AI & Pattern Recognition Classwork 06 Autoencoder

ID： M133206 **Name：** Harsh Agarwal **May 7, 2025**

1. (a) Compare the MSE when the coding size is used as 10, 20, and 40 in the stacked autoencoder.

   (b) Test whether the reconstruction is improved if an additional hidden layer with 100 neurons was used in the stacked autoencoder.

b).
Code size = 10 → MSE = 0.16476
Code size = 20 → MSE = 0.16745
Code size = 40 → MSE = 0.16100
Yes the reconstruction is improved.

a).Code size = 10 → MSE = 0.16776
Code size = 20 → MSE = 0.16902
Code size = 40 → MSE = 0.16275

2. (a) Compare the MSE when the strength (standard deviation) of the Gaussian noise in the denoised autoencoder is set to 0.25and 0.75 respectively.

   (b) Compare the MSE when the percentage of dropout in the denoised autoencoder is set as 0.25 and 0.75.

3. Modify the variational autoencoder that uses σ instead of log variance.

2.
a. Gaussian Noise stddev = 0.25 → Test MSE = 0.11079
Gaussian Noise stddev = 0.75 → Test MSE = 0.13052
b. Dropout rate = 0.25 → Test MSE = 0.12190
Dropout rate = 0.75 → Test MSE = 0.11567

