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Assignment 5

Enrollment Number: 2020CSB039

In [23]:
```
import numpy as np
from tensorflow import keras
from tensorflow.keras.datasets import mnist
from tensorflow.keras.models import Sequential
from tensorflow.keras.layers import Dense, Flatten, Dropout, Input
from sklearn.model_selection import train_test_split
import cv2
import matplotlib.pyplot as plt
import time

# Define the RBF function
def RBF(x, c, s):
    return np.exp(((x - c) ** 2) / (2 * s ** 2))

# Define the transformation function
def transform(image):
    image = np.pad(image, (2, 2))
    c = np.mean(image)
    s = np.std(image)
    return RBF(image, c, s).flatten()

# Load the MNIST dataset
(x_train, y_train), (x_test, y_test) = mnist.load_data()

# Transform the images
x_train_transformed = np.array([transform(image) for image in x_train])
x_test_transformed = np.array([transform(image) for image in x_test])

# Normalize the data to values between 0 and 1
x_train_transformed = x_train_transformed / 255.0
x_test_transformed = x_test_transformed / 255.0

# Split the dataset into training, validation, and test sets
x_train, x_val, y_train, y_val = train_test_split(x_train_transformed, y_
x_val, x_test, y_val, y_test = train_test_split(x_val, y_val, test_size=0
```

In [24]:
```
best_hyperparameters = {}
best_accuracy = 0
model= Sequential()
```

In [25]:
```
def train_model(hyperparameters):
  for hyperparams in hyperparameters:
    # Build and compile the fully connected neural network
    global model
    model = Sequential()
```

```
    model.add(Input(shape=(1024,)))

    for neurons in hyperparams['hidden_layers']:
        model.add(Dense(neurons, activation='sigmoid'))

    model.add(Dropout(hyperparams['rate']))

    # Add output layer
    model.add(Dense(10, activation='softmax'))

    # Compile the model with the specified learning rate
    model.compile(optimizer=keras.optimizers.Adam(learning_rate=hyperpara
                  loss='categorical_crossentropy',
                  metrics=['accuracy'])

    start_time = time.time()

    # Train the model
    history = model.fit(x_train, keras.utils.to_categorical(y_train, 10),
              validation_data=(x_val, keras.utils.to_categorical(y_val, 1
              epochs=50,
              batch_size=64)

    end_time = time.time()

    training_time = end_time - start_time

    # Evaluate the model on the test set
    test_loss, test_accuracy = model.evaluate(x_test, keras.utils.to_cate
    print(f'Test accuracy with hyperparameters {hyperparams}: {test_accur

    global best_hyperparameters
    global best_accuracy

    if test_accuracy > best_accuracy:
      best_accuracy = test_accuracy
      best_hyperparameters = hyperparams

    plot_training_history(history, hyperparams)

    return [test_accuracy, training_time]
```

In [26]:

```
def plot_training_history(history, hyperparams):
    # Extract training and validation loss and accuracy
    train_loss = history.history['loss']
    val_loss = history.history['val_loss']
    train_accuracy = history.history['accuracy']
    val_accuracy = history.history['val_accuracy']

    # Create an array of epoch numbers
    epochs = range(1, len(train_loss) + 1)
```

```
    # Plot loss vs epoch
    plt.figure()
    plt.plot(epochs, train_loss, 'bo', label='Training loss')
    plt.plot(epochs, val_loss, 'b', label='Validation loss')
    plt.title(f'Loss vs Epoch ({hyperparams})')
    plt.xlabel('Epoch')
    plt.ylabel('Loss')
    plt.legend()
    plt.show()

    # Plot accuracy vs epoch
    plt.figure()
    plt.plot(epochs, train_accuracy, 'bo', label='Training accuracy')
    plt.plot(epochs, val_accuracy, 'b', label='Validation accuracy')
    plt.title(f'Loss vs Epoch ({hyperparams})')
    plt.xlabel('Epoch')
    plt.ylabel('Accuracy')
    plt.legend()
    plt.show()
```

In [27]:
```
# Define different sets of hyperparameters
hyperparameters = [
    {'hidden_layers': [16], 'learning_rate': 0.001, 'activation': 'sigmoi
    {'hidden_layers': [16, 32], 'learning_rate': 0.001, 'activation': 'si
    {'hidden_layers': [16, 32, 64], 'learning_rate': 0.001, 'activation':
]
train_model(hyperparameters)
```

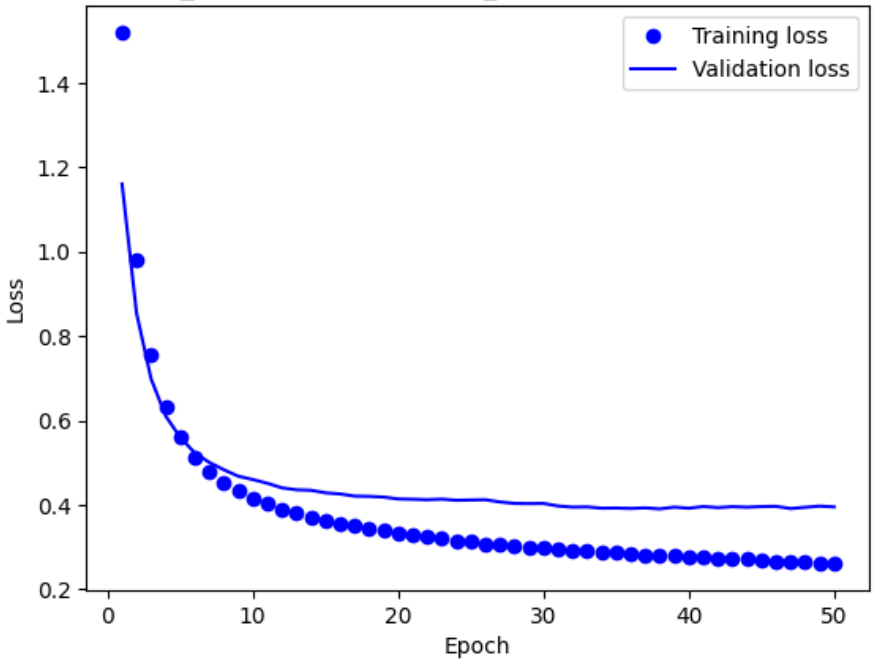
```
Epoch 1/50
750/750 [==============================] - 2s 2ms/step - loss: 1.5199 - ac
curacy: 0.6223 - val_loss: 1.1605 - val_accuracy: 0.7285
Epoch 2/50
750/750 [==============================] - 1s 2ms/step - loss: 0.9817 - ac
curacy: 0.7841 - val_loss: 0.8539 - val_accuracy: 0.8127
Epoch 3/50
750/750 [==============================] - 1s 2ms/step - loss: 0.7550 - ac
curacy: 0.8277 - val_loss: 0.6986 - val_accuracy: 0.8400
Epoch 4/50
750/750 [==============================] - 1s 2ms/step - loss: 0.6325 - ac
curacy: 0.8504 - val_loss: 0.6107 - val_accuracy: 0.8538
Epoch 5/50
750/750 [==============================] - 1s 2ms/step - loss: 0.5597 - ac
curacy: 0.8642 - val_loss: 0.5601 - val_accuracy: 0.8655
Epoch 6/50
750/750 [==============================] - 1s 2ms/step - loss: 0.5118 - ac
curacy: 0.8731 - val_loss: 0.5233 - val_accuracy: 0.8725
Epoch 7/50
750/750 [==============================] - 1s 2ms/step - loss: 0.4782 - ac
curacy: 0.8788 - val_loss: 0.5008 - val_accuracy: 0.8747
Epoch 8/50
750/750 [==============================] - 1s 2ms/step - loss: 0.4539 - ac
curacy: 0.8834 - val_loss: 0.4833 - val_accuracy: 0.8788
Epoch 9/50
750/750 [==============================] - 1s 2ms/step - loss: 0.4329 - ac
```

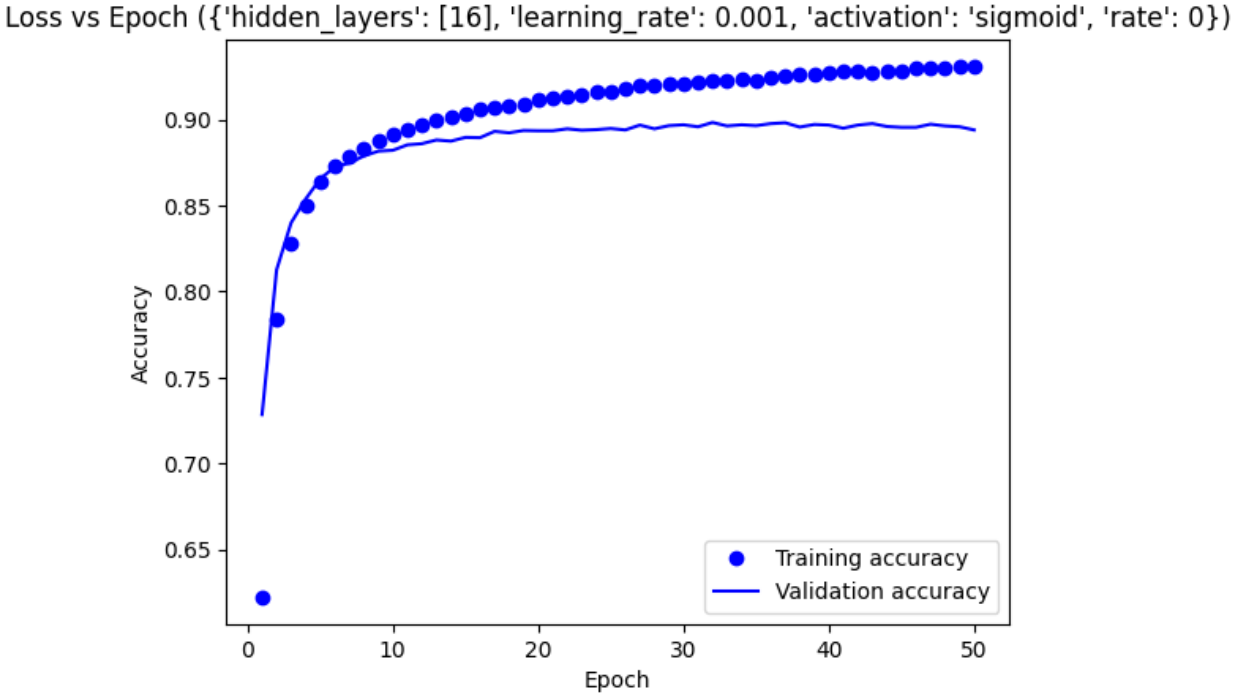
```
curacy: 0.8881 - val_loss: 0.4680 - val_accuracy: 0.8817
Epoch 10/50
750/750 [==============================] - 1s 2ms/step - loss: 0.4159 - ac
curacy: 0.8918 - val_loss: 0.4601 - val_accuracy: 0.8822
Epoch 11/50
750/750 [==============================] - 1s 2ms/step - loss: 0.4020 - ac
curacy: 0.8944 - val_loss: 0.4512 - val_accuracy: 0.8853
Epoch 12/50
750/750 [==============================] - 1s 2ms/step - loss: 0.3899 - ac
curacy: 0.8972 - val_loss: 0.4404 - val_accuracy: 0.8860
Epoch 13/50
750/750 [==============================] - 1s 2ms/step - loss: 0.3797 - ac
curacy: 0.8998 - val_loss: 0.4358 - val_accuracy: 0.8882
Epoch 14/50
750/750 [==============================] - 1s 2ms/step - loss: 0.3710 - ac
curacy: 0.9018 - val_loss: 0.4347 - val_accuracy: 0.8875
Epoch 15/50
750/750 [==============================] - 1s 2ms/step - loss: 0.3639 - ac
curacy: 0.9034 - val_loss: 0.4286 - val_accuracy: 0.8897
Epoch 16/50
750/750 [==============================] - 1s 2ms/step - loss: 0.3565 - ac
curacy: 0.9060 - val_loss: 0.4260 - val_accuracy: 0.8895
Epoch 17/50
750/750 [==============================] - 1s 2ms/step - loss: 0.3497 - ac
curacy: 0.9075 - val_loss: 0.4208 - val_accuracy: 0.8932
Epoch 18/50
750/750 [==============================] - 1s 2ms/step - loss: 0.3447 - ac
curacy: 0.9079 - val_loss: 0.4202 - val_accuracy: 0.8923
Epoch 19/50
750/750 [==============================] - 1s 2ms/step - loss: 0.3388 - ac
curacy: 0.9091 - val_loss: 0.4185 - val_accuracy: 0.8937
Epoch 20/50
750/750 [==============================] - 1s 2ms/step - loss: 0.3333 - ac
curacy: 0.9118 - val_loss: 0.4141 - val_accuracy: 0.8935
Epoch 21/50
750/750 [==============================] - 1s 2ms/step - loss: 0.3274 - ac
curacy: 0.9126 - val_loss: 0.4134 - val_accuracy: 0.8935
Epoch 22/50
750/750 [==============================] - 1s 2ms/step - loss: 0.3234 - ac
curacy: 0.9136 - val_loss: 0.4121 - val_accuracy: 0.8947
Epoch 23/50
750/750 [==============================] - 1s 2ms/step - loss: 0.3201 - ac
curacy: 0.9147 - val_loss: 0.4136 - val_accuracy: 0.8938
Epoch 24/50
750/750 [==============================] - 1s 2ms/step - loss: 0.3156 - ac
curacy: 0.9159 - val_loss: 0.4109 - val_accuracy: 0.8942
Epoch 25/50
750/750 [==============================] - 1s 2ms/step - loss: 0.3121 - ac
curacy: 0.9163 - val_loss: 0.4116 - val_accuracy: 0.8948
Epoch 26/50
750/750 [==============================] - 1s 2ms/step - loss: 0.3074 - ac
curacy: 0.9184 - val_loss: 0.4122 - val_accuracy: 0.8940
Epoch 27/50
```

```
750/750 [==============================] - 1s 2ms/step - loss: 0.3058 - ac
curacy: 0.9195 - val_loss: 0.4070 - val_accuracy: 0.8968
Epoch 28/50
750/750 [==============================] - 2s 2ms/step - loss: 0.3025 - ac
curacy: 0.9199 - val_loss: 0.4034 - val_accuracy: 0.8947
Epoch 29/50
750/750 [==============================] - 1s 2ms/step - loss: 0.3001 - ac
curacy: 0.9206 - val_loss: 0.4030 - val_accuracy: 0.8965
Epoch 30/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2977 - ac
curacy: 0.9212 - val_loss: 0.4034 - val_accuracy: 0.8970
Epoch 31/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2950 - ac
curacy: 0.9217 - val_loss: 0.3974 - val_accuracy: 0.8958
Epoch 32/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2921 - ac
curacy: 0.9223 - val_loss: 0.3947 - val_accuracy: 0.8983
Epoch 33/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2898 - ac
curacy: 0.9230 - val_loss: 0.3952 - val_accuracy: 0.8963
Epoch 34/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2871 - ac
curacy: 0.9235 - val_loss: 0.3922 - val_accuracy: 0.8970
Epoch 35/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2858 - ac
curacy: 0.9231 - val_loss: 0.3925 - val_accuracy: 0.8965
Epoch 36/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2836 - ac
curacy: 0.9247 - val_loss: 0.3916 - val_accuracy: 0.8977
Epoch 37/50
750/750 [==============================] - 2s 2ms/step - loss: 0.2816 - ac
curacy: 0.9252 - val_loss: 0.3929 - val_accuracy: 0.8982
Epoch 38/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2799 - ac
curacy: 0.9262 - val_loss: 0.3905 - val_accuracy: 0.8957
Epoch 39/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2805 - ac
curacy: 0.9261 - val_loss: 0.3947 - val_accuracy: 0.8972
Epoch 40/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2762 - ac
curacy: 0.9271 - val_loss: 0.3920 - val_accuracy: 0.8968
Epoch 41/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2751 - ac
curacy: 0.9278 - val_loss: 0.3961 - val_accuracy: 0.8950
Epoch 42/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2727 - ac
curacy: 0.9277 - val_loss: 0.3936 - val_accuracy: 0.8968
Epoch 43/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2718 - ac
curacy: 0.9276 - val_loss: 0.3958 - val_accuracy: 0.8977
Epoch 44/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2714 - ac
curacy: 0.9283 - val_loss: 0.3946 - val_accuracy: 0.8960
```

```
Epoch 45/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2701 - ac
curacy: 0.9286 - val_loss: 0.3960 - val_accuracy: 0.8955
Epoch 46/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2669 - ac
curacy: 0.9300 - val_loss: 0.3966 - val_accuracy: 0.8955
Epoch 47/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2656 - ac
curacy: 0.9299 - val_loss: 0.3913 - val_accuracy: 0.8973
Epoch 48/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2645 - ac
curacy: 0.9304 - val_loss: 0.3943 - val_accuracy: 0.8963
Epoch 49/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2628 - ac
curacy: 0.9309 - val_loss: 0.3971 - val_accuracy: 0.8958
Epoch 50/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2617 - ac
curacy: 0.9310 - val_loss: 0.3953 - val_accuracy: 0.8940
188/188 [==============================] - 0s 1ms/step - loss: 0.4291 - ac
curacy: 0.8940
Test accuracy with hyperparameters {'hidden_layers': [16], 'learning_rat
e': 0.001, 'activation': 'sigmoid', 'rate': 0}: 0.8939999938011169
```

