0.1202
Epoch 53/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1213 - val_loss: 0.1201
Epoch 54/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1210 - val_loss: 0.1211
Epoch 55/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1207 - val_loss: 0.1192
Epoch 56/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1203 - val_loss: 0.1195
Epoch 57/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1200 - val_loss: 0.1193
Epoch 58/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1198 - val_loss: 0.1190
Epoch 59/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1196 - val_loss: 0.1189
Epoch 60/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1193 - val_loss: 0.1179
Epoch 61/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1191 - val_loss: 0.1178
```

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Epoch 62/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1188 - val_loss: 0.1179
Epoch 63/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1185 - val_loss: 0.1192
Epoch 64/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1184 - val_loss: 0.1171
Epoch 65/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1181 - val_loss: 0.1168
Epoch 66/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1179 - val_loss: 0.1172
Epoch 67/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1176 - val_loss: 0.1180
Epoch 68/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1174 - val_loss: 0.1165
Epoch 69/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1172 - val_loss: 0.1164
Epoch 70/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1171 - val_loss: 0.1164
Epoch 71/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1168 - val_loss: 0.1155
Epoch 72/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1166 - val_loss: 0.1174
Epoch 73/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1164 - val_loss: 0.1149
Epoch 74/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1163 - val_loss: 0.1153
Epoch 75/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1161 - val_loss: 0.1160
Epoch 76/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1158 - val_loss: 0.1152
Epoch 77/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1156 - val_loss: 0.1161
Epoch 78/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1155 - val_loss: 0.1147
Epoch 79/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1155 - val_loss: 0.1147
Epoch 80/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.1151 - val_loss: 0.1147
Epoch 81/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1151 - val_loss: 0.1145
Epoch 82/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1149 - val_loss: 0.1143
Epoch 83/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1148 - val_loss: 0.1147
Epoch 84/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1145 - val_loss: 0.1150
Epoch 85/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1145 - val_loss: 0.1145
```

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Epoch 86/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1143 - val_loss: 0.1146
Epoch 87/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1141 - val_loss: 0.1149
Epoch 88/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1140 - val_loss: 0.1144
Epoch 89/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1139 - val_loss: 0.1132
Epoch 90/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1137 - val_loss: 0.1136
Epoch 91/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1137 - val_loss: 0.1142
Epoch 92/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1135 - val_loss: 0.1144
Epoch 93/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1133 - val_loss: 0.1127
Epoch 94/100
60000/60000 [==============================] - 4s 70us/step - loss: 0.1133 - val_loss: 0.1127
Epoch 95/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1131 - val_loss: 0.1149
Epoch 96/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1130 - val_loss: 0.1131
Epoch 97/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1128 - val_loss: 0.1123
Epoch 98/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1127 - val_loss: 0.1121
Epoch 99/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.1128 - val_loss: 0.1128
Epoch 100/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1125 - val_loss: 0.1122
Train on 60000 samples, validate on 10000 samples
Epoch 1/100
60000/60000 [==============================] - 5s 85us/step - loss: 0.3342 - val_loss: 0.2626
Epoch 2/100
60000/60000 [==============================] - 4s 62us/step - loss: 0.2563 - val_loss: 0.2485
Epoch 3/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.2346 - val_loss: 0.2233
Epoch 4/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.2126 - val_loss: 0.2022
Epoch 5/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1991 - val_loss: 0.1945
Epoch 6/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1901 - val_loss: 0.1859
Epoch 7/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1816 - val_loss: 0.1759
Epoch 8/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1745 - val_loss: 0.1712
Epoch 9/100
```

```
60000/60000 [==============================] - 4s 66us/step - loss: 0.1684 - val_loss: 0.1638
Epoch 10/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.1627 - val_loss: 0.1609
Epoch 11/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1584 - val_loss: 0.1541
Epoch 12/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1551 - val_loss: 0.1528
Epoch 13/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1523 - val_loss: 0.1497
Epoch 14/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1497 - val_loss: 0.1472
Epoch 15/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1471 - val_loss: 0.1461
Epoch 16/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1441 - val_loss: 0.1427
Epoch 17/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1416 - val_loss: 0.1395
Epoch 18/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1397 - val_loss: 0.1378
Epoch 19/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1379 - val_loss: 0.1353
Epoch 20/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1366 - val_loss: 0.1350
Epoch 21/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1351 - val_loss: 0.1323
Epoch 22/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1339 - val_loss: 0.1328
Epoch 23/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1328 - val_loss: 0.1305
Epoch 24/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1315 - val_loss: 0.1302
Epoch 25/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1305 - val_loss: 0.1291
Epoch 26/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1293 - val_loss: 0.1275
Epoch 27/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1283 - val_loss: 0.1279
Epoch 28/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1274 - val_loss: 0.1256
Epoch 29/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1267 - val_loss: 0.1235
Epoch 30/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1258 - val_loss: 0.1236
Epoch 31/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1251 - val_loss: 0.1247
Epoch 32/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.1244 - val_loss: 0.1237
Epoch 33/100
```

```
60000/60000 [==============================] - 4s 66us/step - loss: 0.1236 - val_loss: 0.1224
Epoch 34/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1231 - val_loss: 0.1224
Epoch 35/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1226 - val_loss: 0.1201
Epoch 36/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1219 - val_loss: 0.1210
Epoch 37/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1214 - val_loss: 0.1205
Epoch 38/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1210 - val_loss: 0.1199
Epoch 39/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1205 - val_loss: 0.1198
Epoch 40/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1200 - val_loss: 0.1203
Epoch 41/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1196 - val_loss: 0.1181
Epoch 42/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1192 - val_loss: 0.1181
Epoch 43/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1187 - val_loss: 0.1176
Epoch 44/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1184 - val_loss: 0.1171
Epoch 45/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1180 - val_loss: 0.1171
Epoch 46/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1175 - val_loss: 0.1167
Epoch 47/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.1172 - val_loss: 0.1165
Epoch 48/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1169 - val_loss: 0.1154
Epoch 49/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1165 - val_loss: 0.1159
Epoch 50/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1162 - val_loss: 0.1158
Epoch 51/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1159 - val_loss: 0.1148
Epoch 52/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1157 - val_loss: 0.1152
Epoch 53/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1153 - val_loss: 0.1152
Epoch 54/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1150 - val_loss: 0.1148
Epoch 55/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1146 - val_loss: 0.1137
Epoch 56/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1145 - val_loss: 0.1137
Epoch 57/100
```

```
60000/60000 [==============================] - 4s 68us/step - loss: 0.1142 - val_loss: 0.1135
Epoch 58/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1139 - val_loss: 0.1129
Epoch 59/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1137 - val_loss: 0.1136
Epoch 60/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1134 - val_loss: 0.1129
Epoch 61/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1133 - val_loss: 0.1124
Epoch 62/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1130 - val_loss: 0.1122
Epoch 63/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1127 - val_loss: 0.1118
Epoch 64/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1126 - val_loss: 0.1120
Epoch 65/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1124 - val_loss: 0.1111
Epoch 66/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1121 - val_loss: 0.1114
Epoch 67/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1120 - val_loss: 0.1114
Epoch 68/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.1117 - val_loss: 0.1102
Epoch 69/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1115 - val_loss: 0.1113
Epoch 70/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.1113 - val_loss: 0.1107
Epoch 71/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1112 - val_loss: 0.1118
Epoch 72/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1109 - val_loss: 0.1102
Epoch 73/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1108 - val_loss: 0.1111
Epoch 74/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1107 - val_loss: 0.1100
Epoch 75/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1105 - val_loss: 0.1104
Epoch 76/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1102 - val_loss: 0.1097
Epoch 77/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1101 - val_loss: 0.1098
Epoch 78/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1100 - val_loss: 0.1099
Epoch 79/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1097 - val_loss: 0.1085
Epoch 80/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1096 - val_loss: 0.1088
Epoch 81/100
```