1.Stacked AutoEncoder

a. MSE when the coding size is used as 10, 20, and 40 in the stacked autoencoder.

```
#Using Keras to load the dataset.
import tensorflow as tf
import pandas as pd
import numpy as np
from tensorflow import keras
fashion_mnist = keras.datasets.fashion_mnist
(x_train, y_train), (x_test, y_test) = fashion_mnist.load_data()

x_valid, x_train_n = x_train[:5000]/255.0, x_train[5000:]/255.0
x_test = x_test / 255.0
y_val = y_train[:5000]
y_train_n = y_train[5000:]
```

```
2025-05-21 02:49:45.070071: E
external/local_xla/xla/stream_executor/cuda/cuda_fft.cc:477] Unable to
register cuFFT factory: Attempting to register factory for plugin
cuFFT when one has already been registered
WARNING: All log messages before absl::InitializeLog() is called are
written to STDERR
E0000 00:00:1747795785.564294      35 cuda_dnn.cc:8310] Unable to
register cuDNN factory: Attempting to register factory for plugin
cuDNN when one has already been registered
E0000 00:00:1747795785.700145      35 cuda_blas.cc:1418] Unable to
register cuBLAS factory: Attempting to register factory for plugin
cuBLAS when one has already been registered

Downloading data from https://storage.googleapis.com/tensorflow/tf-
keras-datasets/train-labels-idx1-ubyte.gz
29515/29515 ━━━━━━━━━━━━━━━━━━━━ 0s 0us/step
Downloading data from https://storage.googleapis.com/tensorflow/tf-
keras-datasets/train-images-idx3-ubyte.gz
26421880/26421880 ━━━━━━━━━━━━━━━━━━━━ 0s 0us/step
Downloading data from https://storage.googleapis.com/tensorflow/tf-
keras-datasets/t10k-labels-idx1-ubyte.gz
5148/5148 ━━━━━━━━━━━━━━━━━━━━ 0s 0us/step
Downloading data from https://storage.googleapis.com/tensorflow/tf-
keras-datasets/t10k-images-idx3-ubyte.gz
4422102/4422102 ━━━━━━━━━━━━━━━━━━━━ 0s 0us/step
```

```
assert x_train.shape == (60000, 28, 28)
assert x_test.shape == (10000, 28, 28)
assert y_train.shape == (60000,)
assert y_test.shape == (10000,)
```

```python
#Building the Stacked Autoencoder:
from sklearn.metrics import mean_squared_error
def build_stacked(code_size):
    encoder = keras.models.Sequential([
        keras.layers.Flatten(input_shape=[28,28]),
        keras.layers.Dense(128, activation="selu"),
        keras.layers.Dense(code_size, activation="selu"),
    ])
    decoder = keras.models.Sequential([
        keras.layers.Dense(128,
activation="selu",input_shape=[code_size]),
        keras.layers.Dense(28*28, activation="sigmoid"),
        keras.layers.Reshape([28,28])
    ])

    autoencoder = keras.models.Sequential([encoder,decoder])
    #Compile the model
    autoencoder.compile(loss="mse",
optimizer=keras.optimizers.SGD(learning_rate=0.0001))
    history = autoencoder.fit(x_train_n, x_train_n, epochs=50,
validation_data=(x_valid,x_valid), verbose=1)
    x_test_recon = autoencoder.predict(x_test)
    mse = mean_squared_error(x_test.flatten(),x_test_recon.flatten())

    return mse

for i in [10,20,40]:
    print(f"Code size = {i}")
    mse = build_stacked(code_size=i)
    print(f"Code size = {i} → MSE = {mse:.5f}")
```

```
Code size = 10
Epoch 1/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 5s 2ms/step - loss: 0.1730 - val_loss:
0.1740
Epoch 2/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1729 - val_loss:
0.1738
Epoch 3/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1731 - val_loss:
0.1737
Epoch 4/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1726 - val_loss:
0.1735
Epoch 5/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1727 - val_loss:
0.1734
Epoch 6/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1724 - val_loss:
```

```
0.1732
Epoch 7/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1720 - val_loss:
0.1731
Epoch 8/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1722 - val_loss:
0.1730
Epoch 9/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1717 - val_loss:
0.1728
Epoch 10/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1719 - val_loss:
0.1727
Epoch 11/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1716 - val_loss:
0.1726
Epoch 12/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1715 - val_loss:
0.1725
Epoch 13/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1718 - val_loss:
0.1724
Epoch 14/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1713 - val_loss:
0.1723
Epoch 15/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1712 - val_loss:
0.1722
Epoch 16/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1711 - val_loss:
0.1721
Epoch 17/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1707 - val_loss:
0.1720
Epoch 18/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1708 - val_loss:
0.1719
Epoch 19/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1709 - val_loss:
0.1718
Epoch 20/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1707 - val_loss:
0.1717
Epoch 21/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1706 - val_loss:
0.1716
Epoch 22/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1707 - val_loss:
0.1715
```

```
Epoch 23/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1707 - val_loss:
0.1715
Epoch 24/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1707 - val_loss:
0.1714
Epoch 25/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1703 - val_loss:
0.1713
Epoch 26/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1702 - val_loss:
0.1712
Epoch 27/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1702 - val_loss:
0.1712
Epoch 28/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1702 - val_loss:
0.1711
Epoch 29/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1699 - val_loss:
0.1710
Epoch 30/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1701 - val_loss:
0.1709
Epoch 31/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1700 - val_loss:
0.1709
Epoch 32/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1699 - val_loss:
0.1708
Epoch 33/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1697 - val_loss:
0.1707
Epoch 34/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1696 - val_loss:
0.1706
Epoch 35/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1697 - val_loss:
0.1706
Epoch 36/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1693 - val_loss:
0.1705
Epoch 37/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1694 - val_loss:
0.1704
Epoch 38/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1697 - val_loss:
0.1703
Epoch 39/50
```

```
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1694 - val_loss:
0.1703
Epoch 40/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1693 - val_loss:
0.1702
Epoch 41/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1692 - val_loss:
0.1701
Epoch 42/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1691 - val_loss:
0.1700
Epoch 43/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1691 - val_loss:
0.1700
Epoch 44/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1690 - val_loss:
0.1699
Epoch 45/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1689 - val_loss:
0.1698
Epoch 46/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1689 - val_loss:
0.1697
Epoch 47/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1687 - val_loss:
0.1696
Epoch 48/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1686 - val_loss:
0.1696
Epoch 49/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1685 - val_loss:
0.1695
Epoch 50/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1686 - val_loss:
0.1694
313/313 ━━━━━━━━━━━━━━━━━━━━ 1s 3ms/step
Code size = 10 → MSE = 0.16776
Code size = 20

/usr/local/lib/python3.11/dist-packages/keras/src/layers/reshaping/
flatten.py:37: UserWarning: Do not pass an `input_shape`/`input_dim`
argument to a layer. When using Sequential models, prefer using an
`Input(shape)` object as the first layer in the model instead.
  super().__init__(**kwargs)
/usr/local/lib/python3.11/dist-packages/keras/src/layers/core/dense.py
:87: UserWarning: Do not pass an `input_shape`/`input_dim` argument to
a layer. When using Sequential models, prefer using an `Input(shape)`
object as the first layer in the model instead.
  super().__init__(activity_regularizer=activity_regularizer,
**kwargs)
```

```
Epoch 1/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 5s 3ms/step - loss: 0.1771 - val_loss:
0.1779
Epoch 2/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1769 - val_loss:
0.1776
Epoch 3/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1765 - val_loss:
0.1773
Epoch 4/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1760 - val_loss:
0.1770
Epoch 5/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1759 - val_loss:
0.1768
Epoch 6/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1756 - val_loss:
0.1765
Epoch 7/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1755 - val_loss:
0.1763
Epoch 8/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1753 - val_loss:
0.1761
Epoch 9/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1749 - val_loss:
0.1759
Epoch 10/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1749 - val_loss:
0.1756
Epoch 11/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1747 - val_loss:
0.1754
Epoch 12/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1744 - val_loss:
0.1753
Epoch 13/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1739 - val_loss:
0.1751
Epoch 14/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1740 - val_loss:
0.1749
Epoch 15/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1739 - val_loss:
0.1747
Epoch 16/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1736 - val_loss:
0.1746
Epoch 17/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1733 - val_loss:
```

```
0.1744
Epoch 18/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1733 - val_loss:
0.1743
Epoch 19/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1731 - val_loss:
0.1742
Epoch 20/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1733 - val_loss:
0.1740
Epoch 21/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1732 - val_loss:
0.1739
Epoch 22/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1729 - val_loss:
0.1738
Epoch 23/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1728 - val_loss:
0.1736
Epoch 24/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1724 - val_loss:
0.1735
Epoch 25/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1724 - val_loss:
0.1734
Epoch 26/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1724 - val_loss:
0.1733
Epoch 27/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1721 - val_loss:
0.1732
Epoch 28/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1718 - val_loss:
0.1731
Epoch 29/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1718 - val_loss:
0.1730
Epoch 30/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1718 - val_loss:
0.1729
Epoch 31/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1720 - val_loss:
0.1727
Epoch 32/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1716 - val_loss:
0.1726
Epoch 33/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1717 - val_loss:
0.1725
Epoch 34/50
```

```
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1714 - val_loss:
0.1724
Epoch 35/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1712 - val_loss:
0.1723
Epoch 36/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1714 - val_loss:
0.1722
Epoch 37/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1713 - val_loss:
0.1721
Epoch 38/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1711 - val_loss:
0.1720
Epoch 39/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1709 - val_loss:
0.1719
Epoch 40/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1707 - val_loss:
0.1718
Epoch 41/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1707 - val_loss:
0.1717
Epoch 42/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1707 - val_loss:
0.1716
Epoch 43/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1705 - val_loss:
0.1715
Epoch 44/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1701 - val_loss:
0.1714
Epoch 45/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1700 - val_loss:
0.1712
Epoch 46/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1705 - val_loss:
0.1711
Epoch 47/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1701 - val_loss:
0.1710
Epoch 48/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1701 - val_loss:
0.1709
Epoch 49/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1700 - val_loss:
0.1708
Epoch 50/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1697 - val_loss:
0.1707
```

```
313/313 ━━━━━━━━━━━━━━━━━━━━ 1s 2ms/step
Code size = 20 → MSE = 0.16902
Code size = 40

/usr/local/lib/python3.11/dist-packages/keras/src/layers/reshaping/
flatten.py:37: UserWarning: Do not pass an `input_shape`/`input_dim`
argument to a layer. When using Sequential models, prefer using an
`Input(shape)` object as the first layer in the model instead.
  super().__init__(**kwargs)
/usr/local/lib/python3.11/dist-packages/keras/src/layers/core/dense.py
:87: UserWarning: Do not pass an `input_shape`/`input_dim` argument to
a layer. When using Sequential models, prefer using an `Input(shape)`
object as the first layer in the model instead.
  super().__init__(activity_regularizer=activity_regularizer,
**kwargs)

Epoch 1/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 5s 3ms/step - loss: 0.1743 - val_loss:
0.1750
Epoch 2/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1741 - val_loss:
0.1747
Epoch 3/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1739 - val_loss:
0.1743
Epoch 4/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1731 - val_loss:
0.1740
Epoch 5/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1730 - val_loss:
0.1737
Epoch 6/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1723 - val_loss:
0.1734
Epoch 7/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1723 - val_loss:
0.1731
Epoch 8/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1720 - val_loss:
0.1728
Epoch 9/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1717 - val_loss:
0.1725
Epoch 10/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1715 - val_loss:
0.1722
Epoch 11/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1710 - val_loss:
0.1720
Epoch 12/50
```

```
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1711 - val_loss:
0.1718
Epoch 13/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1706 - val_loss:
0.1715
Epoch 14/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1706 - val_loss:
0.1713
Epoch 15/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1702 - val_loss:
0.1711
Epoch 16/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1701 - val_loss:
0.1708
Epoch 17/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1696 - val_loss:
0.1706
Epoch 18/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1696 - val_loss:
0.1704
Epoch 19/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1694 - val_loss:
0.1702
Epoch 20/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1691 - val_loss:
0.1700
Epoch 21/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1690 - val_loss:
0.1698
Epoch 22/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1689 - val_loss:
0.1696
Epoch 23/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1688 - val_loss:
0.1694
Epoch 24/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1683 - val_loss:
0.1692
Epoch 25/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1682 - val_loss:
0.1690
Epoch 26/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1682 - val_loss:
0.1688
Epoch 27/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1677 - val_loss:
0.1686
Epoch 28/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1677 - val_loss:
```

```
0.1685
Epoch 29/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1676 - val_loss:
0.1683
Epoch 30/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1673 - val_loss:
0.1681
Epoch 31/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1670 - val_loss:
0.1679
Epoch 32/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1668 - val_loss:
0.1677
Epoch 33/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1667 - val_loss:
0.1675
Epoch 34/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1666 - val_loss:
0.1673
Epoch 35/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1662 - val_loss:
0.1672
Epoch 36/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1661 - val_loss:
0.1670
Epoch 37/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1660 - val_loss:
0.1668
Epoch 38/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1659 - val_loss:
0.1666
Epoch 39/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1658 - val_loss:
0.1664
Epoch 40/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1653 - val_loss:
0.1662
Epoch 41/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1651 - val_loss:
0.1660
Epoch 42/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1647 - val_loss:
0.1658
Epoch 43/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1650 - val_loss:
0.1657
Epoch 44/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1649 - val_loss:
0.1655
```

```
Epoch 45/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1646 - val_loss:
0.1653
Epoch 46/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1644 - val_loss:
0.1651
Epoch 47/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1643 - val_loss:
0.1649
Epoch 48/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1638 - val_loss:
0.1647
Epoch 49/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1637 - val_loss:
0.1645
Epoch 50/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1635 - val_loss:
0.1643
313/313 ━━━━━━━━━━━━━━━━━━━━ 1s 2ms/step
Code size = 40 → MSE = 0.16275
```