Loss vs Epoch ({'hidden_layers': [16], 'learning_rate': 0.001, 'activation': 'sigmoid', 'rate': 0})





Out[27]: [0.8939999938011169, 82.57977414131165]

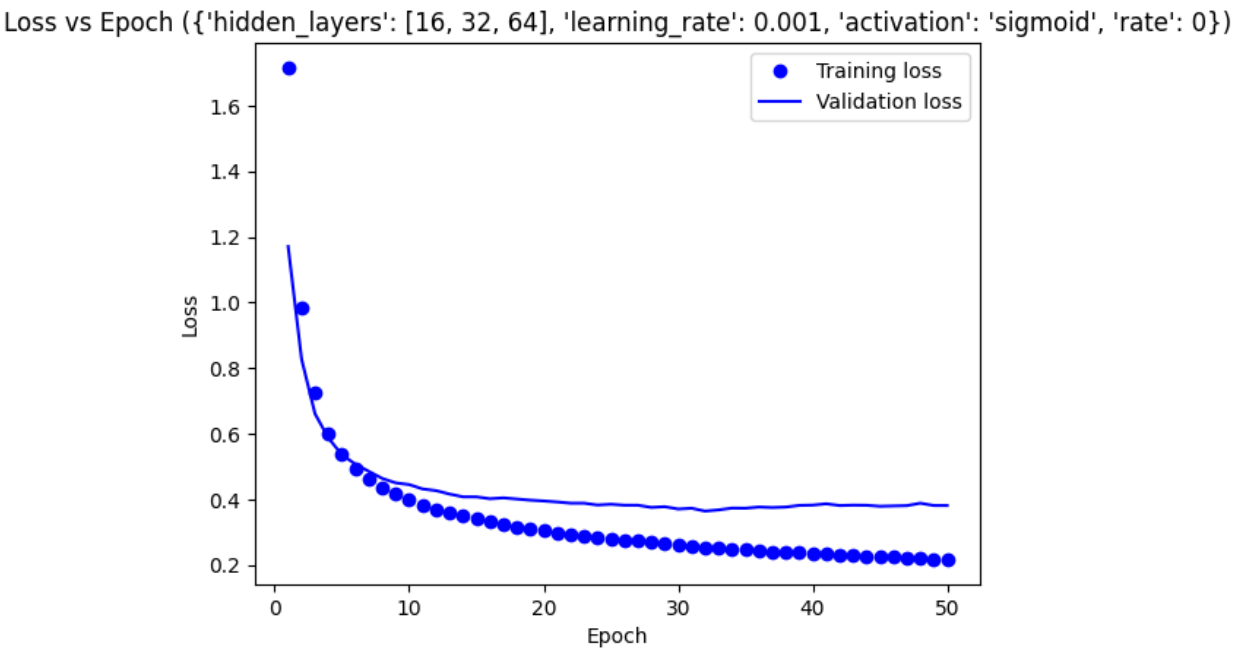
In [28]:
```
# Define different sets of hyperparameters
hyperparameters = [
    {'hidden_layers': [16, 32, 64], 'learning_rate': 0.001, 'activation':
    {'hidden_layers': [16, 32, 64], 'learning_rate': 0.001, 'activation':
    {'hidden_layers': [16, 32, 64], 'learning_rate': 0.001, 'activation':
]
train_model(hyperparameters)
```

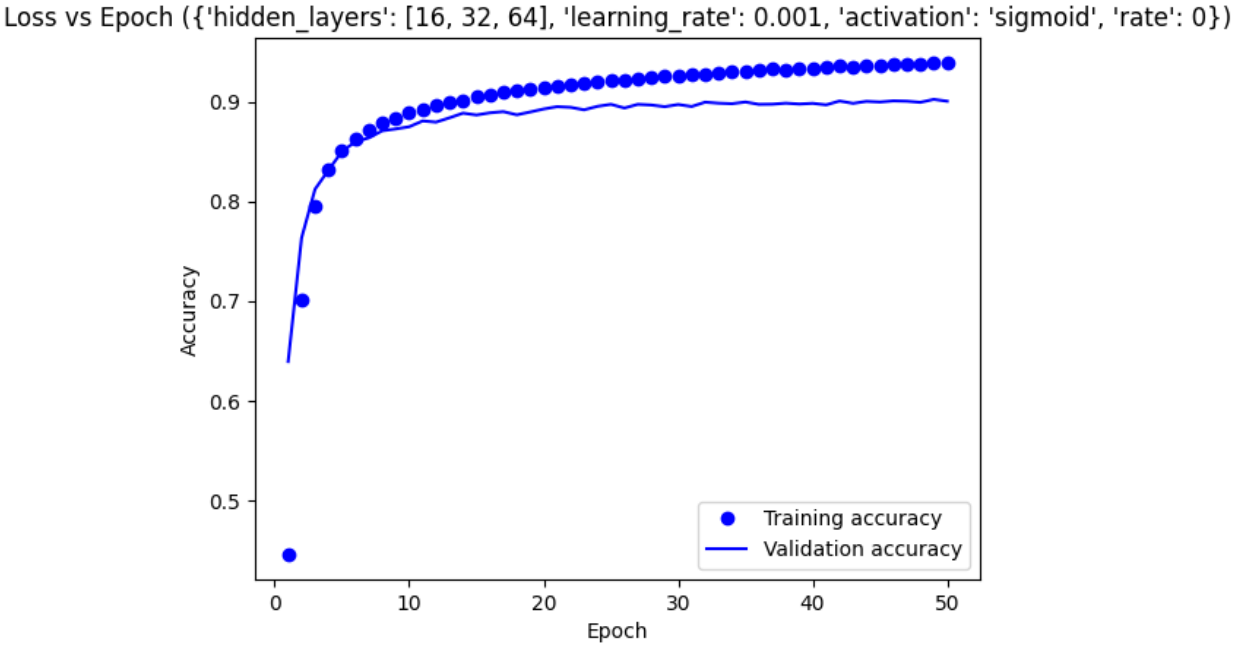
```
Epoch 1/50
750/750 [==============================] - 2s 2ms/step - loss: 1.7158 - ac
curacy: 0.4456 - val_loss: 1.1705 - val_accuracy: 0.6392
Epoch 2/50
750/750 [==============================] - 1s 2ms/step - loss: 0.9842 - ac
curacy: 0.7013 - val_loss: 0.8271 - val_accuracy: 0.7633
Epoch 3/50
750/750 [==============================] - 1s 2ms/step - loss: 0.7251 - ac
curacy: 0.7949 - val_loss: 0.6605 - val_accuracy: 0.8122
Epoch 4/50
750/750 [==============================] - 1s 2ms/step - loss: 0.6021 - ac
curacy: 0.8322 - val_loss: 0.5864 - val_accuracy: 0.8313
Epoch 5/50
750/750 [==============================] - 1s 2ms/step - loss: 0.5385 - ac
curacy: 0.8513 - val_loss: 0.5355 - val_accuracy: 0.8500
Epoch 6/50
750/750 [==============================] - 1s 2ms/step - loss: 0.4941 - ac
curacy: 0.8625 - val_loss: 0.5071 - val_accuracy: 0.8598
Epoch 7/50
750/750 [==============================] - 2s 2ms/step - loss: 0.4620 - ac
curacy: 0.8709 - val_loss: 0.4852 - val_accuracy: 0.8637
Epoch 8/50
750/750 [==============================] - 2s 2ms/step - loss: 0.4355 - ac
```

```
curacy: 0.8782 - val_loss: 0.4635 - val_accuracy: 0.8708
Epoch 9/50
750/750 [==============================] - 1s 2ms/step - loss: 0.4161 - ac
curacy: 0.8830 - val_loss: 0.4501 - val_accuracy: 0.8727
Epoch 10/50
750/750 [==============================] - 1s 2ms/step - loss: 0.3989 - ac
curacy: 0.8885 - val_loss: 0.4449 - val_accuracy: 0.8748
Epoch 11/50
750/750 [==============================] - 1s 2ms/step - loss: 0.3834 - ac
curacy: 0.8928 - val_loss: 0.4315 - val_accuracy: 0.8807
Epoch 12/50
750/750 [==============================] - 1s 2ms/step - loss: 0.3703 - ac
curacy: 0.8961 - val_loss: 0.4265 - val_accuracy: 0.8795
Epoch 13/50
750/750 [==============================] - 1s 2ms/step - loss: 0.3586 - ac
curacy: 0.8988 - val_loss: 0.4160 - val_accuracy: 0.8838
Epoch 14/50
750/750 [==============================] - 1s 2ms/step - loss: 0.3482 - ac
curacy: 0.9016 - val_loss: 0.4076 - val_accuracy: 0.8885
Epoch 15/50
750/750 [==============================] - 1s 2ms/step - loss: 0.3392 - ac
curacy: 0.9046 - val_loss: 0.4074 - val_accuracy: 0.8867
Epoch 16/50
750/750 [==============================] - 2s 2ms/step - loss: 0.3308 - ac
curacy: 0.9065 - val_loss: 0.4017 - val_accuracy: 0.8888
Epoch 17/50
750/750 [==============================] - 1s 2ms/step - loss: 0.3226 - ac
curacy: 0.9093 - val_loss: 0.4044 - val_accuracy: 0.8900
Epoch 18/50
750/750 [==============================] - 1s 2ms/step - loss: 0.3152 - ac
curacy: 0.9107 - val_loss: 0.4009 - val_accuracy: 0.8868
Epoch 19/50
750/750 [==============================] - 1s 2ms/step - loss: 0.3089 - ac
curacy: 0.9128 - val_loss: 0.3974 - val_accuracy: 0.8897
Epoch 20/50
750/750 [==============================] - 1s 2ms/step - loss: 0.3037 - ac
curacy: 0.9144 - val_loss: 0.3949 - val_accuracy: 0.8927
Epoch 21/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2975 - ac
curacy: 0.9161 - val_loss: 0.3919 - val_accuracy: 0.8950
Epoch 22/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2937 - ac
curacy: 0.9165 - val_loss: 0.3882 - val_accuracy: 0.8943
Epoch 23/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2887 - ac
curacy: 0.9178 - val_loss: 0.3882 - val_accuracy: 0.8918
Epoch 24/50
750/750 [==============================] - 2s 2ms/step - loss: 0.2832 - ac
curacy: 0.9196 - val_loss: 0.3827 - val_accuracy: 0.8953
Epoch 25/50
750/750 [==============================] - 2s 2ms/step - loss: 0.2788 - ac
curacy: 0.9212 - val_loss: 0.3849 - val_accuracy: 0.8973
Epoch 26/50
```

```
750/750 [==============================] - 1s 2ms/step - loss: 0.2752 - ac
curacy: 0.9220 - val_loss: 0.3820 - val_accuracy: 0.8937
Epoch 27/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2735 - ac
curacy: 0.9228 - val_loss: 0.3820 - val_accuracy: 0.8973
Epoch 28/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2679 - ac
curacy: 0.9241 - val_loss: 0.3753 - val_accuracy: 0.8967
Epoch 29/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2638 - ac
curacy: 0.9255 - val_loss: 0.3775 - val_accuracy: 0.8950
Epoch 30/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2620 - ac
curacy: 0.9263 - val_loss: 0.3704 - val_accuracy: 0.8972
Epoch 31/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2570 - ac
curacy: 0.9270 - val_loss: 0.3728 - val_accuracy: 0.8952
Epoch 32/50
750/750 [==============================] - 2s 2ms/step - loss: 0.2540 - ac
curacy: 0.9277 - val_loss: 0.3640 - val_accuracy: 0.8995
Epoch 33/50
750/750 [==============================] - 2s 2ms/step - loss: 0.2519 - ac
curacy: 0.9294 - val_loss: 0.3678 - val_accuracy: 0.8985
Epoch 34/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2494 - ac
curacy: 0.9300 - val_loss: 0.3732 - val_accuracy: 0.8980
Epoch 35/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2482 - ac
curacy: 0.9303 - val_loss: 0.3728 - val_accuracy: 0.8997
Epoch 36/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2440 - ac
curacy: 0.9314 - val_loss: 0.3765 - val_accuracy: 0.8973
Epoch 37/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2402 - ac
curacy: 0.9325 - val_loss: 0.3749 - val_accuracy: 0.8975
Epoch 38/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2386 - ac
curacy: 0.9324 - val_loss: 0.3764 - val_accuracy: 0.8985
Epoch 39/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2370 - ac
curacy: 0.9332 - val_loss: 0.3815 - val_accuracy: 0.8977
Epoch 40/50
750/750 [==============================] - 2s 2ms/step - loss: 0.2331 - ac
curacy: 0.9339 - val_loss: 0.3823 - val_accuracy: 0.8983
Epoch 41/50
750/750 [==============================] - 2s 2ms/step - loss: 0.2323 - ac
curacy: 0.9342 - val_loss: 0.3864 - val_accuracy: 0.8968
Epoch 42/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2303 - ac
curacy: 0.9359 - val_loss: 0.3811 - val_accuracy: 0.9007
Epoch 43/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2284 - ac
curacy: 0.9353 - val_loss: 0.3822 - val_accuracy: 0.8983
```

```
Epoch 44/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2264 - ac
curacy: 0.9361 - val_loss: 0.3818 - val_accuracy: 0.9003
Epoch 45/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2257 - ac
curacy: 0.9369 - val_loss: 0.3788 - val_accuracy: 0.8997
Epoch 46/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2242 - ac
curacy: 0.9376 - val_loss: 0.3798 - val_accuracy: 0.9008
Epoch 47/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2230 - ac
curacy: 0.9377 - val_loss: 0.3808 - val_accuracy: 0.9005
Epoch 48/50
750/750 [==============================] - 2s 2ms/step - loss: 0.2203 - ac
curacy: 0.9383 - val_loss: 0.3882 - val_accuracy: 0.8993
Epoch 49/50
750/750 [==============================] - 2s 2ms/step - loss: 0.2186 - ac
curacy: 0.9389 - val_loss: 0.3811 - val_accuracy: 0.9023
Epoch 50/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2168 - ac
curacy: 0.9392 - val_loss: 0.3811 - val_accuracy: 0.9005
188/188 [==============================] - 0s 1ms/step - loss: 0.3632 - ac
curacy: 0.9017
Test accuracy with hyperparameters {'hidden_layers': [16, 32, 64], 'learni
ng_rate': 0.001, 'activation': 'sigmoid', 'rate': 0}: 0.9016666412353516
```