```
60000/60000 [==============================] - 4s 66us/step - loss: 0.1095 - val_loss: 0.1093
Epoch 82/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1093 - val_loss: 0.1098
Epoch 83/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1091 - val_loss: 0.1083
Epoch 84/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1091 - val_loss: 0.1085
Epoch 85/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1089 - val_loss: 0.1088
Epoch 86/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.1087 - val_loss: 0.1081
Epoch 87/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1086 - val_loss: 0.1083
Epoch 88/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1084 - val_loss: 0.1078
Epoch 89/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1084 - val_loss: 0.1075
Epoch 90/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1083 - val_loss: 0.1073
Epoch 91/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1080 - val_loss: 0.1075
Epoch 92/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1080 - val_loss: 0.1072
Epoch 93/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1078 - val_loss: 0.1083
Epoch 94/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1077 - val_loss: 0.1068
Epoch 95/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1077 - val_loss: 0.1073
Epoch 96/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1075 - val_loss: 0.1071
Epoch 97/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1074 - val_loss: 0.1073
Epoch 98/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1072 - val_loss: 0.1070
Epoch 99/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1072 - val_loss: 0.1074
Epoch 100/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1071 - val_loss: 0.1075
Train on 60000 samples, validate on 10000 samples
Epoch 1/100
60000/60000 [==============================] - 5s 86us/step - loss: 0.3428 - val_loss: 0.2620
Epoch 2/100
60000/60000 [==============================] - 4s 62us/step - loss: 0.2519 - val_loss: 0.2428
Epoch 3/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.2382 - val_loss: 0.2306
Epoch 4/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.2230 - val_loss: 0.2106
```

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Epoch 5/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.2014 - val_loss: 0.1955
Epoch 6/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1891 - val_loss: 0.1835
Epoch 7/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1823 - val_loss: 0.1817
Epoch 8/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1773 - val_loss: 0.1739
Epoch 9/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1726 - val_loss: 0.1693
Epoch 10/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1678 - val_loss: 0.1634
Epoch 11/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.1634 - val_loss: 0.1607
Epoch 12/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1600 - val_loss: 0.1570
Epoch 13/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1571 - val_loss: 0.1536
Epoch 14/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1544 - val_loss: 0.1525
Epoch 15/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1522 - val_loss: 0.1491
Epoch 16/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1498 - val_loss: 0.1506
Epoch 17/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1478 - val_loss: 0.1452
Epoch 18/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1459 - val_loss: 0.1441
Epoch 19/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1442 - val_loss: 0.1426
Epoch 20/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1423 - val_loss: 0.1406
Epoch 21/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1409 - val_loss: 0.1379
Epoch 22/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1396 - val_loss: 0.1381
Epoch 23/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1385 - val_loss: 0.1386
Epoch 24/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.1375 - val_loss: 0.1351
Epoch 25/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1364 - val_loss: 0.1367
Epoch 26/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1354 - val_loss: 0.1340
Epoch 27/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1347 - val_loss: 0.1340
Epoch 28/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1337 - val_loss: 0.1333
```

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Epoch 29/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.1330 - val_loss: 0.1320
Epoch 30/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1323 - val_loss: 0.1310
Epoch 31/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1315 - val_loss: 0.1291
Epoch 32/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1309 - val_loss: 0.1299
Epoch 33/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1303 - val_loss: 0.1299
Epoch 34/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1297 - val_loss: 0.1274
Epoch 35/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1291 - val_loss: 0.1270
Epoch 36/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1284 - val_loss: 0.1274
Epoch 37/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1280 - val_loss: 0.1263
Epoch 38/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1275 - val_loss: 0.1267
Epoch 39/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1270 - val_loss: 0.1263
Epoch 40/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1264 - val_loss: 0.1244
Epoch 41/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1260 - val_loss: 0.1240
Epoch 42/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1256 - val_loss: 0.1232
Epoch 43/100
60000/60000 [==============================] - 4s 71us/step - loss: 0.1251 - val_loss: 0.1243
Epoch 44/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1247 - val_loss: 0.1249
Epoch 45/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.1242 - val_loss: 0.1229
Epoch 46/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1239 - val_loss: 0.1247
Epoch 47/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1235 - val_loss: 0.1221
Epoch 48/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1232 - val_loss: 0.1222
Epoch 49/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1229 - val_loss: 0.1228
Epoch 50/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1225 - val_loss: 0.1219
Epoch 51/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1222 - val_loss: 0.1214
Epoch 52/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1218 - val_loss: 0.1204
```

```
Epoch 53/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1215 - val_loss: 0.1203
Epoch 54/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1211 - val_loss: 0.1201
Epoch 55/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1210 - val_loss: 0.1207
Epoch 56/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1206 - val_loss: 0.1192
Epoch 57/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1204 - val_loss: 0.1195
Epoch 58/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1200 - val_loss: 0.1190
Epoch 59/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.1199 - val_loss: 0.1186
Epoch 60/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1196 - val_loss: 0.1203
Epoch 61/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1193 - val_loss: 0.1186
Epoch 62/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1191 - val_loss: 0.1182
Epoch 63/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1188 - val_loss: 0.1184
Epoch 64/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1185 - val_loss: 0.1177
Epoch 65/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1183 - val_loss: 0.1167
Epoch 66/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1182 - val_loss: 0.1187
Epoch 67/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1179 - val_loss: 0.1177
Epoch 68/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1177 - val_loss: 0.1168
Epoch 69/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1176 - val_loss: 0.1164
Epoch 70/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1172 - val_loss: 0.1172
Epoch 71/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1172 - val_loss: 0.1164
Epoch 72/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1170 - val_loss: 0.1165
Epoch 73/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1167 - val_loss: 0.1156
Epoch 74/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1166 - val_loss: 0.1161
Epoch 75/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1164 - val_loss: 0.1163
Epoch 76/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1161 - val_loss: 0.1160
```

```
Epoch 77/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1161 - val_loss: 0.1153
Epoch 78/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1159 - val_loss: 0.1147
Epoch 79/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1156 - val_loss: 0.1153
Epoch 80/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1156 - val_loss: 0.1155
Epoch 81/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1153 - val_loss: 0.1146
Epoch 82/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1152 - val_loss: 0.1147
Epoch 83/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1151 - val_loss: 0.1142
Epoch 84/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1149 - val_loss: 0.1144
Epoch 85/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1148 - val_loss: 0.1145
Epoch 86/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1146 - val_loss: 0.1151
Epoch 87/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1145 - val_loss: 0.1142
Epoch 88/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1144 - val_loss: 0.1154
Epoch 89/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1143 - val_loss: 0.1136
Epoch 90/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1139 - val_loss: 0.1144
Epoch 91/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.1139 - val_loss: 0.1139
Epoch 92/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1138 - val_loss: 0.1132
Epoch 93/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1136 - val_loss: 0.1133
Epoch 94/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1135 - val_loss: 0.1144
Epoch 95/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1134 - val_loss: 0.1124
Epoch 96/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1133 - val_loss: 0.1124
Epoch 97/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1131 - val_loss: 0.1122
Epoch 98/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1131 - val_loss: 0.1129
Epoch 99/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1128 - val_loss: 0.1126
Epoch 100/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1127 - val_loss: 0.1126
```