b.Test whether the reconstruction is improved if an additional hidden layer with 100 neurons was used in the stacked autoencoder.

```
#Building the Stacked Autoencoder:
from sklearn.metrics import mean_squared_error
def build_stacked_ad(code_size):
    encoder = keras.models.Sequential([
        keras.layers.Flatten(input_shape=[28,28]),
        keras.layers.Dense(128, activation="selu"),
        keras.layers.Dense(100, activation="selu"),
        keras.layers.Dense(code_size, activation="selu"),
    ])
    #Note that its not mandatory to have the same number of hidden
layers in the decoder part, the only thing that has to be take care is
that the output and input should match (Dimensions).
    decoder = keras.models.Sequential([
        keras.layers.Dense(100,
activation="selu",input_shape=[code_size]),
        keras.layers.Dense(128, activation="selu"),
        keras.layers.Dense(28*28, activation="sigmoid"),
        keras.layers.Reshape([28,28])
    ])

    autoencoder = keras.models.Sequential([encoder,decoder])
    #Compile the model
    autoencoder.compile(loss="mse",
optimizer=keras.optimizers.SGD(learning_rate=0.0001))
    history = autoencoder.fit(x_train_n, x_train_n, epochs=50,
```

```
validation_data=(x_valid,x_valid), verbose=1)
    x_test_recon = autoencoder.predict(x_test)
    mse = mean_squared_error(x_test.flatten(),x_test_recon.flatten())

    return mse

for i in [10,20,40]:
    print(f"Code size = {i}")
    mse = build_stacked_ad(code_size=i)
    print(f"Code size = {i} → MSE = {mse:.5f}")


Code size = 10

/usr/local/lib/python3.11/dist-packages/keras/src/layers/reshaping/
flatten.py:37: UserWarning: Do not pass an `input_shape`/`input_dim`
argument to a layer. When using Sequential models, prefer using an
`Input(shape)` object as the first layer in the model instead.
  super().__init__(**kwargs)
/usr/local/lib/python3.11/dist-packages/keras/src/layers/core/dense.py
:87: UserWarning: Do not pass an `input_shape`/`input_dim` argument to
a layer. When using Sequential models, prefer using an `Input(shape)`
object as the first layer in the model instead.
  super().__init__(activity_regularizer=activity_regularizer,
**kwargs)

Epoch 1/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 6s 3ms/step - loss: 0.1737 - val_loss:
0.1746
Epoch 2/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1737 - val_loss:
0.1742
Epoch 3/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1729 - val_loss:
0.1739
Epoch 4/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1729 - val_loss:
0.1736
Epoch 5/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1728 - val_loss:
0.1734
Epoch 6/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1723 - val_loss:
0.1731
Epoch 7/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1718 - val_loss:
0.1729
Epoch 8/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1719 - val_loss:
0.1727
```

```
Epoch 9/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1718 - val_loss:
0.1725
Epoch 10/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1715 - val_loss:
0.1723
Epoch 11/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1711 - val_loss:
0.1721
Epoch 12/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1710 - val_loss:
0.1719
Epoch 13/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1709 - val_loss:
0.1717
Epoch 14/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1707 - val_loss:
0.1716
Epoch 15/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1705 - val_loss:
0.1714
Epoch 16/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1707 - val_loss:
0.1713
Epoch 17/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1703 - val_loss:
0.1711
Epoch 18/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1702 - val_loss:
0.1710
Epoch 19/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1699 - val_loss:
0.1708
Epoch 20/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1699 - val_loss:
0.1707
Epoch 21/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1696 - val_loss:
0.1705
Epoch 22/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1694 - val_loss:
0.1704
Epoch 23/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1692 - val_loss:
0.1703
Epoch 24/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1694 - val_loss:
0.1701
Epoch 25/50
```

```
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1692 - val_loss:
0.1700
Epoch 26/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1689 - val_loss:
0.1698
Epoch 27/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1686 - val_loss:
0.1697
Epoch 28/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1687 - val_loss:
0.1696
Epoch 29/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1683 - val_loss:
0.1694
Epoch 30/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1686 - val_loss:
0.1693
Epoch 31/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1680 - val_loss:
0.1691
Epoch 32/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1682 - val_loss:
0.1690
Epoch 33/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1681 - val_loss:
0.1689
Epoch 34/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1677 - val_loss:
0.1687
Epoch 35/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1678 - val_loss:
0.1686
Epoch 36/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1678 - val_loss:
0.1684
Epoch 37/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1673 - val_loss:
0.1683
Epoch 38/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1675 - val_loss:
0.1682
Epoch 39/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1672 - val_loss:
0.1680
Epoch 40/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1673 - val_loss:
0.1679
Epoch 41/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1668 - val_loss:
```

```
0.1677
Epoch 42/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1667 - val_loss:
0.1676
Epoch 43/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1666 - val_loss:
0.1674
Epoch 44/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1665 - val_loss:
0.1673
Epoch 45/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1663 - val_loss:
0.1671
Epoch 46/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1663 - val_loss:
0.1670
Epoch 47/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1658 - val_loss:
0.1668
Epoch 48/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1658 - val_loss:
0.1667
Epoch 49/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1656 - val_loss:
0.1665
Epoch 50/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1656 - val_loss:
0.1664
313/313 ━━━━━━━━━━━━━━━━━━━━ 1s 2ms/step
Code size = 10 → MSE = 0.16476
Code size = 20

/usr/local/lib/python3.11/dist-packages/keras/src/layers/reshaping/
flatten.py:37: UserWarning: Do not pass an `input_shape`/`input_dim`
argument to a layer. When using Sequential models, prefer using an
`Input(shape)` object as the first layer in the model instead.
  super().__init__(**kwargs)
/usr/local/lib/python3.11/dist-packages/keras/src/layers/core/dense.py
:87: UserWarning: Do not pass an `input_shape`/`input_dim` argument to
a layer. When using Sequential models, prefer using an `Input(shape)`
object as the first layer in the model instead.
  super().__init__(activity_regularizer=activity_regularizer,
**kwargs)

Epoch 1/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 5s 3ms/step - loss: 0.1814 - val_loss:
0.1818
Epoch 2/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1806 - val_loss:
0.1809
```

```
Epoch 3/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1797 - val_loss:
0.1800
Epoch 4/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1787 - val_loss:
0.1792
Epoch 5/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1780 - val_loss:
0.1785
Epoch 6/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1774 - val_loss:
0.1779
Epoch 7/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1766 - val_loss:
0.1774
Epoch 8/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1761 - val_loss:
0.1769
Epoch 9/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1758 - val_loss:
0.1765
Epoch 10/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1751 - val_loss:
0.1762
Epoch 11/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1751 - val_loss:
0.1758
Epoch 12/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1750 - val_loss:
0.1755
Epoch 13/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1741 - val_loss:
0.1753
Epoch 14/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1743 - val_loss:
0.1750
Epoch 15/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1739 - val_loss:
0.1748
Epoch 16/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1737 - val_loss:
0.1746
Epoch 17/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1734 - val_loss:
0.1744
Epoch 18/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1735 - val_loss:
0.1742
Epoch 19/50
```

```
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1731 - val_loss:
0.1740
Epoch 20/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1728 - val_loss:
0.1738
Epoch 21/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1726 - val_loss:
0.1737
Epoch 22/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1724 - val_loss:
0.1735
Epoch 23/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1725 - val_loss:
0.1733
Epoch 24/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1725 - val_loss:
0.1732
Epoch 25/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1722 - val_loss:
0.1730
Epoch 26/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1717 - val_loss:
0.1729
Epoch 27/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1717 - val_loss:
0.1727
Epoch 28/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1718 - val_loss:
0.1726
Epoch 29/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1713 - val_loss:
0.1724
Epoch 30/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1713 - val_loss:
0.1723
Epoch 31/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1712 - val_loss:
0.1721
Epoch 32/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1711 - val_loss:
0.1720
Epoch 33/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1706 - val_loss:
0.1718
Epoch 34/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1708 - val_loss:
0.1717
Epoch 35/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1706 - val_loss:
```

```
0.1715
Epoch 36/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1705 - val_loss:
0.1714
Epoch 37/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1700 - val_loss:
0.1712
Epoch 38/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1699 - val_loss:
0.1711
Epoch 39/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1699 - val_loss:
0.1709
Epoch 40/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1700 - val_loss:
0.1708
Epoch 41/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1698 - val_loss:
0.1706
Epoch 42/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1694 - val_loss:
0.1704
Epoch 43/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1693 - val_loss:
0.1703
Epoch 44/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 3s 2ms/step - loss: 0.1693 - val_loss:
0.1701
Epoch 45/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1691 - val_loss:
0.1700
Epoch 46/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1690 - val_loss:
0.1698
Epoch 47/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1687 - val_loss:
0.1696
Epoch 48/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1687 - val_loss:
0.1694
Epoch 49/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1684 - val_loss:
0.1693
Epoch 50/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1685 - val_loss:
0.1691
313/313 ━━━━━━━━━━━━━━━━━━━━ 1s 2ms/step
Code size = 20 → MSE = 0.16745
Code size = 40
```

```
/usr/local/lib/python3.11/dist-packages/keras/src/layers/reshaping/
flatten.py:37: UserWarning: Do not pass an `input_shape`/`input_dim`
argument to a layer. When using Sequential models, prefer using an
`Input(shape)` object as the first layer in the model instead.
  super().__init__(**kwargs)
/usr/local/lib/python3.11/dist-packages/keras/src/layers/core/dense.py
:87: UserWarning: Do not pass an `input_shape`/`input_dim` argument to
a layer. When using Sequential models, prefer using an `Input(shape)`
object as the first layer in the model instead.
  super().__init__(activity_regularizer=activity_regularizer,
**kwargs)

Epoch 1/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 5s 3ms/step - loss: 0.1796 - val_loss:
0.1801
Epoch 2/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1786 - val_loss:
0.1793
Epoch 3/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1782 - val_loss:
0.1785
Epoch 4/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1773 - val_loss:
0.1779
Epoch 5/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1767 - val_loss:
0.1772
Epoch 6/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1760 - val_loss:
0.1767
Epoch 7/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1754 - val_loss:
0.1762
Epoch 8/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1752 - val_loss:
0.1757
Epoch 9/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1744 - val_loss:
0.1753
Epoch 10/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1740 - val_loss:
0.1748
Epoch 11/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1739 - val_loss:
0.1745
Epoch 12/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1734 - val_loss:
0.1741
Epoch 13/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1730 - val_loss:
```

```
0.1737
Epoch 14/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1724 - val_loss:
0.1734
Epoch 15/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1724 - val_loss:
0.1730
Epoch 16/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1719 - val_loss:
0.1727
Epoch 17/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1717 - val_loss:
0.1724
Epoch 18/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1712 - val_loss:
0.1721
Epoch 19/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1710 - val_loss:
0.1718
Epoch 20/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1708 - val_loss:
0.1715
Epoch 21/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1706 - val_loss:
0.1712
Epoch 22/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1702 - val_loss:
0.1709
Epoch 23/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1697 - val_loss:
0.1706
Epoch 24/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1695 - val_loss:
0.1703
Epoch 25/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1694 - val_loss:
0.1700
Epoch 26/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1690 - val_loss:
0.1697
Epoch 27/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1689 - val_loss:
0.1694
Epoch 28/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1685 - val_loss:
0.1691
Epoch 29/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1680 - val_loss:
0.1689
```

```
Epoch 30/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1680 - val_loss:
0.1686
Epoch 31/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1676 - val_loss:
0.1683
Epoch 32/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1671 - val_loss:
0.1680
Epoch 33/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1669 - val_loss:
0.1677
Epoch 34/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1667 - val_loss:
0.1674
Epoch 35/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1663 - val_loss:
0.1671
Epoch 36/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1659 - val_loss:
0.1668
Epoch 37/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1657 - val_loss:
0.1665
Epoch 38/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1657 - val_loss:
0.1662
Epoch 39/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1651 - val_loss:
0.1660
Epoch 40/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1648 - val_loss:
0.1657
Epoch 41/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1645 - val_loss:
0.1654
Epoch 42/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1643 - val_loss:
0.1650
Epoch 43/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1639 - val_loss:
0.1647
Epoch 44/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1636 - val_loss:
0.1644
Epoch 45/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1637 - val_loss:
0.1641
Epoch 46/50
```

```
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1632 - val_loss:
0.1638
Epoch 47/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1628 - val_loss:
0.1635
Epoch 48/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1626 - val_loss:
0.1632
Epoch 49/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1621 - val_loss:
0.1629
Epoch 50/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.1617 - val_loss:
0.1625
313/313 ━━━━━━━━━━━━━━━━━━━━ 1s 2ms/step
Code size = 40 → MSE = 0.16100
```