Out[28]: [0.9016666412353516, 82.64873576164246]

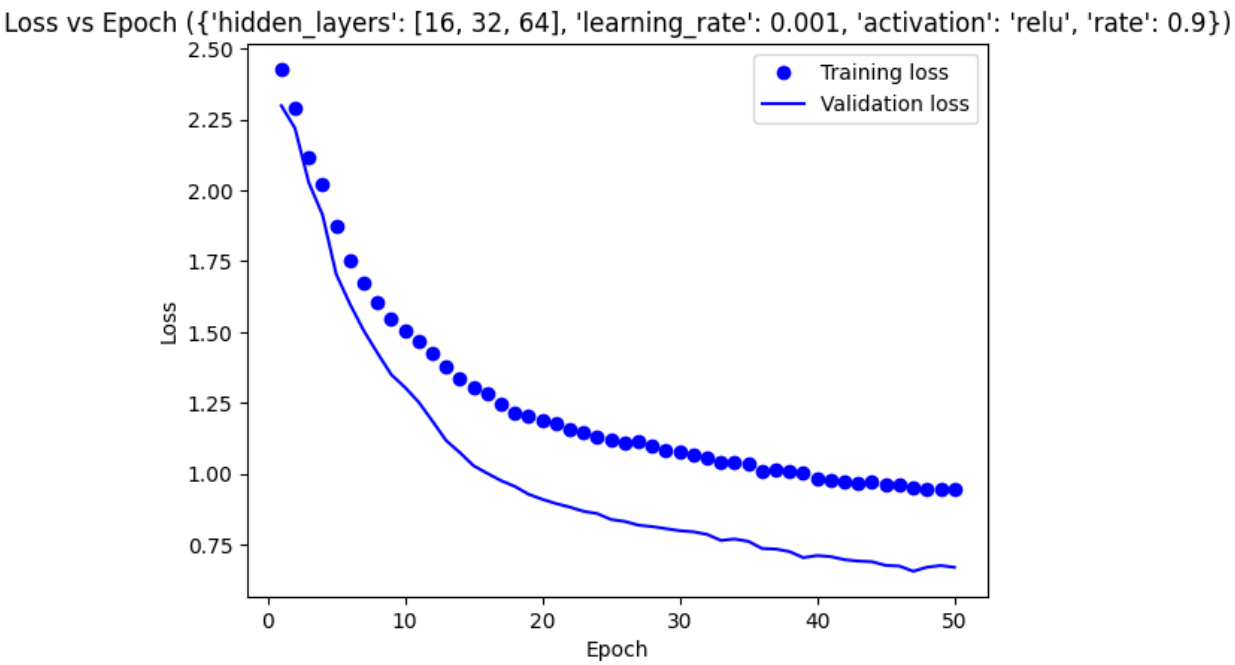
In [29]:
```
# Define different sets of hyperparameters
hyperparameters = [
    {'hidden_layers': [16, 32, 64], 'learning_rate': 0.001, 'activation':
    {'hidden_layers': [16, 32, 64], 'learning_rate': 0.001, 'activation':
    {'hidden_layers': [16, 32, 64], 'learning_rate': 0.001, 'activation':
    {'hidden_layers': [16, 32, 64], 'learning_rate': 0.001, 'activation':
    {'hidden_layers': [16, 32, 64], 'learning_rate': 0.001, 'activation':
]
train_model(hyperparameters)
```

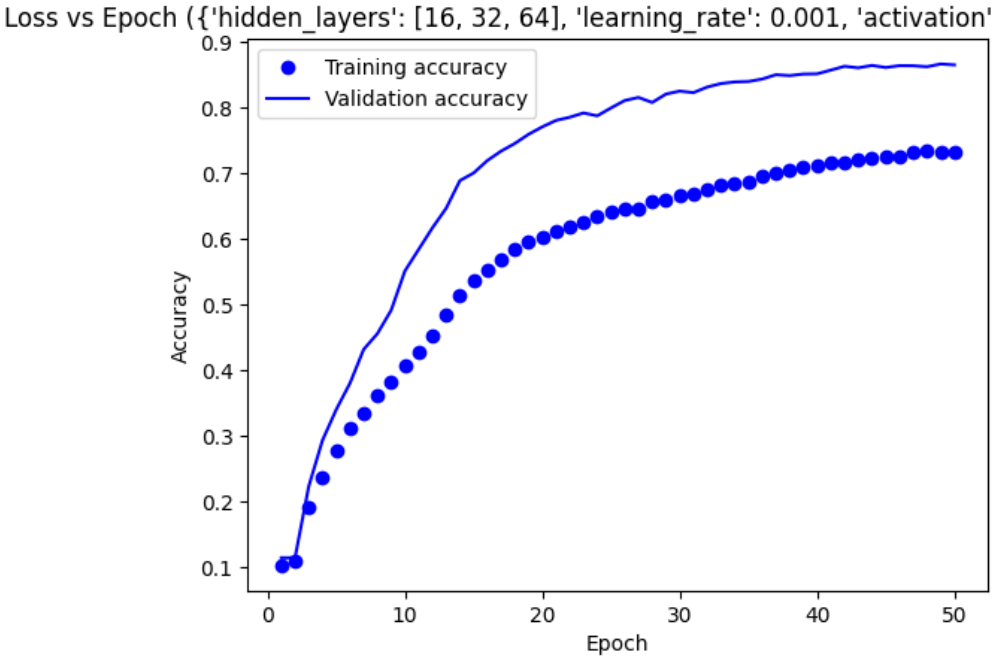
```
Epoch 1/50
750/750 [==============================] - 2s 2ms/step - loss: 2.4283 - ac
curacy: 0.1020 - val_loss: 2.2995 - val_accuracy: 0.1137
Epoch 2/50
750/750 [==============================] - 1s 2ms/step - loss: 2.2934 - ac
curacy: 0.1080 - val_loss: 2.2193 - val_accuracy: 0.1137
Epoch 3/50
750/750 [==============================] - 1s 2ms/step - loss: 2.1175 - ac
curacy: 0.1906 - val_loss: 2.0274 - val_accuracy: 0.2227
Epoch 4/50
750/750 [==============================] - 1s 2ms/step - loss: 2.0234 - ac
curacy: 0.2354 - val_loss: 1.9142 - val_accuracy: 0.2928
Epoch 5/50
750/750 [==============================] - 1s 2ms/step - loss: 1.8751 - ac
curacy: 0.2765 - val_loss: 1.7039 - val_accuracy: 0.3397
Epoch 6/50
750/750 [==============================] - 2s 2ms/step - loss: 1.7509 - ac
curacy: 0.3103 - val_loss: 1.5986 - val_accuracy: 0.3798
Epoch 7/50
750/750 [==============================] - 2s 2ms/step - loss: 1.6736 - ac
curacy: 0.3337 - val_loss: 1.5050 - val_accuracy: 0.4315
Epoch 8/50
750/750 [==============================] - 1s 2ms/step - loss: 1.6023 - ac
```

```
curacy: 0.3608 - val_loss: 1.4259 - val_accuracy: 0.4555
Epoch 9/50
750/750 [==============================] - 1s 2ms/step - loss: 1.5479 - ac
curacy: 0.3825 - val_loss: 1.3501 - val_accuracy: 0.4912
Epoch 10/50
750/750 [==============================] - 1s 2ms/step - loss: 1.5060 - ac
curacy: 0.4073 - val_loss: 1.3049 - val_accuracy: 0.5510
Epoch 11/50
750/750 [==============================] - 2s 2ms/step - loss: 1.4652 - ac
curacy: 0.4282 - val_loss: 1.2527 - val_accuracy: 0.5838
Epoch 12/50
750/750 [==============================] - 1s 2ms/step - loss: 1.4243 - ac
curacy: 0.4527 - val_loss: 1.1858 - val_accuracy: 0.6167
Epoch 13/50
750/750 [==============================] - 1s 2ms/step - loss: 1.3805 - ac
curacy: 0.4832 - val_loss: 1.1169 - val_accuracy: 0.6465
Epoch 14/50
750/750 [==============================] - 2s 2ms/step - loss: 1.3340 - ac
curacy: 0.5141 - val_loss: 1.0744 - val_accuracy: 0.6887
Epoch 15/50
750/750 [==============================] - 1s 2ms/step - loss: 1.3014 - ac
curacy: 0.5362 - val_loss: 1.0279 - val_accuracy: 0.7003
Epoch 16/50
750/750 [==============================] - 1s 2ms/step - loss: 1.2805 - ac
curacy: 0.5522 - val_loss: 1.0010 - val_accuracy: 0.7193
Epoch 17/50
750/750 [==============================] - 1s 2ms/step - loss: 1.2485 - ac
curacy: 0.5684 - val_loss: 0.9753 - val_accuracy: 0.7337
Epoch 18/50
750/750 [==============================] - 1s 2ms/step - loss: 1.2167 - ac
curacy: 0.5848 - val_loss: 0.9550 - val_accuracy: 0.7453
Epoch 19/50
750/750 [==============================] - 1s 2ms/step - loss: 1.2019 - ac
curacy: 0.5954 - val_loss: 0.9273 - val_accuracy: 0.7593
Epoch 20/50
750/750 [==============================] - 1s 2ms/step - loss: 1.1897 - ac
curacy: 0.6028 - val_loss: 0.9095 - val_accuracy: 0.7707
Epoch 21/50
750/750 [==============================] - 2s 2ms/step - loss: 1.1785 - ac
curacy: 0.6109 - val_loss: 0.8943 - val_accuracy: 0.7805
Epoch 22/50
750/750 [==============================] - 2s 2ms/step - loss: 1.1585 - ac
curacy: 0.6182 - val_loss: 0.8820 - val_accuracy: 0.7853
Epoch 23/50
750/750 [==============================] - 1s 2ms/step - loss: 1.1457 - ac
curacy: 0.6258 - val_loss: 0.8671 - val_accuracy: 0.7918
Epoch 24/50
750/750 [==============================] - 1s 2ms/step - loss: 1.1314 - ac
curacy: 0.6337 - val_loss: 0.8590 - val_accuracy: 0.7875
Epoch 25/50
750/750 [==============================] - 1s 2ms/step - loss: 1.1173 - ac
curacy: 0.6416 - val_loss: 0.8382 - val_accuracy: 0.7995
Epoch 26/50
```

```
750/750 [==============================] - 1s 2ms/step - loss: 1.1113 - ac
curacy: 0.6462 - val_loss: 0.8313 - val_accuracy: 0.8108
Epoch 27/50
750/750 [==============================] - 1s 2ms/step - loss: 1.1116 - ac
curacy: 0.6459 - val_loss: 0.8181 - val_accuracy: 0.8155
Epoch 28/50
750/750 [==============================] - 1s 2ms/step - loss: 1.0969 - ac
curacy: 0.6570 - val_loss: 0.8131 - val_accuracy: 0.8078
Epoch 29/50
750/750 [==============================] - 2s 2ms/step - loss: 1.0821 - ac
curacy: 0.6599 - val_loss: 0.8058 - val_accuracy: 0.8207
Epoch 30/50
750/750 [==============================] - 2s 2ms/step - loss: 1.0754 - ac
curacy: 0.6658 - val_loss: 0.7985 - val_accuracy: 0.8252
Epoch 31/50
750/750 [==============================] - 1s 2ms/step - loss: 1.0672 - ac
curacy: 0.6692 - val_loss: 0.7948 - val_accuracy: 0.8228
Epoch 32/50
750/750 [==============================] - 1s 2ms/step - loss: 1.0569 - ac
curacy: 0.6761 - val_loss: 0.7854 - val_accuracy: 0.8313
Epoch 33/50
750/750 [==============================] - 1s 2ms/step - loss: 1.0390 - ac
curacy: 0.6822 - val_loss: 0.7643 - val_accuracy: 0.8367
Epoch 34/50
750/750 [==============================] - 1s 2ms/step - loss: 1.0403 - ac
curacy: 0.6836 - val_loss: 0.7691 - val_accuracy: 0.8392
Epoch 35/50
750/750 [==============================] - 1s 2ms/step - loss: 1.0361 - ac
curacy: 0.6871 - val_loss: 0.7610 - val_accuracy: 0.8398
Epoch 36/50
750/750 [==============================] - 1s 2ms/step - loss: 1.0104 - ac
curacy: 0.6967 - val_loss: 0.7357 - val_accuracy: 0.8435
Epoch 37/50
750/750 [==============================] - 2s 2ms/step - loss: 1.0117 - ac
curacy: 0.7007 - val_loss: 0.7338 - val_accuracy: 0.8502
Epoch 38/50
750/750 [==============================] - 2s 2ms/step - loss: 1.0099 - ac
curacy: 0.7041 - val_loss: 0.7247 - val_accuracy: 0.8488
Epoch 39/50
750/750 [==============================] - 1s 2ms/step - loss: 1.0013 - ac
curacy: 0.7082 - val_loss: 0.7034 - val_accuracy: 0.8512
Epoch 40/50
750/750 [==============================] - 1s 2ms/step - loss: 0.9841 - ac
curacy: 0.7127 - val_loss: 0.7107 - val_accuracy: 0.8515
Epoch 41/50
750/750 [==============================] - 1s 2ms/step - loss: 0.9771 - ac
curacy: 0.7152 - val_loss: 0.7070 - val_accuracy: 0.8572
Epoch 42/50
750/750 [==============================] - 1s 2ms/step - loss: 0.9734 - ac
curacy: 0.7165 - val_loss: 0.6963 - val_accuracy: 0.8630
Epoch 43/50
750/750 [==============================] - 1s 2ms/step - loss: 0.9665 - ac
curacy: 0.7206 - val_loss: 0.6913 - val_accuracy: 0.8607
```

```
Epoch 44/50
750/750 [==============================] - 1s 2ms/step - loss: 0.9727 - ac
curacy: 0.7225 - val_loss: 0.6890 - val_accuracy: 0.8643
Epoch 45/50
750/750 [==============================] - 2s 2ms/step - loss: 0.9631 - ac
curacy: 0.7243 - val_loss: 0.6761 - val_accuracy: 0.8612
Epoch 46/50
750/750 [==============================] - 2s 2ms/step - loss: 0.9591 - ac
curacy: 0.7255 - val_loss: 0.6737 - val_accuracy: 0.8640
Epoch 47/50
750/750 [==============================] - 1s 2ms/step - loss: 0.9505 - ac
curacy: 0.7311 - val_loss: 0.6554 - val_accuracy: 0.8638
Epoch 48/50
750/750 [==============================] - 1s 2ms/step - loss: 0.9445 - ac
curacy: 0.7333 - val_loss: 0.6697 - val_accuracy: 0.8623
Epoch 49/50
750/750 [==============================] - 1s 2ms/step - loss: 0.9437 - ac
curacy: 0.7328 - val_loss: 0.6756 - val_accuracy: 0.8665
Epoch 50/50
750/750 [==============================] - 1s 2ms/step - loss: 0.9441 - ac
curacy: 0.7321 - val_loss: 0.6693 - val_accuracy: 0.8652
188/188 [==============================] - 0s 1ms/step - loss: 0.7478 - ac
curacy: 0.8593
Test accuracy with hyperparameters {'hidden_layers': [16, 32, 64], 'learni
ng_rate': 0.001, 'activation': 'relu', 'rate': 0.9}: 0.859333336353302
```