```
Train on 60000 samples, validate on 10000 samples
Epoch 1/100
60000/60000 [==============================] - 5s 88us/step - loss: 0.3690 - val_loss: 0.2641
Epoch 2/100
60000/60000 [==============================] - 4s 61us/step - loss: 0.2585 - val_loss: 0.2526
Epoch 3/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.2425 - val_loss: 0.2291
Epoch 4/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.2215 - val_loss: 0.2127
Epoch 5/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.2050 - val_loss: 0.1977
Epoch 6/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1930 - val_loss: 0.1860
Epoch 7/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1839 - val_loss: 0.1780
Epoch 8/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1759 - val_loss: 0.1732
Epoch 9/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1693 - val_loss: 0.1632
Epoch 10/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1640 - val_loss: 0.1588
Epoch 11/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1593 - val_loss: 0.1557
Epoch 12/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1550 - val_loss: 0.1517
Epoch 13/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1510 - val_loss: 0.1497
Epoch 14/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1474 - val_loss: 0.1466
Epoch 15/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1447 - val_loss: 0.1414
Epoch 16/100
60000/60000 [==============================] - 4s 69us/step - loss: 0.1419 - val_loss: 0.1392
Epoch 17/100
60000/60000 [==============================] - 4s 73us/step - loss: 0.1394 - val_loss: 0.1380
Epoch 18/100
60000/60000 [==============================] - 4s 70us/step - loss: 0.1375 - val_loss: 0.1346
Epoch 19/100
60000/60000 [==============================] - 4s 69us/step - loss: 0.1357 - val_loss: 0.1334
Epoch 20/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1339 - val_loss: 0.1350
Epoch 21/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.1325 - val_loss: 0.1296
Epoch 22/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.1309 - val_loss: 0.1292
Epoch 23/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.1296 - val_loss: 0.1285
Epoch 24/100
```

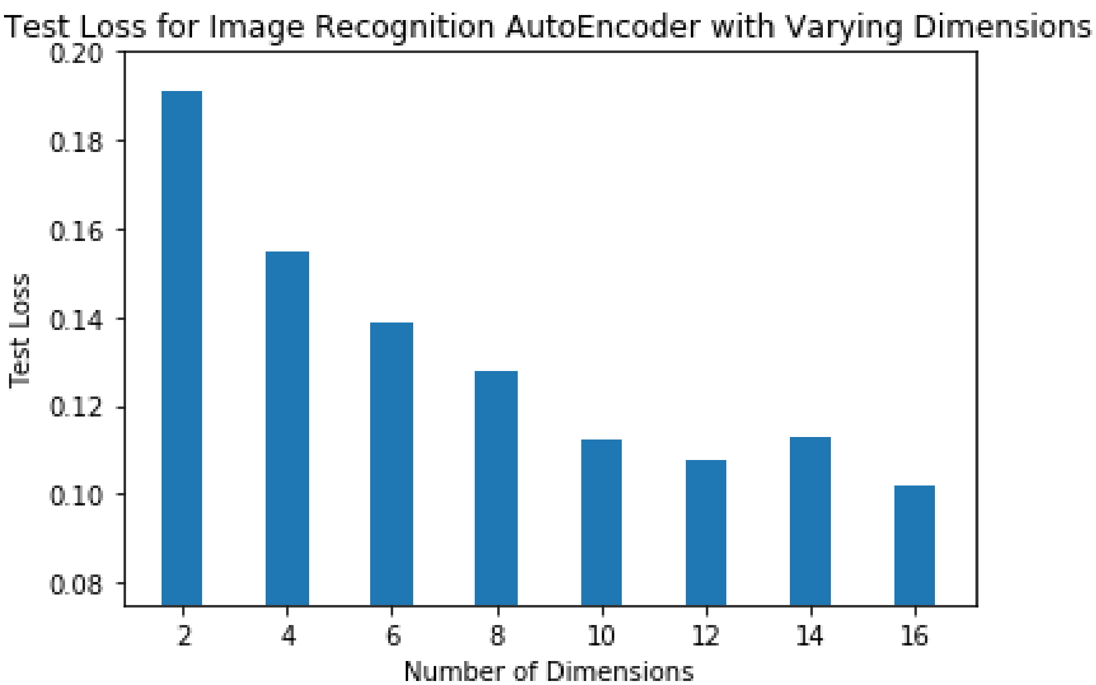
```
60000/60000 [==============================] - 4s 68us/step - loss: 0.1281 - val_loss: 0.1272
Epoch 25/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.1270 - val_loss: 0.1259
Epoch 26/100
60000/60000 [==============================] - 4s 69us/step - loss: 0.1258 - val_loss: 0.1237
Epoch 27/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.1247 - val_loss: 0.1226
Epoch 28/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.1239 - val_loss: 0.1213
Epoch 29/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.1229 - val_loss: 0.1207
Epoch 30/100
60000/60000 [==============================] - 4s 69us/step - loss: 0.1220 - val_loss: 0.1200
Epoch 31/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.1212 - val_loss: 0.1194
Epoch 32/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.1203 - val_loss: 0.1188
Epoch 33/100
60000/60000 [==============================] - 4s 69us/step - loss: 0.1195 - val_loss: 0.1193
Epoch 34/100
60000/60000 [==============================] - 4s 69us/step - loss: 0.1189 - val_loss: 0.1171
Epoch 35/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.1184 - val_loss: 0.1171
Epoch 36/100
60000/60000 [==============================] - 4s 69us/step - loss: 0.1176 - val_loss: 0.1166
Epoch 37/100
60000/60000 [==============================] - 4s 70us/step - loss: 0.1170 - val_loss: 0.1151
Epoch 38/100
60000/60000 [==============================] - 4s 69us/step - loss: 0.1164 - val_loss: 0.1144
Epoch 39/100
60000/60000 [==============================] - 4s 69us/step - loss: 0.1159 - val_loss: 0.1154
Epoch 40/100
60000/60000 [==============================] - 4s 69us/step - loss: 0.1153 - val_loss: 0.1131
Epoch 41/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.1150 - val_loss: 0.1129
Epoch 42/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.1143 - val_loss: 0.1136
Epoch 43/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.1140 - val_loss: 0.1133
Epoch 44/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.1135 - val_loss: 0.1125
Epoch 45/100
60000/60000 [==============================] - 4s 69us/step - loss: 0.1130 - val_loss: 0.1122
Epoch 46/100
60000/60000 [==============================] - 4s 69us/step - loss: 0.1128 - val_loss: 0.1112
Epoch 47/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.1122 - val_loss: 0.1104
Epoch 48/100
```

```
60000/60000 [==============================] - 4s 68us/step - loss: 0.1120 - val_loss: 0.1120
Epoch 49/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.1116 - val_loss: 0.1106
Epoch 50/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.1112 - val_loss: 0.1098
Epoch 51/100
60000/60000 [==============================] - 4s 69us/step - loss: 0.1109 - val_loss: 0.1101
Epoch 52/100
60000/60000 [==============================] - 4s 69us/step - loss: 0.1107 - val_loss: 0.1092
Epoch 53/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.1103 - val_loss: 0.1104
Epoch 54/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1100 - val_loss: 0.1088
Epoch 55/100
60000/60000 [==============================] - 4s 69us/step - loss: 0.1097 - val_loss: 0.1084
Epoch 56/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.1094 - val_loss: 0.1077
Epoch 57/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.1091 - val_loss: 0.1086
Epoch 58/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.1089 - val_loss: 0.1085
Epoch 59/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.1087 - val_loss: 0.1079
Epoch 60/100
60000/60000 [==============================] - 4s 70us/step - loss: 0.1084 - val_loss: 0.1073
Epoch 61/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1082 - val_loss: 0.1068
Epoch 62/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1079 - val_loss: 0.1077
Epoch 63/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1077 - val_loss: 0.1088
Epoch 64/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1074 - val_loss: 0.1066
Epoch 65/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1072 - val_loss: 0.1071
Epoch 66/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1070 - val_loss: 0.1060
Epoch 67/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.1067 - val_loss: 0.1083
Epoch 68/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1067 - val_loss: 0.1060
Epoch 69/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1064 - val_loss: 0.1059
Epoch 70/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1061 - val_loss: 0.1061
Epoch 71/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1060 - val_loss: 0.1050
Epoch 72/100
```