2. Denoised Autoencoder:

a.) Compare the MSE when the strength (standard deviation) of the Gaussian noise in the denoised autoencoder is set to 0.25and 0.75 respectively.

```
from tensorflow import keras
from sklearn.metrics import mean_squared_error

def train_denoise_gaussian(stddev):
    encoder = keras.models.Sequential([
        keras.layers.Flatten(input_shape=[28, 28]),
        keras.layers.GaussianNoise(stddev),
        keras.layers.Dense(100, activation="selu"),
        keras.layers.Dense(30, activation="selu")
    ])

    decoder = keras.models.Sequential([
        keras.layers.Dense(100, activation="selu", input_shape=[30]),
        keras.layers.Dense(28 * 28, activation="sigmoid"),
        keras.layers.Reshape([28, 28])
    ])

    model = keras.models.Sequential([encoder, decoder])
    model.compile(loss="mse",
optimizer=keras.optimizers.SGD(learning_rate=0.0005))
    model.fit(x_train_n, x_train_n, epochs=50,
validation_data=(x_valid, x_valid), verbose=0)

    x_test_recon = model.predict(x_test)
```

```
    mse = mean_squared_error(x_test.flatten(), x_test_recon.flatten())
    return mse

# Compare
for std in [0.25, 0.75]:
    mse = train_denoise_gaussian(stddev=std)
    print(f"Gaussian Noise stddev = {std} → Test MSE = {mse:.5f}")
```

```
/usr/local/lib/python3.11/dist-packages/keras/src/layers/reshaping/
flatten.py:37: UserWarning: Do not pass an `input_shape`/`input_dim`
argument to a layer. When using Sequential models, prefer using an
`Input(shape)` object as the first layer in the model instead.
  super().__init__(**kwargs)
/usr/local/lib/python3.11/dist-packages/keras/src/layers/core/dense.py
:87: UserWarning: Do not pass an `input_shape`/`input_dim` argument to
a layer. When using Sequential models, prefer using an `Input(shape)`
object as the first layer in the model instead.
  super().__init__(activity_regularizer=activity_regularizer,
**kwargs)

313/313 ━━━━━━━━━━━━━━━━━━━━ 1s 2ms/step
Gaussian Noise stddev = 0.25 → Test MSE = 0.11079

/usr/local/lib/python3.11/dist-packages/keras/src/layers/reshaping/
flatten.py:37: UserWarning: Do not pass an `input_shape`/`input_dim`
argument to a layer. When using Sequential models, prefer using an
`Input(shape)` object as the first layer in the model instead.
  super().__init__(**kwargs)
/usr/local/lib/python3.11/dist-packages/keras/src/layers/core/dense.py
:87: UserWarning: Do not pass an `input_shape`/`input_dim` argument to
a layer. When using Sequential models, prefer using an `Input(shape)`
object as the first layer in the model instead.
  super().__init__(activity_regularizer=activity_regularizer,
**kwargs)

313/313 ━━━━━━━━━━━━━━━━━━━━ 1s 2ms/step
Gaussian Noise stddev = 0.75 → Test MSE = 0.13052
```

```
def train_denoise_dropout(dropout_rate):
    encoder = keras.models.Sequential([
        keras.layers.Flatten(input_shape=[28, 28]),
        keras.layers.Dropout(dropout_rate),
        keras.layers.Dense(100, activation="selu"),
        keras.layers.Dense(30, activation="selu")
    ])

    decoder = keras.models.Sequential([
        keras.layers.Dense(100, activation="selu", input_shape=[30]),
        keras.layers.Dense(28 * 28, activation="sigmoid"),
        keras.layers.Reshape([28, 28])
    ])
```

```
    model = keras.models.Sequential([encoder, decoder])
    model.compile(loss="mse",
optimizer=keras.optimizers.SGD(learning_rate=0.0005))
    model.fit(x_train_n, x_train_n, epochs=50,
validation_data=(x_valid, x_valid), verbose=0)

    x_test_recon = model.predict(x_test)
    mse = mean_squared_error(x_test.flatten(), x_test_recon.flatten())
    return mse

# Compare
for drop in [0.25, 0.75]:
    mse = train_denoise_dropout(dropout_rate=drop)
    print(f"Dropout rate = {drop} → Test MSE = {mse:.5f}")
```

```
/usr/local/lib/python3.11/dist-packages/keras/src/layers/reshaping/
flatten.py:37: UserWarning: Do not pass an `input_shape`/`input_dim`
argument to a layer. When using Sequential models, prefer using an
`Input(shape)` object as the first layer in the model instead.
  super().__init__(**kwargs)
/usr/local/lib/python3.11/dist-packages/keras/src/layers/core/dense.py
:87: UserWarning: Do not pass an `input_shape`/`input_dim` argument to
a layer. When using Sequential models, prefer using an `Input(shape)`
object as the first layer in the model instead.
  super().__init__(activity_regularizer=activity_regularizer,
**kwargs)

313/313 ━━━━━━━━━━━━━━━━━━━━ 1s 2ms/step
Dropout rate = 0.25 → Test MSE = 0.12190

/usr/local/lib/python3.11/dist-packages/keras/src/layers/reshaping/
flatten.py:37: UserWarning: Do not pass an `input_shape`/`input_dim`
argument to a layer. When using Sequential models, prefer using an
`Input(shape)` object as the first layer in the model instead.
  super().__init__(**kwargs)
/usr/local/lib/python3.11/dist-packages/keras/src/layers/core/dense.py
:87: UserWarning: Do not pass an `input_shape`/`input_dim` argument to
a layer. When using Sequential models, prefer using an `Input(shape)`
object as the first layer in the model instead.
  super().__init__(activity_regularizer=activity_regularizer,
**kwargs)

313/313 ━━━━━━━━━━━━━━━━━━━━ 1s 2ms/step
Dropout rate = 0.75 → Test MSE = 0.11567
```