Out[29]: [0.859333336353302, 82.6546847820282]

In [30]:
```
print(best_hyperparameters)
print(best_accuracy)
```

```
{'hidden_layers': [16, 32, 64], 'learning_rate': 0.001, 'activation': 'sig
moid', 'rate': 0}
0.9016666412353516
```

In [31]:
```
import time
learning_rates_to_test = [0.01, 0.001, 0.005, 0.0001, 0.0005]
```

In [32]:
```
best_accuracy_rate = 0
best_learning_rate = 0
best_training_time = 0

for lr in learning_rates_to_test:
    best_hyperparameters['learning_rate'] = lr
    result = train_model([best_hyperparameters])

    if result[0] > best_accuracy_rate:
      best_accuracy_rate = result[0]
      best_learning_rate = lr
      best_training_time = result[1]

best_hyperparameters['learning_rate']=best_learning_rate

print(f"Best learning rate: {best_learning_rate}")
print(f"Best validation accuracy: {best_accuracy}")
print(f"Time to achieve best validation accuracy: {best_training_time} se
```

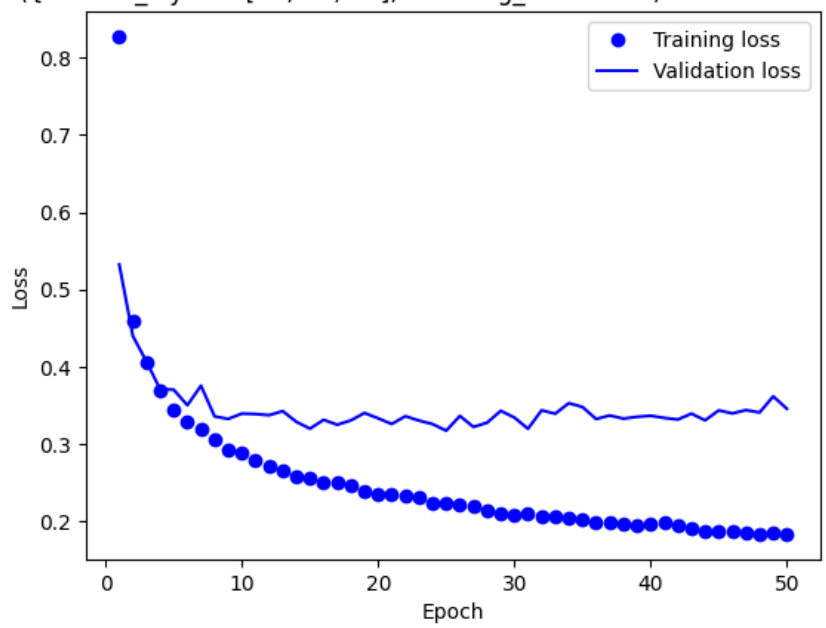
```
Epoch 1/50
750/750 [==============================] - 2s 2ms/step - loss: 0.8277 - ac
curacy: 0.7350 - val_loss: 0.5324 - val_accuracy: 0.8510
```

```
Epoch 2/50
750/750 [==============================] - 1s 2ms/step - loss: 0.4591 - ac
curacy: 0.8637 - val_loss: 0.4396 - val_accuracy: 0.8713
Epoch 3/50
750/750 [==============================] - 1s 2ms/step - loss: 0.4057 - ac
curacy: 0.8806 - val_loss: 0.4065 - val_accuracy: 0.8827
Epoch 4/50
750/750 [==============================] - 1s 2ms/step - loss: 0.3684 - ac
curacy: 0.8915 - val_loss: 0.3707 - val_accuracy: 0.8953
Epoch 5/50
750/750 [==============================] - 2s 2ms/step - loss: 0.3435 - ac
curacy: 0.8979 - val_loss: 0.3701 - val_accuracy: 0.8928
Epoch 6/50
750/750 [==============================] - 2s 2ms/step - loss: 0.3284 - ac
curacy: 0.9021 - val_loss: 0.3499 - val_accuracy: 0.8942
Epoch 7/50
750/750 [==============================] - 1s 2ms/step - loss: 0.3190 - ac
curacy: 0.9046 - val_loss: 0.3753 - val_accuracy: 0.8928
Epoch 8/50
750/750 [==============================] - 1s 2ms/step - loss: 0.3064 - ac
curacy: 0.9089 - val_loss: 0.3355 - val_accuracy: 0.9050
Epoch 9/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2919 - ac
curacy: 0.9123 - val_loss: 0.3323 - val_accuracy: 0.9033
Epoch 10/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2881 - ac
curacy: 0.9137 - val_loss: 0.3391 - val_accuracy: 0.9028
Epoch 11/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2781 - ac
curacy: 0.9176 - val_loss: 0.3386 - val_accuracy: 0.9035
Epoch 12/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2711 - ac
curacy: 0.9193 - val_loss: 0.3371 - val_accuracy: 0.9022
Epoch 13/50
750/750 [==============================] - 2s 2ms/step - loss: 0.2650 - ac
curacy: 0.9196 - val_loss: 0.3423 - val_accuracy: 0.9050
Epoch 14/50
750/750 [==============================] - 2s 2ms/step - loss: 0.2570 - ac
curacy: 0.9219 - val_loss: 0.3285 - val_accuracy: 0.9067
Epoch 15/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2557 - ac
curacy: 0.9230 - val_loss: 0.3196 - val_accuracy: 0.9083
Epoch 16/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2494 - ac
curacy: 0.9254 - val_loss: 0.3311 - val_accuracy: 0.9047
Epoch 17/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2499 - ac
curacy: 0.9245 - val_loss: 0.3247 - val_accuracy: 0.9065
Epoch 18/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2467 - ac
curacy: 0.9252 - val_loss: 0.3303 - val_accuracy: 0.9085
Epoch 19/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2377 - ac
```

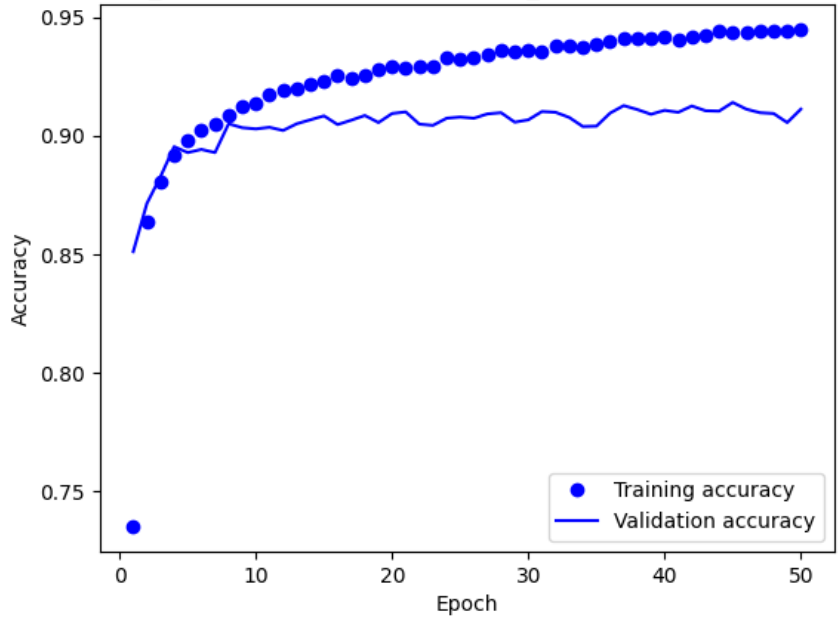
```
curacy: 0.9278 - val_loss: 0.3399 - val_accuracy: 0.9055
Epoch 20/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2354 - ac
curacy: 0.9289 - val_loss: 0.3331 - val_accuracy: 0.9093
Epoch 21/50
750/750 [==============================] - 2s 2ms/step - loss: 0.2341 - ac
curacy: 0.9289 - val_loss: 0.3257 - val_accuracy: 0.9100
Epoch 22/50
750/750 [==============================] - 2s 2ms/step - loss: 0.2319 - ac
curacy: 0.9294 - val_loss: 0.3358 - val_accuracy: 0.9048
Epoch 23/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2310 - ac
curacy: 0.9295 - val_loss: 0.3301 - val_accuracy: 0.9043
Epoch 24/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2239 - ac
curacy: 0.9327 - val_loss: 0.3255 - val_accuracy: 0.9073
Epoch 25/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2223 - ac
curacy: 0.9324 - val_loss: 0.3170 - val_accuracy: 0.9078
Epoch 26/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2209 - ac
curacy: 0.9331 - val_loss: 0.3361 - val_accuracy: 0.9073
Epoch 27/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2198 - ac
curacy: 0.9343 - val_loss: 0.3218 - val_accuracy: 0.9092
Epoch 28/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2128 - ac
curacy: 0.9361 - val_loss: 0.3274 - val_accuracy: 0.9097
Epoch 29/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2099 - ac
curacy: 0.9352 - val_loss: 0.3427 - val_accuracy: 0.9057
Epoch 30/50
750/750 [==============================] - 2s 2ms/step - loss: 0.2086 - ac
curacy: 0.9361 - val_loss: 0.3341 - val_accuracy: 0.9067
Epoch 31/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2095 - ac
curacy: 0.9357 - val_loss: 0.3195 - val_accuracy: 0.9102
Epoch 32/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2055 - ac
curacy: 0.9377 - val_loss: 0.3434 - val_accuracy: 0.9098
Epoch 33/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2062 - ac
curacy: 0.9382 - val_loss: 0.3390 - val_accuracy: 0.9077
Epoch 34/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2047 - ac
curacy: 0.9376 - val_loss: 0.3527 - val_accuracy: 0.9038
Epoch 35/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2028 - ac
curacy: 0.9387 - val_loss: 0.3477 - val_accuracy: 0.9040
Epoch 36/50
750/750 [==============================] - 1s 2ms/step - loss: 0.1984 - ac
curacy: 0.9401 - val_loss: 0.3321 - val_accuracy: 0.9095
Epoch 37/50
```

```
750/750 [==============================] - 1s 2ms/step - loss: 0.1978 - ac
curacy: 0.9409 - val_loss: 0.3367 - val_accuracy: 0.9127
Epoch 38/50
750/750 [==============================] - 2s 2ms/step - loss: 0.1967 - ac
curacy: 0.9412 - val_loss: 0.3326 - val_accuracy: 0.9110
Epoch 39/50
750/750 [==============================] - 1s 2ms/step - loss: 0.1951 - ac
curacy: 0.9411 - val_loss: 0.3349 - val_accuracy: 0.9090
Epoch 40/50
750/750 [==============================] - 1s 2ms/step - loss: 0.1956 - ac
curacy: 0.9418 - val_loss: 0.3364 - val_accuracy: 0.9107
Epoch 41/50
750/750 [==============================] - 1s 2ms/step - loss: 0.1972 - ac
curacy: 0.9402 - val_loss: 0.3335 - val_accuracy: 0.9098
Epoch 42/50
750/750 [==============================] - 1s 2ms/step - loss: 0.1941 - ac
curacy: 0.9419 - val_loss: 0.3315 - val_accuracy: 0.9125
Epoch 43/50
750/750 [==============================] - 1s 2ms/step - loss: 0.1906 - ac
curacy: 0.9424 - val_loss: 0.3391 - val_accuracy: 0.9105
Epoch 44/50
750/750 [==============================] - 1s 2ms/step - loss: 0.1870 - ac
curacy: 0.9440 - val_loss: 0.3304 - val_accuracy: 0.9103
Epoch 45/50
750/750 [==============================] - 1s 2ms/step - loss: 0.1873 - ac
curacy: 0.9438 - val_loss: 0.3433 - val_accuracy: 0.9140
Epoch 46/50
750/750 [==============================] - 2s 2ms/step - loss: 0.1875 - ac
curacy: 0.9433 - val_loss: 0.3394 - val_accuracy: 0.9112
Epoch 47/50
750/750 [==============================] - 1s 2ms/step - loss: 0.1842 - ac
curacy: 0.9442 - val_loss: 0.3436 - val_accuracy: 0.9097
Epoch 48/50
750/750 [==============================] - 1s 2ms/step - loss: 0.1836 - ac
curacy: 0.9444 - val_loss: 0.3406 - val_accuracy: 0.9093
Epoch 49/50
750/750 [==============================] - 1s 2ms/step - loss: 0.1856 - ac
curacy: 0.9443 - val_loss: 0.3614 - val_accuracy: 0.9055
Epoch 50/50
750/750 [==============================] - 1s 2ms/step - loss: 0.1829 - ac
curacy: 0.9449 - val_loss: 0.3455 - val_accuracy: 0.9112
188/188 [==============================] - 0s 1ms/step - loss: 0.3539 - ac
curacy: 0.9073
Test accuracy with hyperparameters {'hidden_layers': [16, 32, 64], 'learni
ng_rate': 0.01, 'activation': 'sigmoid', 'rate': 0}: 0.9073333144187927
```

Loss vs Epoch ({'hidden_layers': [16, 32, 64], 'learning_rate': 0.01, 'activation': 'sigmoid', 'rate': 0})