```
60000/60000 [==============================] - 4s 66us/step - loss: 0.1058 - val_loss: 0.1049
Epoch 73/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1056 - val_loss: 0.1063
Epoch 74/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1055 - val_loss: 0.1047
Epoch 75/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1053 - val_loss: 0.1057
Epoch 76/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1050 - val_loss: 0.1039
Epoch 77/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.1050 - val_loss: 0.1039
Epoch 78/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1048 - val_loss: 0.1043
Epoch 79/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1046 - val_loss: 0.1048
Epoch 80/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1044 - val_loss: 0.1049
Epoch 81/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1042 - val_loss: 0.1039
Epoch 82/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1041 - val_loss: 0.1035
Epoch 83/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1040 - val_loss: 0.1033
Epoch 84/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1038 - val_loss: 0.1031
Epoch 85/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.1037 - val_loss: 0.1031
Epoch 86/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1035 - val_loss: 0.1034
Epoch 87/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1035 - val_loss: 0.1032
Epoch 88/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1032 - val_loss: 0.1045
Epoch 89/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1031 - val_loss: 0.1034
Epoch 90/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1030 - val_loss: 0.1022
Epoch 91/100
60000/60000 [==============================] - 4s 70us/step - loss: 0.1029 - val_loss: 0.1018
Epoch 92/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1027 - val_loss: 0.1022
Epoch 93/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.1026 - val_loss: 0.1010
Epoch 94/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1024 - val_loss: 0.1025
Epoch 95/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1023 - val_loss: 0.1023
Epoch 96/100
```

```
60000/60000 [==============================] - 4s 67us/step - loss: 0.1022 - val_loss: 0.1023
Epoch 97/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1021 - val_loss: 0.1017
Epoch 98/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1019 - val_loss: 0.1016
Epoch 99/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.1019 - val_loss: 0.1020
Epoch 100/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1017 - val_loss: 0.1022
```

```
In [52]: plt.bar(dims, losses)
         plt.title('Test Loss for Image Recognition AutoEncoder with Varying Dimensions')
         plt.xlabel('Number of Dimensions')
         plt.xticks(dims)
         plt.ylabel('Test Loss')
         plt.ylim(0.075, 0.2)
         plt.show()
```



Judging by the graph, 16 dimensions appears to yield the lowest loss score

1.0.2 2. Using the previous assignment's model of detecting images, how does the accuracy change when you run the digit-prediction model on these 'decoded' values?

```
In [65]: #reload x/y data
         (xtrain, ytrain), (xtest, ytest) = mnist.load_data()
```

```
xtrain = xtrain.astype('float32') / 255.
xtest = xtest.astype('float32') / 255.
xtrain = xtrain.reshape((len(xtrain), np.prod(xtrain.shape[1:])))
xtest = xtest.reshape((len(xtest), np.prod(xtest.shape[1:])))
xtrain.shape, xtest.shape, ytrain.shape, ytest.shape
```

Out[65]: ((60000, 784), (10000, 784), (60000,), (10000,))

In [67]:
```
#run best model, then decode images
dim = 16

encoding_dim = dim  # 32 floats -> compression of factor 24.5, assuming the input is

loss = []

# this is our input placeholder
x = input_img = Input(shape=(784,))
# "encoded" is the encoded representation of the input
x = Dense(256, activation='relu')(x)
x = Dense(128, activation='relu')(x)
encoded = Dense(encoding_dim, activation='relu')(x)


# "decoded" is the lossy reconstruction of the input
x = Dense(128, activation='relu')(encoded)
x = Dense(256, activation='relu')(x)
decoded = Dense(784, activation='sigmoid')(x)

# this model maps an input to its reconstruction
autoencoder = Model(input_img, decoded)
encoder = Model(input_img, encoded)

# create a placeholder for an encoded (32-dimensional) input
encoded_input = Input(shape=(encoding_dim,))
# retrieve the last layer of the autoencoder model
dcd1 = autoencoder.layers[-1]
dcd2 = autoencoder.layers[-2]
dcd3 = autoencoder.layers[-3]

# create the decoder model
decoder = Model(encoded_input, dcd1(dcd2(dcd3(encoded_input))))

autoencoder.compile(optimizer='adadelta', loss='binary_crossentropy')

history = autoencoder.fit(xtrain, xtrain,
                epochs=100,
                batch_size=256,
```

```
                        shuffle=True,
                        validation_data=(xtest, xtest))
                        #callbacks=[TensorBoard(log_dir='/tmp/autoencoder')])


        loss.append(history.history['val_loss'][-1])

        encoded_imgs = encoder.predict(xtest)
        decoded_imgs = decoder.predict(encoded_imgs)
```

```
Train on 60000 samples, validate on 10000 samples
Epoch 1/100
60000/60000 [==============================] - 6s 96us/step - loss: 0.3218 - val_loss: 0.2619
Epoch 2/100
60000/60000 [==============================] - 4s 64us/step - loss: 0.2536 - val_loss: 0.2430
Epoch 3/100
60000/60000 [==============================] - 4s 62us/step - loss: 0.2328 - val_loss: 0.2227
Epoch 4/100
60000/60000 [==============================] - 4s 62us/step - loss: 0.2137 - val_loss: 0.2021
Epoch 5/100
60000/60000 [==============================] - 4s 62us/step - loss: 0.1972 - val_loss: 0.1910
Epoch 6/100
60000/60000 [==============================] - 4s 63us/step - loss: 0.1863 - val_loss: 0.1815
Epoch 7/100
60000/60000 [==============================] - 4s 64us/step - loss: 0.1780 - val_loss: 0.1728
Epoch 8/100
60000/60000 [==============================] - 4s 64us/step - loss: 0.1703 - val_loss: 0.1667
Epoch 9/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1640 - val_loss: 0.1606
Epoch 10/100
60000/60000 [==============================] - 4s 64us/step - loss: 0.1592 - val_loss: 0.1552
Epoch 11/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1551 - val_loss: 0.1527
Epoch 12/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1517 - val_loss: 0.1494
Epoch 13/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1484 - val_loss: 0.1452
Epoch 14/100
60000/60000 [==============================] - 4s 73us/step - loss: 0.1455 - val_loss: 0.1413
Epoch 15/100
60000/60000 [==============================] - 4s 70us/step - loss: 0.1430 - val_loss: 0.1406
Epoch 16/100
60000/60000 [==============================] - 4s 73us/step - loss: 0.1408 - val_loss: 0.1389
Epoch 17/100
60000/60000 [==============================] - 4s 70us/step - loss: 0.1391 - val_loss: 0.1366
Epoch 18/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1374 - val_loss: 0.1348
Epoch 19/100
```