Latent loss

- Kullback–Leibler (KL) divergence between the Gaussian distribution and the actual distribution of the codings

$$\mathscr{L} = -\frac{1}{2}\sum_{i=1}^{n}\left[1 + \log\left(\sigma_i^2\right) - \sigma_i^2 - \mu_i^2\right]$$

n is the codings' dimensionality

$\gamma = log(\sigma^2)$

$$\mathscr{L} = -\frac{1}{2}\sum_{i=1}^{n}\left[1 + \gamma_i - \exp\left(\gamma_i\right) - \mu_i^2\right]$$

3.Modify the variational autoencoder that uses σ instead of log variance.

```
import tensorflow as tf
from tensorflow import keras
from tensorflow.keras import backend as K

# Sampling Layer (Reparameterization Trick)
class Sampling(keras.layers.Layer):
    def call(self, inputs):
        mean, sigma = inputs
        epsilon = K.random_normal(shape=tf.shape(sigma))
        return mean + sigma * epsilon

# Custom KL Divergence Layer (adds KL loss to model)
class KLDivergenceLayer(keras.layers.Layer):
    def call(self, inputs):
        mean, sigma = inputs
        kl_loss = -0.5 * tf.reduce_sum(
            1 + tf.math.log(tf.square(sigma) + 1e-8) -
```

```
tf.square(sigma) - tf.square(mean),
            axis=1
        )
        self.add_loss(tf.reduce_mean(kl_loss) / 784.)  # normalize by
image size
        return inputs  # pass forward

# Build the Variational Autoencoder
def building_vae(code_size):
    # ----- Encoder -----
    inputs = keras.layers.Input(shape=(28, 28))
    x = keras.layers.Flatten()(inputs)
    x = keras.layers.Dense(150, activation="selu")(x)
    x = keras.layers.Dense(100, activation="selu")(x)

    codings_mean = keras.layers.Dense(code_size)(x)
    codings_sigma = keras.layers.Dense(code_size,
activation="softplus")(x)  # σ > 0

    # Add KL loss via custom layer
    codings_mean, codings_sigma = KLDivergenceLayer()([codings_mean,
codings_sigma])
    codings = Sampling()([codings_mean, codings_sigma])

    # ----- Decoder -----
    decoder_inputs = keras.layers.Input(shape=(code_size,))
    x = keras.layers.Dense(100, activation="selu")(decoder_inputs)
    x = keras.layers.Dense(150, activation="selu")(x)
    x = keras.layers.Dense(28 * 28, activation="sigmoid")(x)
    decoder_outputs = keras.layers.Reshape((28, 28))(x)

    # Define decoder model
    decoder = keras.Model(inputs=decoder_inputs,
outputs=decoder_outputs)

    # Connect encoder and decoder
    reconstructed = decoder(codings)
    vae = keras.Model(inputs=inputs, outputs=reconstructed)

    # Compile
    vae.compile(loss="binary_crossentropy", optimizer="rmsprop")

    return vae

# Load and prepare dataset
(X_train_full, _), (X_test, _) =
keras.datasets.fashion_mnist.load_data()
X_train, X_valid = X_train_full[5000:] / 255.0, X_train_full[:5000] /
255.0
X_test = X_test / 255.0
```

```python
# Build and train the model
vae = building_vae(code_size=10)
vae.summary()
vae.fit(X_train, X_train, epochs=50, batch_size=32,
validation_data=(X_valid, X_valid),verbose=1)
```

```
Model: "functional_14"
```