Loss vs Epoch ({'hidden_layers': [16, 32, 64], 'learning_rate': 0.01, 'activation': 'sigmoid', 'rate': 0})



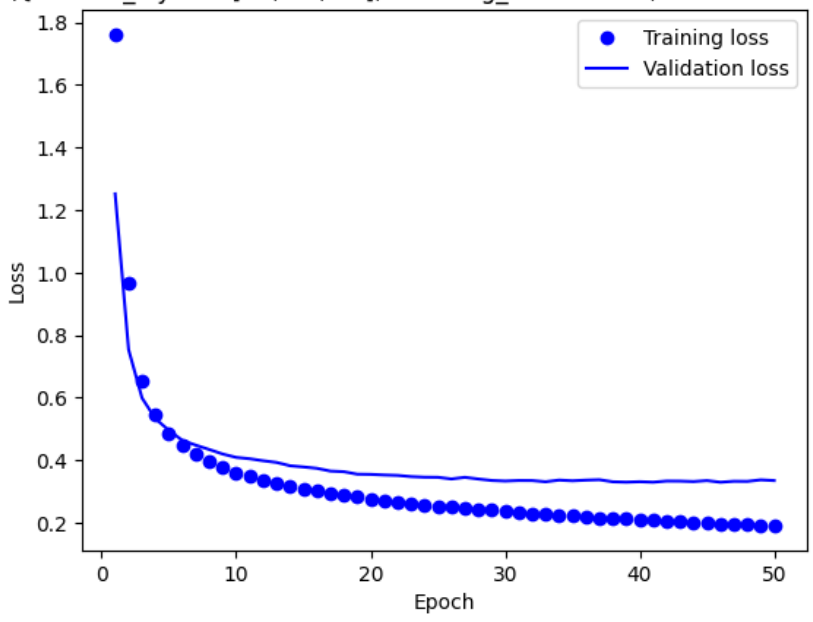

```
Epoch 1/50
750/750 [==============================] - 2s 2ms/step - loss: 1.7614 - ac
curacy: 0.3961 - val_loss: 1.2518 - val_accuracy: 0.6122
Epoch 2/50
750/750 [==============================] - 2s 2ms/step - loss: 0.9665 - ac
curacy: 0.7235 - val_loss: 0.7535 - val_accuracy: 0.7823
Epoch 3/50
750/750 [==============================] - 2s 2ms/step - loss: 0.6548 - ac
curacy: 0.8202 - val_loss: 0.5987 - val_accuracy: 0.8308
Epoch 4/50
750/750 [==============================] - 1s 2ms/step - loss: 0.5446 - ac
curacy: 0.8507 - val_loss: 0.5321 - val_accuracy: 0.8523
Epoch 5/50
750/750 [==============================] - 1s 2ms/step - loss: 0.4866 - ac
curacy: 0.8674 - val_loss: 0.4952 - val_accuracy: 0.8640
Epoch 6/50
```

```
750/750 [==============================] - 1s 2ms/step - loss: 0.4484 - ac
curacy: 0.8774 - val_loss: 0.4631 - val_accuracy: 0.8718
Epoch 7/50
750/750 [==============================] - 1s 2ms/step - loss: 0.4204 - ac
curacy: 0.8849 - val_loss: 0.4479 - val_accuracy: 0.8780
Epoch 8/50
750/750 [==============================] - 1s 2ms/step - loss: 0.3969 - ac
curacy: 0.8902 - val_loss: 0.4339 - val_accuracy: 0.8803
Epoch 9/50
750/750 [==============================] - 1s 2ms/step - loss: 0.3774 - ac
curacy: 0.8959 - val_loss: 0.4195 - val_accuracy: 0.8860
Epoch 10/50
750/750 [==============================] - 1s 2ms/step - loss: 0.3607 - ac
curacy: 0.9000 - val_loss: 0.4088 - val_accuracy: 0.8887
Epoch 11/50
750/750 [==============================] - 2s 3ms/step - loss: 0.3470 - ac
curacy: 0.9029 - val_loss: 0.4045 - val_accuracy: 0.8892
Epoch 12/50
750/750 [==============================] - 1s 2ms/step - loss: 0.3361 - ac
curacy: 0.9061 - val_loss: 0.3980 - val_accuracy: 0.8930
Epoch 13/50
750/750 [==============================] - 1s 2ms/step - loss: 0.3262 - ac
curacy: 0.9084 - val_loss: 0.3927 - val_accuracy: 0.8970
Epoch 14/50
750/750 [==============================] - 1s 2ms/step - loss: 0.3162 - ac
curacy: 0.9115 - val_loss: 0.3821 - val_accuracy: 0.8978
Epoch 15/50
750/750 [==============================] - 1s 2ms/step - loss: 0.3072 - ac
curacy: 0.9144 - val_loss: 0.3782 - val_accuracy: 0.8983
Epoch 16/50
750/750 [==============================] - 1s 2ms/step - loss: 0.3013 - ac
curacy: 0.9163 - val_loss: 0.3739 - val_accuracy: 0.9032
Epoch 17/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2941 - ac
curacy: 0.9186 - val_loss: 0.3650 - val_accuracy: 0.9033
Epoch 18/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2884 - ac
curacy: 0.9193 - val_loss: 0.3631 - val_accuracy: 0.9017
Epoch 19/50
750/750 [==============================] - 2s 2ms/step - loss: 0.2817 - ac
curacy: 0.9205 - val_loss: 0.3551 - val_accuracy: 0.9055
Epoch 20/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2755 - ac
curacy: 0.9221 - val_loss: 0.3545 - val_accuracy: 0.9048
Epoch 21/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2703 - ac
curacy: 0.9249 - val_loss: 0.3526 - val_accuracy: 0.9068
Epoch 22/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2650 - ac
curacy: 0.9249 - val_loss: 0.3512 - val_accuracy: 0.9065
Epoch 23/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2620 - ac
curacy: 0.9272 - val_loss: 0.3474 - val_accuracy: 0.9067
```

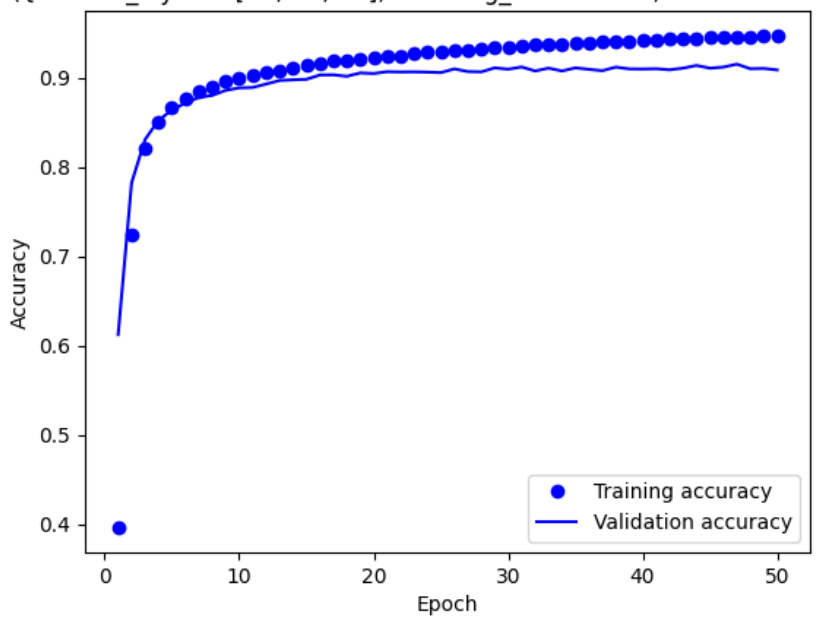
```
Epoch 24/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2568 - ac
curacy: 0.9285 - val_loss: 0.3455 - val_accuracy: 0.9063
Epoch 25/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2529 - ac
curacy: 0.9296 - val_loss: 0.3451 - val_accuracy: 0.9058
Epoch 26/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2494 - ac
curacy: 0.9301 - val_loss: 0.3398 - val_accuracy: 0.9100
Epoch 27/50
750/750 [==============================] - 2s 2ms/step - loss: 0.2451 - ac
curacy: 0.9313 - val_loss: 0.3451 - val_accuracy: 0.9070
Epoch 28/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2424 - ac
curacy: 0.9323 - val_loss: 0.3397 - val_accuracy: 0.9067
Epoch 29/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2396 - ac
curacy: 0.9335 - val_loss: 0.3350 - val_accuracy: 0.9112
Epoch 30/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2355 - ac
curacy: 0.9345 - val_loss: 0.3332 - val_accuracy: 0.9097
Epoch 31/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2323 - ac
curacy: 0.9358 - val_loss: 0.3349 - val_accuracy: 0.9122
Epoch 32/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2297 - ac
curacy: 0.9367 - val_loss: 0.3347 - val_accuracy: 0.9077
Epoch 33/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2255 - ac
curacy: 0.9371 - val_loss: 0.3309 - val_accuracy: 0.9108
Epoch 34/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2236 - ac
curacy: 0.9374 - val_loss: 0.3362 - val_accuracy: 0.9077
Epoch 35/50
750/750 [==============================] - 2s 2ms/step - loss: 0.2208 - ac
curacy: 0.9391 - val_loss: 0.3340 - val_accuracy: 0.9112
Epoch 36/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2191 - ac
curacy: 0.9392 - val_loss: 0.3360 - val_accuracy: 0.9095
Epoch 37/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2159 - ac
curacy: 0.9398 - val_loss: 0.3374 - val_accuracy: 0.9080
Epoch 38/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2150 - ac
curacy: 0.9404 - val_loss: 0.3308 - val_accuracy: 0.9120
Epoch 39/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2130 - ac
curacy: 0.9405 - val_loss: 0.3296 - val_accuracy: 0.9100
Epoch 40/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2100 - ac
curacy: 0.9416 - val_loss: 0.3310 - val_accuracy: 0.9098
Epoch 41/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2078 - ac
```

```
curacy: 0.9429 - val_loss: 0.3295 - val_accuracy: 0.9102
Epoch 42/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2056 - ac
curacy: 0.9433 - val_loss: 0.3331 - val_accuracy: 0.9090
Epoch 43/50
750/750 [==============================] - 2s 2ms/step - loss: 0.2047 - ac
curacy: 0.9434 - val_loss: 0.3329 - val_accuracy: 0.9108
Epoch 44/50
750/750 [==============================] - 2s 2ms/step - loss: 0.2018 - ac
curacy: 0.9439 - val_loss: 0.3315 - val_accuracy: 0.9138
Epoch 45/50
750/750 [==============================] - 1s 2ms/step - loss: 0.1990 - ac
curacy: 0.9447 - val_loss: 0.3346 - val_accuracy: 0.9108
Epoch 46/50
750/750 [==============================] - 1s 2ms/step - loss: 0.1970 - ac
curacy: 0.9448 - val_loss: 0.3294 - val_accuracy: 0.9120
Epoch 47/50
750/750 [==============================] - 1s 2ms/step - loss: 0.1962 - ac
curacy: 0.9455 - val_loss: 0.3324 - val_accuracy: 0.9153
Epoch 48/50
750/750 [==============================] - 1s 2ms/step - loss: 0.1949 - ac
curacy: 0.9450 - val_loss: 0.3321 - val_accuracy: 0.9102
Epoch 49/50
750/750 [==============================] - 1s 2ms/step - loss: 0.1916 - ac
curacy: 0.9471 - val_loss: 0.3369 - val_accuracy: 0.9105
Epoch 50/50
750/750 [==============================] - 1s 2ms/step - loss: 0.1907 - ac
curacy: 0.9473 - val_loss: 0.3347 - val_accuracy: 0.9088
188/188 [==============================] - 0s 1ms/step - loss: 0.3305 - ac
curacy: 0.9103
Test accuracy with hyperparameters {'hidden_layers': [16, 32, 64], 'learni
ng_rate': 0.001, 'activation': 'sigmoid', 'rate': 0}: 0.9103333353996277
```

Loss vs Epoch ({'hidden_layers': [16, 32, 64], 'learning_rate': 0.001, 'activation': 'sigmoid', 'rate': 0})



Loss vs Epoch ({'hidden_layers': [16, 32, 64], 'learning_rate': 0.001, 'activation': 'sigmoid', 'rate': 0})