```
60000/60000 [==============================] - 4s 74us/step - loss: 0.1358 - val_loss: 0.1346
Epoch 20/100
60000/60000 [==============================] - 4s 72us/step - loss: 0.1342 - val_loss: 0.1317
Epoch 21/100
60000/60000 [==============================] - 5s 83us/step - loss: 0.1327 - val_loss: 0.1296
Epoch 22/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.1314 - val_loss: 0.1292
Epoch 23/100
60000/60000 [==============================] - 4s 74us/step - loss: 0.1300 - val_loss: 0.1289
Epoch 24/100
60000/60000 [==============================] - 4s 71us/step - loss: 0.1287 - val_loss: 0.1263
Epoch 25/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1273 - val_loss: 0.1264
Epoch 26/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1263 - val_loss: 0.1234
Epoch 27/100
60000/60000 [==============================] - 4s 63us/step - loss: 0.1253 - val_loss: 0.1240
Epoch 28/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1243 - val_loss: 0.1223
Epoch 29/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.1235 - val_loss: 0.1226
Epoch 30/100
60000/60000 [==============================] - 4s 64us/step - loss: 0.1226 - val_loss: 0.1214
Epoch 31/100
60000/60000 [==============================] - 4s 65us/step - loss: 0.1218 - val_loss: 0.1197
Epoch 32/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1212 - val_loss: 0.1195
Epoch 33/100
60000/60000 [==============================] - 5s 80us/step - loss: 0.1204 - val_loss: 0.1184
Epoch 34/100
60000/60000 [==============================] - 4s 73us/step - loss: 0.1197 - val_loss: 0.1183
Epoch 35/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.1190 - val_loss: 0.1172
Epoch 36/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.1184 - val_loss: 0.1159
Epoch 37/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.1175 - val_loss: 0.1160
Epoch 38/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.1170 - val_loss: 0.1164
Epoch 39/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.1164 - val_loss: 0.1137
Epoch 40/100
60000/60000 [==============================] - 4s 69us/step - loss: 0.1159 - val_loss: 0.1136
Epoch 41/100
60000/60000 [==============================] - 4s 70us/step - loss: 0.1153 - val_loss: 0.1131
Epoch 42/100
60000/60000 [==============================] - 4s 69us/step - loss: 0.1148 - val_loss: 0.1126
Epoch 43/100
```

```
60000/60000 [==============================] - 4s 70us/step - loss: 0.1143 - val_loss: 0.1140
Epoch 44/100
60000/60000 [==============================] - 4s 70us/step - loss: 0.1139 - val_loss: 0.1122
Epoch 45/100
60000/60000 [==============================] - 4s 71us/step - loss: 0.1135 - val_loss: 0.1123
Epoch 46/100
60000/60000 [==============================] - 4s 70us/step - loss: 0.1130 - val_loss: 0.1138
Epoch 47/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.1126 - val_loss: 0.1114
Epoch 48/100
60000/60000 [==============================] - 4s 69us/step - loss: 0.1122 - val_loss: 0.1121
Epoch 49/100
60000/60000 [==============================] - 4s 71us/step - loss: 0.1118 - val_loss: 0.1105
Epoch 50/100
60000/60000 [==============================] - 4s 70us/step - loss: 0.1115 - val_loss: 0.1104
Epoch 51/100
60000/60000 [==============================] - 4s 70us/step - loss: 0.1111 - val_loss: 0.1103
Epoch 52/100
60000/60000 [==============================] - 4s 70us/step - loss: 0.1107 - val_loss: 0.1100
Epoch 53/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.1104 - val_loss: 0.1094
Epoch 54/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1100 - val_loss: 0.1088
Epoch 55/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1096 - val_loss: 0.1079
Epoch 56/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.1092 - val_loss: 0.1083
Epoch 57/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1091 - val_loss: 0.1073
Epoch 58/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1086 - val_loss: 0.1074
Epoch 59/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.1084 - val_loss: 0.1078
Epoch 60/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.1081 - val_loss: 0.1070
Epoch 61/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1078 - val_loss: 0.1068
Epoch 62/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1075 - val_loss: 0.1066
Epoch 63/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.1071 - val_loss: 0.1066
Epoch 64/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1069 - val_loss: 0.1061
Epoch 65/100
60000/60000 [==============================] - 4s 69us/step - loss: 0.1066 - val_loss: 0.1050
Epoch 66/100
60000/60000 [==============================] - 4s 69us/step - loss: 0.1063 - val_loss: 0.1055
Epoch 67/100
```

```
60000/60000 [==============================] - 4s 69us/step - loss: 0.1060 - val_loss: 0.1057
Epoch 68/100
60000/60000 [==============================] - 5s 75us/step - loss: 0.1059 - val_loss: 0.1057
Epoch 69/100
60000/60000 [==============================] - 4s 72us/step - loss: 0.1057 - val_loss: 0.1053
Epoch 70/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.1054 - val_loss: 0.1040
Epoch 71/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.1052 - val_loss: 0.1052
Epoch 72/100
60000/60000 [==============================] - 4s 69us/step - loss: 0.1050 - val_loss: 0.1036
Epoch 73/100
60000/60000 [==============================] - 4s 69us/step - loss: 0.1047 - val_loss: 0.1043
Epoch 74/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.1045 - val_loss: 0.1041
Epoch 75/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.1043 - val_loss: 0.1030
Epoch 76/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.1042 - val_loss: 0.1032
Epoch 77/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1039 - val_loss: 0.1040
Epoch 78/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1037 - val_loss: 0.1021
Epoch 79/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1035 - val_loss: 0.1025
Epoch 80/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1033 - val_loss: 0.1031
Epoch 81/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1032 - val_loss: 0.1023
Epoch 82/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1030 - val_loss: 0.1021
Epoch 83/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1028 - val_loss: 0.1030
Epoch 84/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1026 - val_loss: 0.1015
Epoch 85/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1025 - val_loss: 0.1013
Epoch 86/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1024 - val_loss: 0.1023
Epoch 87/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1021 - val_loss: 0.1014
Epoch 88/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1019 - val_loss: 0.1017
Epoch 89/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1019 - val_loss: 0.1008
Epoch 90/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1016 - val_loss: 0.1022
Epoch 91/100
```