Layer (type) Connected to	Output Shape	Param #
input_layer_13 - (InputLayer)	(None, 28, 28)	0
flatten_6 (Flatten) input_layer_13[0][0]	(None, 784)	0
dense_38 (Dense) flatten_6[0][0]	(None, 150)	117,750
dense_39 (Dense) dense_38[0][0]	(None, 100)	15,100
dense_40 (Dense) dense_39[0][0]	(None, 10)	1,010
dense_41 (Dense) dense_39[0][0]	(None, 10)	1,010
kl_divergence_layer_1 dense_40[0][0], (KLDivergenceLayer) dense_41[0][0]	[(None, 10), (None, 10)]	0
sampling_5 (Sampling) kl_divergence_layer_1…	(None, 10)	0

```
│                              │                             │
 kl_divergence_layer_1… │
├──────────────────────────────┼─────────────────────────────┼──────────────────
┼──────────────────────────────┤
 functional_13                │ (None, 28, 28)              │         134,634
 sampling_5[0][0]             │
 (Functional)                 │                             │
                              │
└──────────────────────────────┴─────────────────────────────┴──────────────────
┴──────────────────────────────┘

 Total params: 269,504 (1.03 MB)

 Trainable params: 269,504 (1.03 MB)

 Non-trainable params: 0 (0.00 B)

Epoch 1/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 9s 4ms/step - loss: 0.4066 - val_loss:
0.3354
Epoch 2/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.3352 - val_loss:
0.3237
Epoch 3/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.3270 - val_loss:
0.3231
Epoch 4/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.3219 - val_loss:
0.3163
Epoch 5/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.3199 - val_loss:
0.3143
Epoch 6/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.3187 - val_loss:
0.3146
Epoch 7/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.3159 - val_loss:
0.3133
Epoch 8/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.3154 - val_loss:
0.3120
Epoch 9/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.3148 - val_loss:
0.3126
Epoch 10/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.3149 - val_loss:
0.3111
Epoch 11/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.3135 - val_loss:
0.3104
```

```
Epoch 12/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.3138 - val_loss:
0.3102
Epoch 13/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.3129 - val_loss:
0.3101
Epoch 14/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.3116 - val_loss:
0.3098
Epoch 15/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.3115 - val_loss:
0.3093
Epoch 16/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.3113 - val_loss:
0.3084
Epoch 17/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.3121 - val_loss:
0.3085
Epoch 18/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.3117 - val_loss:
0.3090
Epoch 19/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.3108 - val_loss:
0.3084
Epoch 20/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.3108 - val_loss:
0.3106
Epoch 21/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.3106 - val_loss:
0.3076
Epoch 22/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.3091 - val_loss:
0.3088
Epoch 23/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.3098 - val_loss:
0.3075
Epoch 24/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.3101 - val_loss:
0.3072
Epoch 25/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.3087 - val_loss:
0.3071
Epoch 26/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.3095 - val_loss:
0.3063
Epoch 27/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.3101 - val_loss:
0.3090
Epoch 28/50
```

```
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.3097 - val_loss:
0.3075
Epoch 29/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.3094 - val_loss:
0.3064
Epoch 30/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.3085 - val_loss:
0.3065
Epoch 31/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.3096 - val_loss:
0.3058
Epoch 32/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.3085 - val_loss:
0.3072
Epoch 33/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.3084 - val_loss:
0.3055
Epoch 34/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.3093 - val_loss:
0.3063
Epoch 35/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.3078 - val_loss:
0.3068
Epoch 36/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.3079 - val_loss:
0.3059
Epoch 37/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.3087 - val_loss:
0.3071
Epoch 38/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.3084 - val_loss:
0.3059
Epoch 39/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.3078 - val_loss:
0.3051
Epoch 40/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.3074 - val_loss:
0.3068
Epoch 41/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.3073 - val_loss:
0.3063
Epoch 42/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.3077 - val_loss:
0.3075
Epoch 43/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.3080 - val_loss:
0.3058
Epoch 44/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.3079 - val_loss:
```

```
0.3059
Epoch 45/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.3085 - val_loss:
0.3051
Epoch 46/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.3065 - val_loss:
0.3052
Epoch 47/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.3080 - val_loss:
0.3049
Epoch 48/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.3072 - val_loss:
0.3052
Epoch 49/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.3077 - val_loss:
0.3053
Epoch 50/50
1719/1719 ━━━━━━━━━━━━━━━━━━━━ 4s 2ms/step - loss: 0.3074 - val_loss:
0.3080

<keras.src.callbacks.history.History at 0x7956b85230d0>
```

```python
import matplotlib.pyplot as plt

# Function to display images side by side: original vs reconstructed
def plot_image(image):
    plt.imshow(image, cmap="gray")
    plt.axis("off")

def show_original_and_reconstructed(originals, reconstructions,
n_images=12):
    plt.figure(figsize=(n_images * 1.5, 3))
    for i in range(n_images):
        # Original image
        plt.subplot(2, n_images, i + 1)
        plot_image(originals[i])
        if i == 0:
            plt.title("Original")

        # Reconstructed image
        plt.subplot(2, n_images, i + 1 + n_images)
        plot_image(reconstructions[i])
        if i == 0:
            plt.title("Reconstructed")

    plt.tight_layout()
    plt.show()

# Reconstruct 12 test images using the full VAE model
test_samples = X_test[:12]
```

```
reconstructed_images = vae.predict(test_samples)

# Visualize
show_original_and_reconstructed(test_samples, reconstructed_images,
n_images=12)
```

```
1/1 ━━━━━━━━━━━━━━━━━━━━ 1s 925ms/step
```