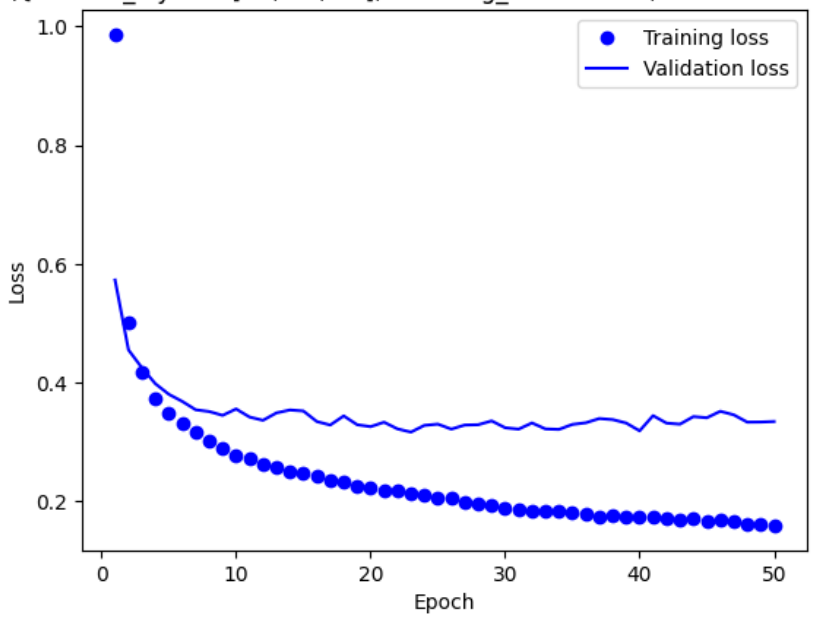

```
Epoch 1/50
750/750 [==============================] - 2s 2ms/step - loss: 0.9859 - ac
curacy: 0.6896 - val_loss: 0.5727 - val_accuracy: 0.8332
Epoch 2/50
750/750 [==============================] - 1s 2ms/step - loss: 0.5024 - ac
curacy: 0.8547 - val_loss: 0.4551 - val_accuracy: 0.8698
Epoch 3/50
750/750 [==============================] - 1s 2ms/step - loss: 0.4175 - ac
curacy: 0.8780 - val_loss: 0.4249 - val_accuracy: 0.8790
Epoch 4/50
750/750 [==============================] - 1s 2ms/step - loss: 0.3742 - ac
curacy: 0.8889 - val_loss: 0.3981 - val_accuracy: 0.8873
Epoch 5/50
750/750 [==============================] - 1s 2ms/step - loss: 0.3488 - ac
curacy: 0.8969 - val_loss: 0.3804 - val_accuracy: 0.8893
Epoch 6/50
750/750 [==============================] - 1s 2ms/step - loss: 0.3305 - ac
curacy: 0.9020 - val_loss: 0.3684 - val_accuracy: 0.8940
Epoch 7/50
750/750 [==============================] - 1s 2ms/step - loss: 0.3178 - ac
curacy: 0.9057 - val_loss: 0.3543 - val_accuracy: 0.8940
Epoch 8/50
750/750 [==============================] - 2s 2ms/step - loss: 0.3009 - ac
curacy: 0.9114 - val_loss: 0.3514 - val_accuracy: 0.8995
Epoch 9/50
750/750 [==============================] - 2s 2ms/step - loss: 0.2888 - ac
curacy: 0.9145 - val_loss: 0.3450 - val_accuracy: 0.9003
Epoch 10/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2769 - ac
curacy: 0.9199 - val_loss: 0.3557 - val_accuracy: 0.8967
Epoch 11/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2725 - ac
curacy: 0.9190 - val_loss: 0.3421 - val_accuracy: 0.9022
Epoch 12/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2632 - ac
```

```
curacy: 0.9227 - val_loss: 0.3366 - val_accuracy: 0.9018
Epoch 13/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2583 - ac
curacy: 0.9244 - val_loss: 0.3491 - val_accuracy: 0.8988
Epoch 14/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2509 - ac
curacy: 0.9258 - val_loss: 0.3540 - val_accuracy: 0.8983
Epoch 15/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2478 - ac
curacy: 0.9270 - val_loss: 0.3523 - val_accuracy: 0.8998
Epoch 16/50
750/750 [==============================] - 2s 2ms/step - loss: 0.2422 - ac
curacy: 0.9284 - val_loss: 0.3346 - val_accuracy: 0.9023
Epoch 17/50
750/750 [==============================] - 2s 2ms/step - loss: 0.2367 - ac
curacy: 0.9308 - val_loss: 0.3287 - val_accuracy: 0.9075
Epoch 18/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2333 - ac
curacy: 0.9308 - val_loss: 0.3440 - val_accuracy: 0.9025
Epoch 19/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2262 - ac
curacy: 0.9327 - val_loss: 0.3292 - val_accuracy: 0.9080
Epoch 20/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2232 - ac
curacy: 0.9339 - val_loss: 0.3259 - val_accuracy: 0.9058
Epoch 21/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2190 - ac
curacy: 0.9355 - val_loss: 0.3334 - val_accuracy: 0.9077
Epoch 22/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2176 - ac
curacy: 0.9364 - val_loss: 0.3222 - val_accuracy: 0.9080
Epoch 23/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2128 - ac
curacy: 0.9374 - val_loss: 0.3168 - val_accuracy: 0.9120
Epoch 24/50
750/750 [==============================] - 2s 2ms/step - loss: 0.2098 - ac
curacy: 0.9384 - val_loss: 0.3281 - val_accuracy: 0.9067
Epoch 25/50
750/750 [==============================] - 2s 2ms/step - loss: 0.2061 - ac
curacy: 0.9394 - val_loss: 0.3302 - val_accuracy: 0.9098
Epoch 26/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2056 - ac
curacy: 0.9390 - val_loss: 0.3218 - val_accuracy: 0.9088
Epoch 27/50
750/750 [==============================] - 1s 2ms/step - loss: 0.1982 - ac
curacy: 0.9422 - val_loss: 0.3286 - val_accuracy: 0.9080
Epoch 28/50
750/750 [==============================] - 1s 2ms/step - loss: 0.1952 - ac
curacy: 0.9426 - val_loss: 0.3292 - val_accuracy: 0.9097
Epoch 29/50
750/750 [==============================] - 1s 2ms/step - loss: 0.1925 - ac
curacy: 0.9427 - val_loss: 0.3356 - val_accuracy: 0.9087
Epoch 30/50
```

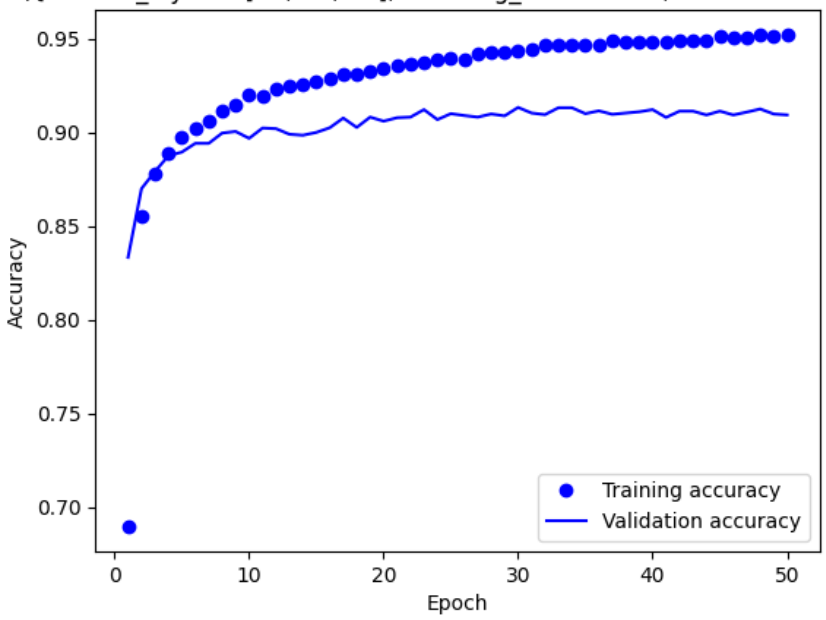
```
750/750 [==============================] - 1s 2ms/step - loss: 0.1896 - ac
curacy: 0.9437 - val_loss: 0.3241 - val_accuracy: 0.9132
Epoch 31/50
750/750 [==============================] - 1s 2ms/step - loss: 0.1869 - ac
curacy: 0.9445 - val_loss: 0.3218 - val_accuracy: 0.9102
Epoch 32/50
750/750 [==============================] - 2s 2ms/step - loss: 0.1832 - ac
curacy: 0.9461 - val_loss: 0.3322 - val_accuracy: 0.9093
Epoch 33/50
750/750 [==============================] - 2s 2ms/step - loss: 0.1845 - ac
curacy: 0.9464 - val_loss: 0.3221 - val_accuracy: 0.9130
Epoch 34/50
750/750 [==============================] - 1s 2ms/step - loss: 0.1827 - ac
curacy: 0.9463 - val_loss: 0.3213 - val_accuracy: 0.9130
Epoch 35/50
750/750 [==============================] - 1s 2ms/step - loss: 0.1815 - ac
curacy: 0.9468 - val_loss: 0.3297 - val_accuracy: 0.9098
Epoch 36/50
750/750 [==============================] - 1s 2ms/step - loss: 0.1797 - ac
curacy: 0.9467 - val_loss: 0.3325 - val_accuracy: 0.9113
Epoch 37/50
750/750 [==============================] - 1s 2ms/step - loss: 0.1736 - ac
curacy: 0.9489 - val_loss: 0.3396 - val_accuracy: 0.9095
Epoch 38/50
750/750 [==============================] - 1s 2ms/step - loss: 0.1754 - ac
curacy: 0.9483 - val_loss: 0.3378 - val_accuracy: 0.9102
Epoch 39/50
750/750 [==============================] - 1s 2ms/step - loss: 0.1745 - ac
curacy: 0.9478 - val_loss: 0.3321 - val_accuracy: 0.9108
Epoch 40/50
750/750 [==============================] - 2s 2ms/step - loss: 0.1744 - ac
curacy: 0.9479 - val_loss: 0.3189 - val_accuracy: 0.9120
Epoch 41/50
750/750 [==============================] - 2s 2ms/step - loss: 0.1736 - ac
curacy: 0.9479 - val_loss: 0.3445 - val_accuracy: 0.9078
Epoch 42/50
750/750 [==============================] - 1s 2ms/step - loss: 0.1714 - ac
curacy: 0.9487 - val_loss: 0.3319 - val_accuracy: 0.9112
Epoch 43/50
750/750 [==============================] - 1s 2ms/step - loss: 0.1698 - ac
curacy: 0.9491 - val_loss: 0.3301 - val_accuracy: 0.9112
Epoch 44/50
750/750 [==============================] - 2s 2ms/step - loss: 0.1712 - ac
curacy: 0.9488 - val_loss: 0.3429 - val_accuracy: 0.9092
Epoch 45/50
750/750 [==============================] - 1s 2ms/step - loss: 0.1675 - ac
curacy: 0.9508 - val_loss: 0.3409 - val_accuracy: 0.9112
Epoch 46/50
750/750 [==============================] - 1s 2ms/step - loss: 0.1682 - ac
curacy: 0.9503 - val_loss: 0.3518 - val_accuracy: 0.9092
Epoch 47/50
750/750 [==============================] - 1s 2ms/step - loss: 0.1677 - ac
curacy: 0.9502 - val_loss: 0.3458 - val_accuracy: 0.9107
```

```
Epoch 48/50
750/750 [==============================] - 2s 2ms/step - loss: 0.1620 - ac
curacy: 0.9516 - val_loss: 0.3336 - val_accuracy: 0.9123
Epoch 49/50
750/750 [==============================] - 2s 2ms/step - loss: 0.1614 - ac
curacy: 0.9514 - val_loss: 0.3337 - val_accuracy: 0.9097
Epoch 50/50
750/750 [==============================] - 2s 2ms/step - loss: 0.1595 - ac
curacy: 0.9520 - val_loss: 0.3346 - val_accuracy: 0.9092
188/188 [==============================] - 0s 1ms/step - loss: 0.3359 - ac
curacy: 0.9123
Test accuracy with hyperparameters {'hidden_layers': [16, 32, 64], 'learni
ng_rate': 0.005, 'activation': 'sigmoid', 'rate': 0}: 0.9123333096504211
```

Loss vs Epoch ({'hidden_layers': [16, 32, 64], 'learning_rate': 0.005, 'activation': 'sigmoid', 'rate': 0})



Loss vs Epoch ({'hidden_layers': [16, 32, 64], 'learning_rate': 0.005, 'activation': 'sigmoid', 'rate': 0})



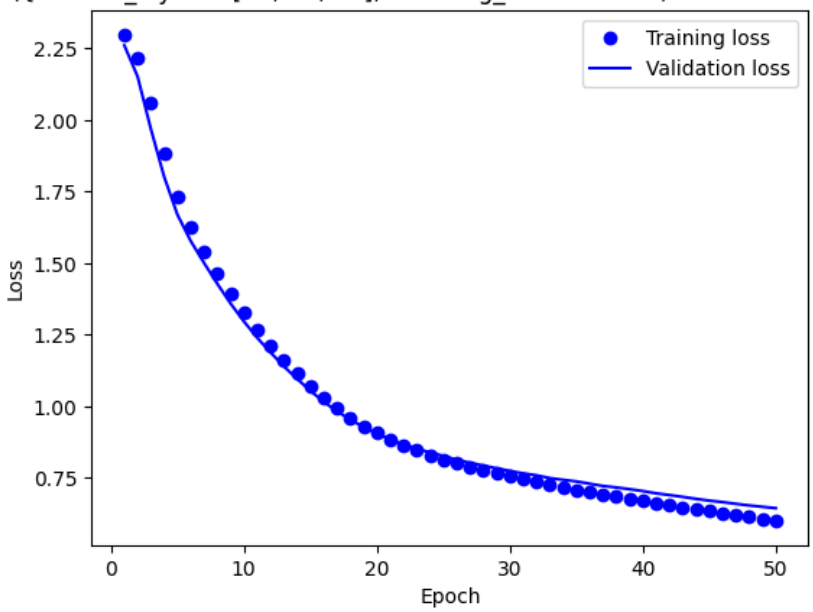

```
Epoch 1/50
750/750 [==============================] - 3s 2ms/step - loss: 2.2983 - ac
curacy: 0.1329 - val_loss: 2.2614 - val_accuracy: 0.1685
```

```
Epoch 2/50
750/750 [==============================] - 1s 2ms/step - loss: 2.2163 - ac
curacy: 0.2547 - val_loss: 2.1525 - val_accuracy: 0.3277
Epoch 3/50
750/750 [==============================] - 2s 2ms/step - loss: 2.0623 - ac
curacy: 0.3442 - val_loss: 1.9690 - val_accuracy: 0.3570
Epoch 4/50
750/750 [==============================] - 1s 2ms/step - loss: 1.8856 - ac
curacy: 0.3606 - val_loss: 1.8020 - val_accuracy: 0.3938
Epoch 5/50
750/750 [==============================] - 2s 2ms/step - loss: 1.7340 - ac
curacy: 0.3956 - val_loss: 1.6696 - val_accuracy: 0.4542
Epoch 6/50
750/750 [==============================] - 2s 2ms/step - loss: 1.6238 - ac
curacy: 0.4550 - val_loss: 1.5778 - val_accuracy: 0.5110
Epoch 7/50
750/750 [==============================] - 2s 2ms/step - loss: 1.5408 - ac
curacy: 0.5222 - val_loss: 1.5012 - val_accuracy: 0.5598
Epoch 8/50
750/750 [==============================] - 2s 2ms/step - loss: 1.4660 - ac
curacy: 0.5621 - val_loss: 1.4284 - val_accuracy: 0.5877
Epoch 9/50
750/750 [==============================] - 2s 2ms/step - loss: 1.3936 - ac
curacy: 0.5931 - val_loss: 1.3593 - val_accuracy: 0.6002
Epoch 10/50
750/750 [==============================] - 1s 2ms/step - loss: 1.3272 - ac
curacy: 0.6073 - val_loss: 1.2968 - val_accuracy: 0.6147
Epoch 11/50
750/750 [==============================] - 1s 2ms/step - loss: 1.2674 - ac
curacy: 0.6218 - val_loss: 1.2397 - val_accuracy: 0.6330
Epoch 12/50
750/750 [==============================] - 1s 2ms/step - loss: 1.2127 - ac
curacy: 0.6389 - val_loss: 1.1888 - val_accuracy: 0.6502
Epoch 13/50
750/750 [==============================] - 1s 2ms/step - loss: 1.1619 - ac
curacy: 0.6525 - val_loss: 1.1401 - val_accuracy: 0.6655
Epoch 14/50
750/750 [==============================] - 1s 2ms/step - loss: 1.1145 - ac
curacy: 0.6680 - val_loss: 1.0963 - val_accuracy: 0.6772
Epoch 15/50
750/750 [==============================] - 2s 2ms/step - loss: 1.0696 - ac
curacy: 0.6817 - val_loss: 1.0546 - val_accuracy: 0.6922
Epoch 16/50
750/750 [==============================] - 2s 2ms/step - loss: 1.0287 - ac
curacy: 0.6941 - val_loss: 1.0161 - val_accuracy: 0.7030
Epoch 17/50
750/750 [==============================] - 2s 2ms/step - loss: 0.9924 - ac
curacy: 0.7041 - val_loss: 0.9832 - val_accuracy: 0.7133
Epoch 18/50
750/750 [==============================] - 2s 2ms/step - loss: 0.9602 - ac
curacy: 0.7131 - val_loss: 0.9535 - val_accuracy: 0.7160
Epoch 19/50
750/750 [==============================] - 1s 2ms/step - loss: 0.9314 - ac
```