```
60000/60000 [==============================] - 4s 67us/step - loss: 0.1015 - val_loss: 0.1012
Epoch 92/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1015 - val_loss: 0.1009
Epoch 93/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1012 - val_loss: 0.1007
Epoch 94/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1011 - val_loss: 0.1014
Epoch 95/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1011 - val_loss: 0.0998
Epoch 96/100
60000/60000 [==============================] - 4s 66us/step - loss: 0.1008 - val_loss: 0.1001
Epoch 97/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1007 - val_loss: 0.1014
Epoch 98/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1006 - val_loss: 0.1013
Epoch 99/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.1004 - val_loss: 0.1006
Epoch 100/100
60000/60000 [==============================] - 4s 67us/step - loss: 0.1004 - val_loss: 0.1003
```

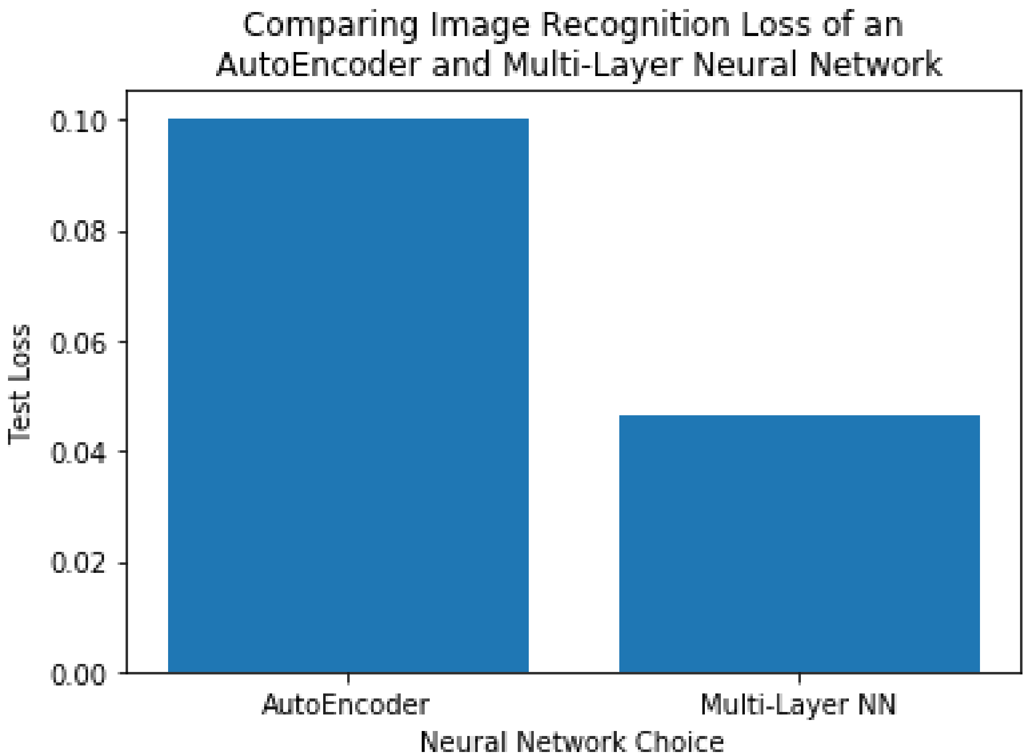
In [71]:
```
from keras.models import Sequential
from keras.layers import Dropout
from keras.optimizers import RMSprop

#run best model from last week's assignment
batch_size = 128
num_classes = 10
epochs = 20


# convert class vectors to binary class matrices
y_train = keras.utils.to_categorical(ytrain, num_classes)
y_test = keras.utils.to_categorical(ytest, num_classes)

model = Sequential()
model.add(Dense(512, activation='relu', input_shape=(784,)))
model.add(Dropout(0.2))
model.add(Dense(512, activation='relu'))
model.add(Dropout(0.2))
model.add(Dense(10, activation='softmax'))

model.summary()

model.compile(loss='categorical_crossentropy',
              optimizer=RMSprop(),
              metrics=['accuracy'])
```

```
    model.fit(decoded_imgs, y_test,
                        batch_size=batch_size,
                        epochs=epochs,
                        verbose=1,
                        validation_data=(x_test, y_test))
    loss.append(model.evaluate(x_test, y_test, verbose=0)[0])
```

```
Model: "sequential_6"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
dense_236 (Dense)            (None, 512)               401920
_________________________________________________________________
dropout_9 (Dropout)          (None, 512)               0
_________________________________________________________________
dense_237 (Dense)            (None, 512)               262656
_________________________________________________________________
dropout_10 (Dropout)         (None, 512)               0
_________________________________________________________________
dense_238 (Dense)            (None, 10)                5130
=================================================================
Total params: 669,706
Trainable params: 669,706
Non-trainable params: 0
_________________________________________________________________
Train on 10000 samples, validate on 10000 samples
Epoch 1/20
10000/10000 [==============================] - 2s 196us/step - loss: 0.5157 - accuracy: 0.8384
Epoch 2/20
10000/10000 [==============================] - 1s 85us/step - loss: 0.2343 - accuracy: 0.9241 -
Epoch 3/20
10000/10000 [==============================] - 1s 84us/step - loss: 0.1748 - accuracy: 0.9464 -
Epoch 4/20
10000/10000 [==============================] - 1s 93us/step - loss: 0.1439 - accuracy: 0.9538 -
Epoch 5/20
10000/10000 [==============================] - 1s 86us/step - loss: 0.1150 - accuracy: 0.9627 -
Epoch 6/20
10000/10000 [==============================] - 1s 85us/step - loss: 0.0974 - accuracy: 0.9675 -
Epoch 7/20
10000/10000 [==============================] - 1s 85us/step - loss: 0.0898 - accuracy: 0.9688 -
Epoch 8/20
10000/10000 [==============================] - 1s 84us/step - loss: 0.0802 - accuracy: 0.9725 -
Epoch 9/20
10000/10000 [==============================] - 1s 83us/step - loss: 0.0659 - accuracy: 0.9766 -
Epoch 10/20
10000/10000 [==============================] - 1s 85us/step - loss: 0.0651 - accuracy: 0.9776 -
Epoch 11/20
10000/10000 [==============================] - 1s 84us/step - loss: 0.0546 - accuracy: 0.9818 -
```

```
Epoch 12/20
10000/10000 [==============================] - 1s 85us/step - loss: 0.0453 - accuracy: 0.9834 -
Epoch 13/20
10000/10000 [==============================] - 1s 84us/step - loss: 0.0422 - accuracy: 0.9868 -
Epoch 14/20
10000/10000 [==============================] - 1s 83us/step - loss: 0.0404 - accuracy: 0.9864 -
Epoch 15/20
10000/10000 [==============================] - 1s 85us/step - loss: 0.0376 - accuracy: 0.9873 -
Epoch 16/20
10000/10000 [==============================] - 1s 84us/step - loss: 0.0358 - accuracy: 0.9872 -
Epoch 17/20
10000/10000 [==============================] - 1s 85us/step - loss: 0.0294 - accuracy: 0.9875 -
Epoch 18/20
10000/10000 [==============================] - 1s 87us/step - loss: 0.0296 - accuracy: 0.9899 -
Epoch 19/20
10000/10000 [==============================] - 1s 97us/step - loss: 0.0291 - accuracy: 0.9903 -
Epoch 20/20
10000/10000 [==============================] - 1s 90us/step - loss: 0.0260 - accuracy: 0.9904 -
```

```
In [72]: models = ['AutoEncoder', 'Multi-Layer NN']
         plt.bar(models, loss)
         plt.xlabel('Neural Network Choice')
         plt.title('Comparing Image Recognition Loss of an\n AutoEncoder and Multi-Layer Neural
         #plt.xticks(dims)
         plt.ylabel('Test Loss')
         #plt.ylim(0.075, 0.2)
         plt.show()
```



Judging the above graph, the MLNN actually appears to perform better than the AutoEncoder.

1.0.3 3. Apply noise to only the input of the autoencoder (not the output). demonstrate that your autoencoder can strip out noise.

In [76]:
```
#import random noise packages
from skimage.util import random_noise

xtrain_noise = random_noise(xtrain, seed = 1234, var = 0.25)
xtest_noise = random_noise(xtest, seed = 1234, var = 0.25)

#rerun encoder with noise

loss = []

encoding_dim = dim  # 32 floats -> compression of factor 24.5, assuming the input is 

# this is our input placeholder
x = input_img = Input(shape=(784,))
# "encoded" is the encoded representation of the input
x = Dense(256, activation='relu')(x)
x = Dense(128, activation='relu')(x)
encoded = Dense(encoding_dim, activation='relu')(x)
```

```python
# "decoded" is the lossy reconstruction of the input
x = Dense(128, activation='relu')(encoded)
x = Dense(256, activation='relu')(x)
decoded = Dense(784, activation='sigmoid')(x)

# this model maps an input to its reconstruction
autoencoder = Model(input_img, decoded)
encoder = Model(input_img, encoded)