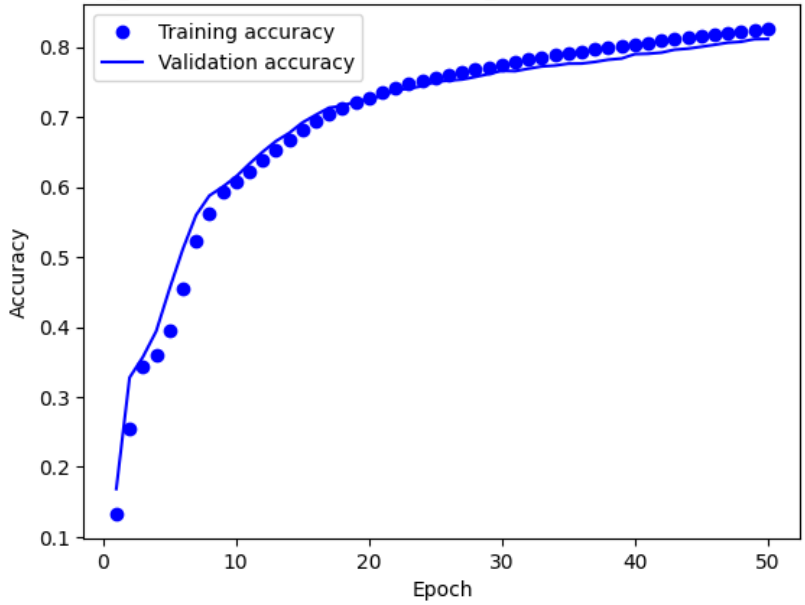
```
curacy: 0.7211 - val_loss: 0.9286 - val_accuracy: 0.7222
Epoch 20/50
750/750 [==============================] - 2s 2ms/step - loss: 0.9066 - ac
curacy: 0.7275 - val_loss: 0.9056 - val_accuracy: 0.7260
Epoch 21/50
750/750 [==============================] - 1s 2ms/step - loss: 0.8841 - ac
curacy: 0.7345 - val_loss: 0.8852 - val_accuracy: 0.7297
Epoch 22/50
750/750 [==============================] - 2s 2ms/step - loss: 0.8636 - ac
curacy: 0.7413 - val_loss: 0.8681 - val_accuracy: 0.7380
Epoch 23/50
750/750 [==============================] - 1s 2ms/step - loss: 0.8458 - ac
curacy: 0.7468 - val_loss: 0.8531 - val_accuracy: 0.7407
Epoch 24/50
750/750 [==============================] - 2s 2ms/step - loss: 0.8297 - ac
curacy: 0.7516 - val_loss: 0.8388 - val_accuracy: 0.7442
Epoch 25/50
750/750 [==============================] - 2s 2ms/step - loss: 0.8149 - ac
curacy: 0.7559 - val_loss: 0.8274 - val_accuracy: 0.7505
Epoch 26/50
750/750 [==============================] - 2s 2ms/step - loss: 0.8015 - ac
curacy: 0.7601 - val_loss: 0.8137 - val_accuracy: 0.7522
Epoch 27/50
750/750 [==============================] - 1s 2ms/step - loss: 0.7886 - ac
curacy: 0.7650 - val_loss: 0.8036 - val_accuracy: 0.7537
Epoch 28/50
750/750 [==============================] - 2s 2ms/step - loss: 0.7768 - ac
curacy: 0.7683 - val_loss: 0.7935 - val_accuracy: 0.7573
Epoch 29/50
750/750 [==============================] - 1s 2ms/step - loss: 0.7655 - ac
curacy: 0.7713 - val_loss: 0.7840 - val_accuracy: 0.7615
Epoch 30/50
750/750 [==============================] - 2s 2ms/step - loss: 0.7549 - ac
curacy: 0.7755 - val_loss: 0.7749 - val_accuracy: 0.7662
Epoch 31/50
750/750 [==============================] - 1s 2ms/step - loss: 0.7452 - ac
curacy: 0.7783 - val_loss: 0.7663 - val_accuracy: 0.7657
Epoch 32/50
750/750 [==============================] - 2s 2ms/step - loss: 0.7356 - ac
curacy: 0.7822 - val_loss: 0.7596 - val_accuracy: 0.7692
Epoch 33/50
750/750 [==============================] - 2s 2ms/step - loss: 0.7267 - ac
curacy: 0.7854 - val_loss: 0.7498 - val_accuracy: 0.7723
Epoch 34/50
750/750 [==============================] - 1s 2ms/step - loss: 0.7175 - ac
curacy: 0.7881 - val_loss: 0.7436 - val_accuracy: 0.7737
Epoch 35/50
750/750 [==============================] - 1s 2ms/step - loss: 0.7091 - ac
curacy: 0.7916 - val_loss: 0.7382 - val_accuracy: 0.7763
Epoch 36/50
750/750 [==============================] - 1s 2ms/step - loss: 0.7004 - ac
curacy: 0.7937 - val_loss: 0.7301 - val_accuracy: 0.7765
Epoch 37/50
```

```
750/750 [==============================] - 2s 2ms/step - loss: 0.6923 - ac
curacy: 0.7964 - val_loss: 0.7224 - val_accuracy: 0.7788
Epoch 38/50
750/750 [==============================] - 1s 2ms/step - loss: 0.6847 - ac
curacy: 0.7989 - val_loss: 0.7171 - val_accuracy: 0.7820
Epoch 39/50
750/750 [==============================] - 1s 2ms/step - loss: 0.6772 - ac
curacy: 0.8017 - val_loss: 0.7111 - val_accuracy: 0.7837
Epoch 40/50
750/750 [==============================] - 2s 2ms/step - loss: 0.6699 - ac
curacy: 0.8044 - val_loss: 0.7045 - val_accuracy: 0.7900
Epoch 41/50
750/750 [==============================] - 1s 2ms/step - loss: 0.6625 - ac
curacy: 0.8065 - val_loss: 0.6966 - val_accuracy: 0.7905
Epoch 42/50
750/750 [==============================] - 1s 2ms/step - loss: 0.6554 - ac
curacy: 0.8091 - val_loss: 0.6906 - val_accuracy: 0.7922
Epoch 43/50
750/750 [==============================] - 1s 2ms/step - loss: 0.6481 - ac
curacy: 0.8109 - val_loss: 0.6842 - val_accuracy: 0.7963
Epoch 44/50
750/750 [==============================] - 1s 2ms/step - loss: 0.6415 - ac
curacy: 0.8137 - val_loss: 0.6773 - val_accuracy: 0.7978
Epoch 45/50
750/750 [==============================] - 1s 2ms/step - loss: 0.6345 - ac
curacy: 0.8154 - val_loss: 0.6711 - val_accuracy: 0.8005
Epoch 46/50
750/750 [==============================] - 1s 2ms/step - loss: 0.6272 - ac
curacy: 0.8179 - val_loss: 0.6660 - val_accuracy: 0.8033
Epoch 47/50
750/750 [==============================] - 2s 2ms/step - loss: 0.6203 - ac
curacy: 0.8201 - val_loss: 0.6599 - val_accuracy: 0.8063
Epoch 48/50
750/750 [==============================] - 2s 2ms/step - loss: 0.6140 - ac
curacy: 0.8220 - val_loss: 0.6543 - val_accuracy: 0.8077
Epoch 49/50
750/750 [==============================] - 1s 2ms/step - loss: 0.6074 - ac
curacy: 0.8241 - val_loss: 0.6495 - val_accuracy: 0.8113
Epoch 50/50
750/750 [==============================] - 2s 2ms/step - loss: 0.6011 - ac
curacy: 0.8264 - val_loss: 0.6449 - val_accuracy: 0.8117
188/188 [==============================] - 0s 1ms/step - loss: 0.6767 - ac
curacy: 0.8063
Test accuracy with hyperparameters {'hidden_layers': [16, 32, 64], 'learni
ng_rate': 0.0001, 'activation': 'sigmoid', 'rate': 0}: 0.8063333630561829
```

Loss vs Epoch ({'hidden_layers': [16, 32, 64], 'learning_rate': 0.0001, 'activation': 'sigmoid', 'rate': 0})



Loss vs Epoch ({'hidden_layers': [16, 32, 64], 'learning_rate': 0.0001, 'activation': 'sigmoid', 'rate': 0})



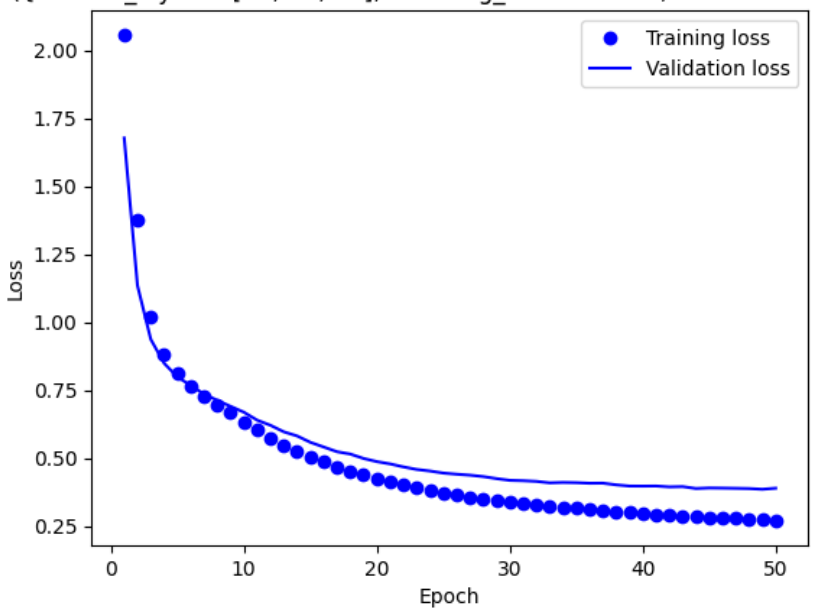

```
Epoch 1/50
750/750 [==============================] - 2s 2ms/step - loss: 2.0573 - ac
curacy: 0.2863 - val_loss: 1.6773 - val_accuracy: 0.5158
Epoch 2/50
750/750 [==============================] - 2s 2ms/step - loss: 1.3758 - ac
curacy: 0.5995 - val_loss: 1.1339 - val_accuracy: 0.6712
Epoch 3/50
750/750 [==============================] - 1s 2ms/step - loss: 1.0183 - ac
curacy: 0.6996 - val_loss: 0.9363 - val_accuracy: 0.7170
Epoch 4/50
750/750 [==============================] - 2s 2ms/step - loss: 0.8817 - ac
curacy: 0.7345 - val_loss: 0.8485 - val_accuracy: 0.7450
Epoch 5/50
750/750 [==============================] - 2s 2ms/step - loss: 0.8115 - ac
curacy: 0.7544 - val_loss: 0.7979 - val_accuracy: 0.7597
Epoch 6/50
750/750 [==============================] - 1s 2ms/step - loss: 0.7638 - ac
```