# create a placeholder for an encoded (32-dimensional) input
encoded_input = Input(shape=(encoding_dim,))
# retrieve the last layer of the autoencoder model
dcd1 = autoencoder.layers[-1]
dcd2 = autoencoder.layers[-2]
dcd3 = autoencoder.layers[-3]

# create the decoder model
decoder = Model(encoded_input, dcd1(dcd2(dcd3(encoded_input))))

autoencoder.compile(optimizer='adadelta', loss='binary_crossentropy')

autoencoder.fit(xtrain_noise, xtrain_noise,
                epochs=100,
                batch_size=256,
                shuffle=True,
                validation_data=(xtest_noise, xtest_noise))
                #callbacks=[TensorBoard(log_dir='/tmp/autoencoder')])
```

```
Train on 60000 samples, validate on 10000 samples
Epoch 1/100
60000/60000 [==============================] - 6s 100us/step - loss: 0.5973 - val_loss: 0.5649
Epoch 2/100
60000/60000 [==============================] - 4s 70us/step - loss: 0.5644 - val_loss: 0.5643
Epoch 3/100
60000/60000 [==============================] - 4s 68us/step - loss: 0.5639 - val_loss: 0.5638
Epoch 4/100
60000/60000 [==============================] - 4s 69us/step - loss: 0.5634 - val_loss: 0.5631
Epoch 5/100
60000/60000 [==============================] - 4s 69us/step - loss: 0.5620 - val_loss: 0.5608
Epoch 6/100
60000/60000 [==============================] - 4s 69us/step - loss: 0.5591 - val_loss: 0.5575
Epoch 7/100
60000/60000 [==============================] - 4s 71us/step - loss: 0.5563 - val_loss: 0.5552
Epoch 8/100
60000/60000 [==============================] - 4s 75us/step - loss: 0.5540 - val_loss: 0.5529
Epoch 9/100
```

```
60000/60000 [==============================] - 5s 76us/step - loss: 0.5521 - val_loss: 0.5514
Epoch 10/100
60000/60000 [==============================] - 5s 76us/step - loss: 0.5509 - val_loss: 0.5501
Epoch 11/100
60000/60000 [==============================] - 5s 78us/step - loss: 0.5496 - val_loss: 0.5488
Epoch 12/100
60000/60000 [==============================] - 5s 79us/step - loss: 0.5483 - val_loss: 0.5475
Epoch 13/100
60000/60000 [==============================] - 4s 74us/step - loss: 0.5473 - val_loss: 0.5467
Epoch 14/100
60000/60000 [==============================] - 5s 77us/step - loss: 0.5464 - val_loss: 0.5456
Epoch 15/100
60000/60000 [==============================] - 5s 77us/step - loss: 0.5452 - val_loss: 0.5443
Epoch 16/100
60000/60000 [==============================] - 4s 75us/step - loss: 0.5440 - val_loss: 0.5431
Epoch 17/100
60000/60000 [==============================] - 4s 73us/step - loss: 0.5430 - val_loss: 0.5421
Epoch 18/100
60000/60000 [==============================] - 4s 72us/step - loss: 0.5420 - val_loss: 0.5412
Epoch 19/100
60000/60000 [==============================] - 4s 73us/step - loss: 0.5412 - val_loss: 0.5403
Epoch 20/100
60000/60000 [==============================] - 4s 73us/step - loss: 0.5404 - val_loss: 0.5397
Epoch 21/100
60000/60000 [==============================] - 4s 73us/step - loss: 0.5397 - val_loss: 0.5390
Epoch 22/100
60000/60000 [==============================] - 4s 73us/step - loss: 0.5389 - val_loss: 0.5381
Epoch 23/100
60000/60000 [==============================] - 4s 73us/step - loss: 0.5382 - val_loss: 0.5375
Epoch 24/100
60000/60000 [==============================] - 4s 73us/step - loss: 0.5376 - val_loss: 0.5369
Epoch 25/100
60000/60000 [==============================] - 4s 73us/step - loss: 0.5371 - val_loss: 0.5365
Epoch 26/100
60000/60000 [==============================] - 4s 73us/step - loss: 0.5365 - val_loss: 0.5361
Epoch 27/100
60000/60000 [==============================] - 4s 73us/step - loss: 0.5361 - val_loss: 0.5353
Epoch 28/100
60000/60000 [==============================] - 4s 75us/step - loss: 0.5356 - val_loss: 0.5353
Epoch 29/100
60000/60000 [==============================] - 4s 74us/step - loss: 0.5352 - val_loss: 0.5348
Epoch 30/100
60000/60000 [==============================] - 4s 73us/step - loss: 0.5348 - val_loss: 0.5344
Epoch 31/100
60000/60000 [==============================] - 4s 74us/step - loss: 0.5345 - val_loss: 0.5342
Epoch 32/100
60000/60000 [==============================] - 4s 74us/step - loss: 0.5342 - val_loss: 0.5337
Epoch 33/100
```

```
60000/60000 [==============================] - 4s 74us/step - loss: 0.5338 - val_loss: 0.5334
Epoch 34/100
60000/60000 [==============================] - 4s 75us/step - loss: 0.5336 - val_loss: 0.5329
Epoch 35/100
60000/60000 [==============================] - 4s 74us/step - loss: 0.5334 - val_loss: 0.5327
Epoch 36/100
60000/60000 [==============================] - 5s 76us/step - loss: 0.5331 - val_loss: 0.5328
Epoch 37/100
60000/60000 [==============================] - 4s 74us/step - loss: 0.5329 - val_loss: 0.5331
Epoch 38/100
60000/60000 [==============================] - 4s 74us/step - loss: 0.5327 - val_loss: 0.5329
Epoch 39/100
60000/60000 [==============================] - 4s 74us/step - loss: 0.5325 - val_loss: 0.5326
Epoch 40/100
60000/60000 [==============================] - 4s 74us/step - loss: 0.5323 - val_loss: 0.5317
Epoch 41/100
60000/60000 [==============================] - 4s 74us/step - loss: 0.5321 - val_loss: 0.5318
Epoch 42/100
60000/60000 [==============================] - 4s 74us/step - loss: 0.5320 - val_loss: 0.5323
Epoch 43/100
60000/60000 [==============================] - 4s 75us/step - loss: 0.5317 - val_loss: 0.5319
Epoch 44/100
60000/60000 [==============================] - 4s 74us/step - loss: 0.5316 - val_loss: 0.5310
Epoch 45/100
60000/60000 [==============================] - 4s 75us/step - loss: 0.5314 - val_loss: 0.5316
Epoch 46/100
60000/60000 [==============================] - 4s 75us/step - loss: 0.5313 - val_loss: 0.5310
Epoch 47/100
60000/60000 [==============================] - 4s 74us/step - loss: 0.5312 - val_loss: 0.5307
Epoch 48/100
60000/60000 [==============================] - 4s 74us/step - loss: 0.5310 - val_loss: 0.5305
Epoch 49/100
60000/60000 [==============================] - 4s 75us/step - loss: 0.5310 - val_loss: 0.5308
Epoch 50/100
60000/60000 [==============================] - 4s 75us/step - loss: 0.5309 - val_loss: 0.5308
Epoch 51/100
60000/60000 [==============================] - 4s 74us/step - loss: 0.5308 - val_loss: 0.5310
Epoch 52/100
60000/60000 [==============================] - 4s 74us/step - loss: 0.5306 - val_loss: 0.5304
Epoch 53/100
60000/60000 [==============================] - 4s 75us/step - loss: 0.5305 - val_loss: 0.5305
Epoch 54/100
60000/60000 [==============================] - 4s 74us/step - loss: 0.5305 - val_loss: 0.5302
Epoch 55/100
60000/60000 [==============================] - 4s 74us/step - loss: 0.5303 - val_loss: 0.5299
Epoch 56/100
60000/60000 [==============================] - 4s 75us/step - loss: 0.5303 - val_loss: 0.5298
Epoch 57/100
```

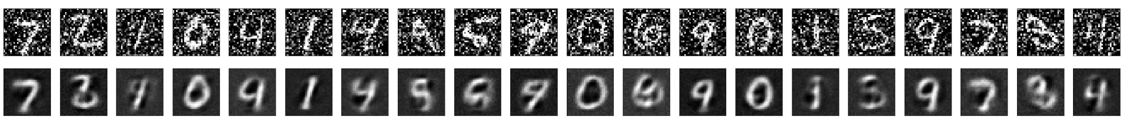
```
60000/60000 [==============================] - 4s 74us/step - loss: 0.5302 - val_loss: 0.5297
Epoch 58/100
60000/60000 [==============================] - 5s 76us/step - loss: 0.5301 - val_loss: 0.5297
Epoch 59/100
60000/60000 [==============================] - 4s 74us/step - loss: 0.5301 - val_loss: 0.5296
Epoch 60/100
60000/60000 [==============================] - 4s 74us/step - loss: 0.5300 - val_loss: 0.5296
Epoch 61/100
60000/60000 [==============================] - 4s 74us/step - loss: 0.5299 - val_loss: 0.5298
Epoch 62/100
60000/60000 [==============================] - 5s 75us/step - loss: 0.5299 - val_loss: 0.5296
Epoch 63/100
60000/60000 [==============================] - 5s 75us/step - loss: 0.5298 - val_loss: 0.5295
Epoch 64/100
60000/60000 [==============================] - 5s 76us/step - loss: 0.5298 - val_loss: 0.5299
Epoch 65/100
60000/60000 [==============================] - 4s 74us/step - loss: 0.5297 - val_loss: 0.5293
Epoch 66/100
60000/60000 [==============================] - 5s 76us/step - loss: 0.5296 - val_loss: 0.5297
Epoch 67/100
60000/60000 [==============================] - 4s 74us/step - loss: 0.5296 - val_loss: 0.5292
Epoch 68/100
60000/60000 [==============================] - 5s 75us/step - loss: 0.5295 - val_loss: 0.5293
Epoch 69/100
60000/60000 [==============================] - 4s 74us/step - loss: 0.5295 - val_loss: 0.5289
Epoch 70/100
60000/60000 [==============================] - 5s 75us/step - loss: 0.5294 - val_loss: 0.5288
Epoch 71/100
60000/60000 [==============================] - 5s 75us/step - loss: 0.5293 - val_loss: 0.5294
Epoch 72/100
60000/60000 [==============================] - 5s 75us/step - loss: 0.5293 - val_loss: 0.5292
Epoch 73/100
60000/60000 [==============================] - 5s 76us/step - loss: 0.5292 - val_loss: 0.5294
Epoch 74/100
60000/60000 [==============================] - 5s 75us/step - loss: 0.5292 - val_loss: 0.5290
Epoch 75/100
60000/60000 [==============================] - 5s 75us/step - loss: 0.5292 - val_loss: 0.5287
Epoch 76/100
60000/60000 [==============================] - 5s 75us/step - loss: 0.5291 - val_loss: 0.5288
Epoch 77/100
60000/60000 [==============================] - 4s 75us/step - loss: 0.5290 - val_loss: 0.5287
Epoch 78/100
60000/60000 [==============================] - 4s 75us/step - loss: 0.5290 - val_loss: 0.5289
Epoch 79/100
60000/60000 [==============================] - 5s 75us/step - loss: 0.5290 - val_loss: 0.5292
Epoch 80/100
60000/60000 [==============================] - 4s 75us/step - loss: 0.5289 - val_loss: 0.5285
Epoch 81/100
```

```
60000/60000 [==============================] - 5s 75us/step - loss: 0.5288 - val_loss: 0.5292
Epoch 82/100
60000/60000 [==============================] - 4s 75us/step - loss: 0.5288 - val_loss: 0.5282
Epoch 83/100
60000/60000 [==============================] - 4s 75us/step - loss: 0.5287 - val_loss: 0.5284
Epoch 84/100
60000/60000 [==============================] - 4s 75us/step - loss: 0.5287 - val_loss: 0.5281
Epoch 85/100
60000/60000 [==============================] - 5s 75us/step - loss: 0.5286 - val_loss: 0.5281
Epoch 86/100
60000/60000 [==============================] - 5s 76us/step - loss: 0.5286 - val_loss: 0.5282
Epoch 87/100
60000/60000 [==============================] - 5s 76us/step - loss: 0.5285 - val_loss: 0.5285
Epoch 88/100
60000/60000 [==============================] - 5s 76us/step - loss: 0.5285 - val_loss: 0.5284
Epoch 89/100
60000/60000 [==============================] - 5s 75us/step - loss: 0.5284 - val_loss: 0.5284
Epoch 90/100
60000/60000 [==============================] - 5s 76us/step - loss: 0.5283 - val_loss: 0.5279
Epoch 91/100
60000/60000 [==============================] - 5s 75us/step - loss: 0.5284 - val_loss: 0.5283
Epoch 92/100
60000/60000 [==============================] - 5s 76us/step - loss: 0.5282 - val_loss: 0.5281
Epoch 93/100
60000/60000 [==============================] - 5s 76us/step - loss: 0.5282 - val_loss: 0.5281
Epoch 94/100
60000/60000 [==============================] - 5s 77us/step - loss: 0.5282 - val_loss: 0.5279
Epoch 95/100
60000/60000 [==============================] - 5s 79us/step - loss: 0.5281 - val_loss: 0.5277
Epoch 96/100
60000/60000 [==============================] - 5s 76us/step - loss: 0.5281 - val_loss: 0.5283
Epoch 97/100
60000/60000 [==============================] - 5s 76us/step - loss: 0.5281 - val_loss: 0.5280
Epoch 98/100
60000/60000 [==============================] - 5s 76us/step - loss: 0.5279 - val_loss: 0.5277
Epoch 99/100
60000/60000 [==============================] - 5s 76us/step - loss: 0.5280 - val_loss: 0.5277
Epoch 100/100
60000/60000 [==============================] - 5s 77us/step - loss: 0.5279 - val_loss: 0.5279
```

```
Out[76]: <keras.callbacks.callbacks.History at 0xb684645f8>
```

```
In [77]: encoded_imgs = encoder.predict(xtest_noise)
         decoded_imgs = decoder.predict(encoded_imgs)
         import matplotlib.pyplot as plt

         n = 20  # how many digits we will display
```

```python
plt.figure(figsize=(40, 4))
for i in range(n):
    # display original
    ax = plt.subplot(2, n, i + 1)
    plt.imshow(xtest_noise[i].reshape(28, 28))
    plt.gray()
    ax.get_xaxis().set_visible(False)
    ax.get_yaxis().set_visible(False)

    # display reconstruction
    ax = plt.subplot(2, n, i + 1 + n)
    plt.imshow(decoded_imgs[i].reshape(28, 28))
    plt.gray()
    ax.get_xaxis().set_visible(False)
    ax.get_yaxis().set_visible(False)
plt.show()
```



Looking at the above image comparisons, you can tell that, for the most part, the auto-encoder can strip out most of the input noise. It does not do a perfect job with noise at 0.25 variance, but I think that at least ~60% of the above images are correct and discernable.