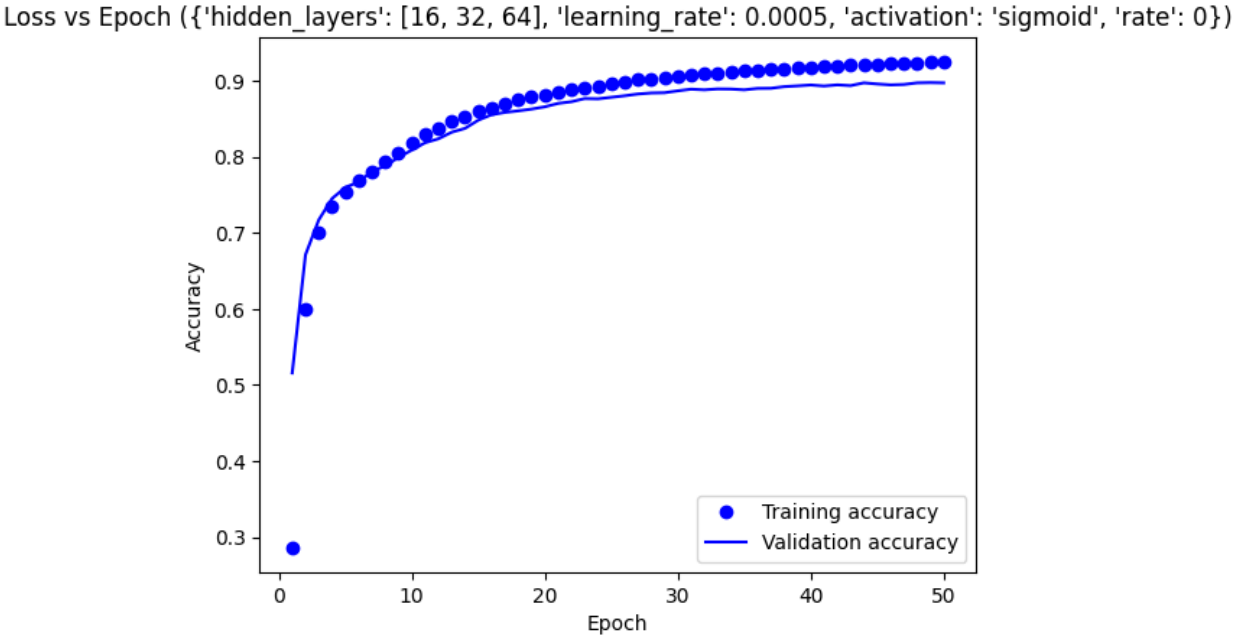
```
curacy: 0.7690 - val_loss: 0.7669 - val_accuracy: 0.7668
Epoch 7/50
750/750 [==============================] - 1s 2ms/step - loss: 0.7273 - ac
curacy: 0.7806 - val_loss: 0.7351 - val_accuracy: 0.7808
Epoch 8/50
750/750 [==============================] - 2s 2ms/step - loss: 0.6957 - ac
curacy: 0.7934 - val_loss: 0.7120 - val_accuracy: 0.7877
Epoch 9/50
750/750 [==============================] - 1s 2ms/step - loss: 0.6652 - ac
curacy: 0.8048 - val_loss: 0.6897 - val_accuracy: 0.7992
Epoch 10/50
750/750 [==============================] - 2s 2ms/step - loss: 0.6329 - ac
curacy: 0.8177 - val_loss: 0.6682 - val_accuracy: 0.8087
Epoch 11/50
750/750 [==============================] - 2s 2ms/step - loss: 0.6028 - ac
curacy: 0.8290 - val_loss: 0.6389 - val_accuracy: 0.8183
Epoch 12/50
750/750 [==============================] - 2s 2ms/step - loss: 0.5740 - ac
curacy: 0.8377 - val_loss: 0.6201 - val_accuracy: 0.8235
Epoch 13/50
750/750 [==============================] - 2s 2ms/step - loss: 0.5480 - ac
curacy: 0.8462 - val_loss: 0.5961 - val_accuracy: 0.8322
Epoch 14/50
750/750 [==============================] - 1s 2ms/step - loss: 0.5253 - ac
curacy: 0.8533 - val_loss: 0.5809 - val_accuracy: 0.8372
Epoch 15/50
750/750 [==============================] - 1s 2ms/step - loss: 0.5054 - ac
curacy: 0.8591 - val_loss: 0.5574 - val_accuracy: 0.8480
Epoch 16/50
750/750 [==============================] - 1s 2ms/step - loss: 0.4874 - ac
curacy: 0.8639 - val_loss: 0.5402 - val_accuracy: 0.8552
Epoch 17/50
750/750 [==============================] - 1s 2ms/step - loss: 0.4671 - ac
curacy: 0.8702 - val_loss: 0.5228 - val_accuracy: 0.8582
Epoch 18/50
750/750 [==============================] - 2s 2ms/step - loss: 0.4513 - ac
curacy: 0.8745 - val_loss: 0.5143 - val_accuracy: 0.8602
Epoch 19/50
750/750 [==============================] - 1s 2ms/step - loss: 0.4369 - ac
curacy: 0.8791 - val_loss: 0.4981 - val_accuracy: 0.8625
Epoch 20/50
750/750 [==============================] - 2s 2ms/step - loss: 0.4250 - ac
curacy: 0.8812 - val_loss: 0.4864 - val_accuracy: 0.8655
Epoch 21/50
750/750 [==============================] - 2s 2ms/step - loss: 0.4116 - ac
curacy: 0.8853 - val_loss: 0.4780 - val_accuracy: 0.8700
Epoch 22/50
750/750 [==============================] - 1s 2ms/step - loss: 0.3994 - ac
curacy: 0.8883 - val_loss: 0.4670 - val_accuracy: 0.8722
Epoch 23/50
750/750 [==============================] - 2s 2ms/step - loss: 0.3899 - ac
curacy: 0.8911 - val_loss: 0.4576 - val_accuracy: 0.8763
Epoch 24/50
```

```
750/750 [==============================] - 2s 2ms/step - loss: 0.3818 - ac
curacy: 0.8932 - val_loss: 0.4518 - val_accuracy: 0.8760
Epoch 25/50
750/750 [==============================] - 2s 2ms/step - loss: 0.3722 - ac
curacy: 0.8967 - val_loss: 0.4443 - val_accuracy: 0.8780
Epoch 26/50
750/750 [==============================] - 2s 2ms/step - loss: 0.3634 - ac
curacy: 0.8982 - val_loss: 0.4401 - val_accuracy: 0.8800
Epoch 27/50
750/750 [==============================] - 2s 2ms/step - loss: 0.3553 - ac
curacy: 0.9013 - val_loss: 0.4365 - val_accuracy: 0.8823
Epoch 28/50
750/750 [==============================] - 2s 2ms/step - loss: 0.3486 - ac
curacy: 0.9024 - val_loss: 0.4314 - val_accuracy: 0.8837
Epoch 29/50
750/750 [==============================] - 1s 2ms/step - loss: 0.3430 - ac
curacy: 0.9041 - val_loss: 0.4239 - val_accuracy: 0.8840
Epoch 30/50
750/750 [==============================] - 1s 2ms/step - loss: 0.3376 - ac
curacy: 0.9059 - val_loss: 0.4175 - val_accuracy: 0.8865
Epoch 31/50
750/750 [==============================] - 2s 2ms/step - loss: 0.3317 - ac
curacy: 0.9078 - val_loss: 0.4161 - val_accuracy: 0.8887
Epoch 32/50
750/750 [==============================] - 1s 2ms/step - loss: 0.3265 - ac
curacy: 0.9086 - val_loss: 0.4138 - val_accuracy: 0.8878
Epoch 33/50
750/750 [==============================] - 2s 2ms/step - loss: 0.3225 - ac
curacy: 0.9097 - val_loss: 0.4083 - val_accuracy: 0.8890
Epoch 34/50
750/750 [==============================] - 2s 2ms/step - loss: 0.3181 - ac
curacy: 0.9110 - val_loss: 0.4098 - val_accuracy: 0.8888
Epoch 35/50
750/750 [==============================] - 2s 2ms/step - loss: 0.3140 - ac
curacy: 0.9128 - val_loss: 0.4089 - val_accuracy: 0.8878
Epoch 36/50
750/750 [==============================] - 2s 2ms/step - loss: 0.3095 - ac
curacy: 0.9137 - val_loss: 0.4069 - val_accuracy: 0.8897
Epoch 37/50
750/750 [==============================] - 2s 2ms/step - loss: 0.3052 - ac
curacy: 0.9146 - val_loss: 0.4072 - val_accuracy: 0.8898
Epoch 38/50
750/750 [==============================] - 1s 2ms/step - loss: 0.3024 - ac
curacy: 0.9157 - val_loss: 0.4010 - val_accuracy: 0.8920
Epoch 39/50
750/750 [==============================] - 2s 2ms/step - loss: 0.2991 - ac
curacy: 0.9165 - val_loss: 0.3965 - val_accuracy: 0.8930
Epoch 40/50
750/750 [==============================] - 2s 2ms/step - loss: 0.2954 - ac
curacy: 0.9177 - val_loss: 0.3962 - val_accuracy: 0.8942
Epoch 41/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2922 - ac
curacy: 0.9187 - val_loss: 0.3966 - val_accuracy: 0.8928
```

```
Epoch 42/50
750/750 [==============================] - 2s 2ms/step - loss: 0.2906 - ac
curacy: 0.9187 - val_loss: 0.3934 - val_accuracy: 0.8943
Epoch 43/50
750/750 [==============================] - 2s 2ms/step - loss: 0.2858 - ac
curacy: 0.9214 - val_loss: 0.3944 - val_accuracy: 0.8933
Epoch 44/50
750/750 [==============================] - 2s 2ms/step - loss: 0.2856 - ac
curacy: 0.9201 - val_loss: 0.3874 - val_accuracy: 0.8970
Epoch 45/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2811 - ac
curacy: 0.9210 - val_loss: 0.3894 - val_accuracy: 0.8955
Epoch 46/50
750/750 [==============================] - 2s 2ms/step - loss: 0.2786 - ac
curacy: 0.9220 - val_loss: 0.3889 - val_accuracy: 0.8943
Epoch 47/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2767 - ac
curacy: 0.9231 - val_loss: 0.3881 - val_accuracy: 0.8948
Epoch 48/50
750/750 [==============================] - 2s 2ms/step - loss: 0.2739 - ac
curacy: 0.9235 - val_loss: 0.3872 - val_accuracy: 0.8970
Epoch 49/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2717 - ac
curacy: 0.9245 - val_loss: 0.3846 - val_accuracy: 0.8973
Epoch 50/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2691 - ac
curacy: 0.9247 - val_loss: 0.3885 - val_accuracy: 0.8970
188/188 [==============================] - 0s 1ms/step - loss: 0.4016 - ac
curacy: 0.8927
Test accuracy with hyperparameters {'hidden_layers': [16, 32, 64], 'learni
ng_rate': 0.0005, 'activation': 'sigmoid', 'rate': 0}: 0.8926666378974915
```

Loss vs Epoch ({'hidden_layers': [16, 32, 64], 'learning_rate': 0.0005, 'activation': 'sigmoid', 'rate': 0})






```
Best learning rate: 0.005
Best validation accuracy: 0.9123333096504211
Time to achieve best validation accuracy: 82.78418731689453 seconds
```

In [33]:
```
train_model([best_hyperparameters])
```

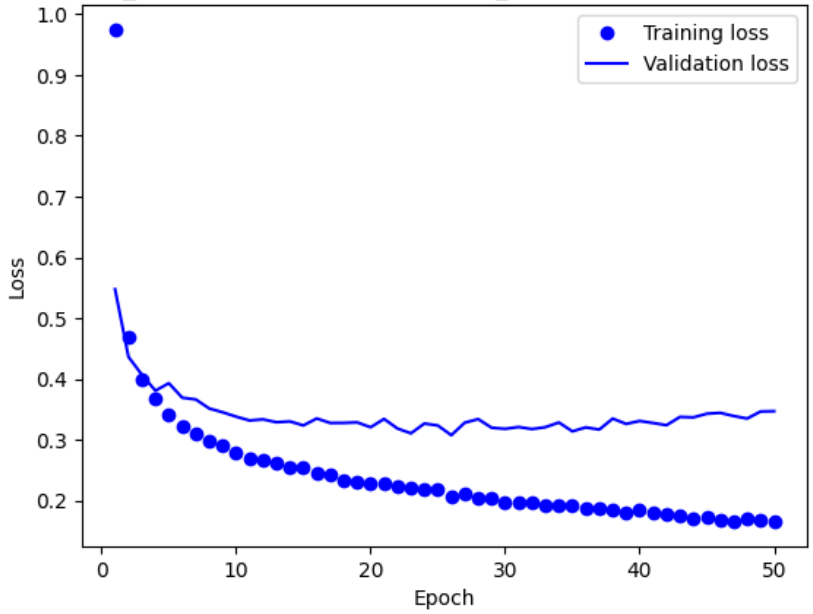
```
Epoch 1/50
750/750 [==============================] - 2s 2ms/step - loss: 0.9746 - ac
curacy: 0.6852 - val_loss: 0.5476 - val_accuracy: 0.8458
Epoch 2/50
750/750 [==============================] - 1s 2ms/step - loss: 0.4700 - ac
curacy: 0.8641 - val_loss: 0.4364 - val_accuracy: 0.8757
Epoch 3/50
750/750 [==============================] - 1s 2ms/step - loss: 0.3981 - ac
curacy: 0.8847 - val_loss: 0.4070 - val_accuracy: 0.8857
Epoch 4/50
750/750 [==============================] - 1s 2ms/step - loss: 0.3672 - ac
curacy: 0.8934 - val_loss: 0.3809 - val_accuracy: 0.8898
Epoch 5/50
750/750 [==============================] - 2s 2ms/step - loss: 0.3411 - ac
curacy: 0.8999 - val_loss: 0.3931 - val_accuracy: 0.8845
Epoch 6/50
750/750 [==============================] - 1s 2ms/step - loss: 0.3218 - ac
curacy: 0.9057 - val_loss: 0.3693 - val_accuracy: 0.8958
Epoch 7/50
750/750 [==============================] - 1s 2ms/step - loss: 0.3101 - ac
curacy: 0.9077 - val_loss: 0.3665 - val_accuracy: 0.8972
Epoch 8/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2988 - ac
curacy: 0.9111 - val_loss: 0.3517 - val_accuracy: 0.8998
Epoch 9/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2906 - ac
curacy: 0.9149 - val_loss: 0.3454 - val_accuracy: 0.9028
Epoch 10/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2788 - ac
curacy: 0.9177 - val_loss: 0.3382 - val_accuracy: 0.9040
```

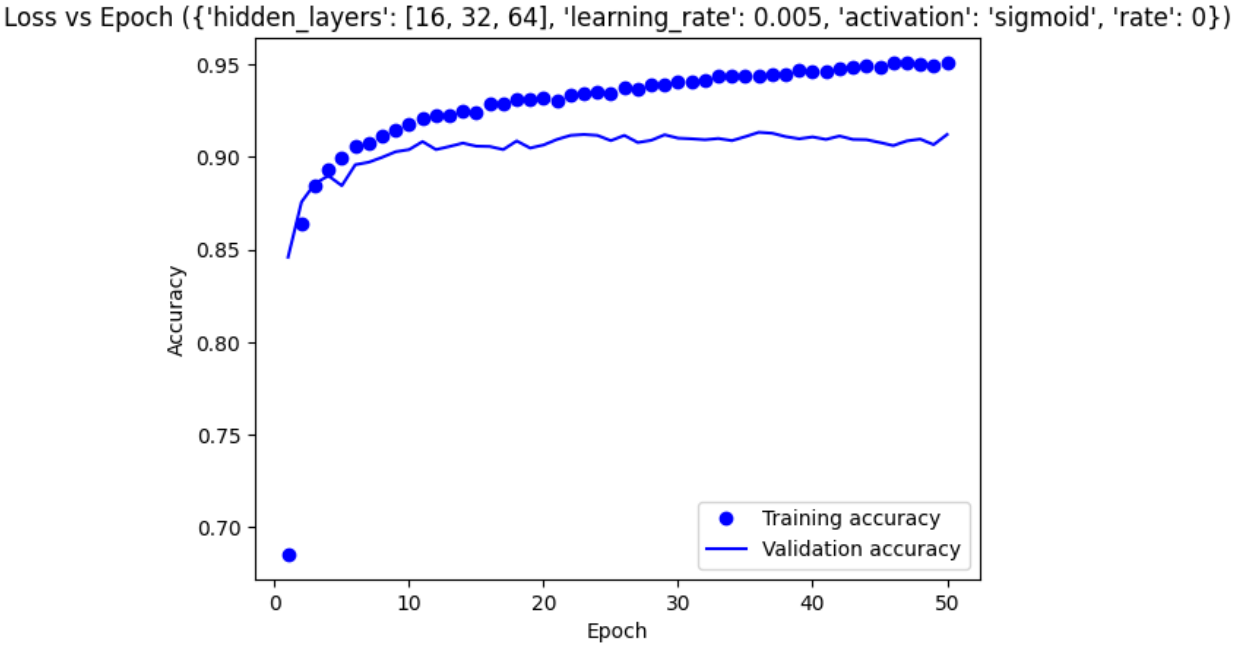
```
Epoch 11/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2693 - ac
curacy: 0.9211 - val_loss: 0.3319 - val_accuracy: 0.9083
Epoch 12/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2664 - ac
curacy: 0.9224 - val_loss: 0.3337 - val_accuracy: 0.9040
Epoch 13/50
750/750 [==============================] - 2s 2ms/step - loss: 0.2611 - ac
curacy: 0.9222 - val_loss: 0.3291 - val_accuracy: 0.9057
Epoch 14/50
750/750 [==============================] - 2s 2ms/step - loss: 0.2552 - ac
curacy: 0.9249 - val_loss: 0.3303 - val_accuracy: 0.9075
Epoch 15/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2556 - ac
curacy: 0.9239 - val_loss: 0.3238 - val_accuracy: 0.9058
Epoch 16/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2453 - ac
curacy: 0.9284 - val_loss: 0.3352 - val_accuracy: 0.9057
Epoch 17/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2418 - ac
curacy: 0.9285 - val_loss: 0.3278 - val_accuracy: 0.9040
Epoch 18/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2340 - ac
curacy: 0.9315 - val_loss: 0.3279 - val_accuracy: 0.9087
Epoch 19/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2297 - ac
curacy: 0.9312 - val_loss: 0.3288 - val_accuracy: 0.9048
Epoch 20/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2277 - ac
curacy: 0.9320 - val_loss: 0.3208 - val_accuracy: 0.9065
Epoch 21/50
750/750 [==============================] - 2s 2ms/step - loss: 0.2273 - ac
curacy: 0.9308 - val_loss: 0.3344 - val_accuracy: 0.9095
Epoch 22/50
750/750 [==============================] - 2s 2ms/step - loss: 0.2244 - ac
curacy: 0.9337 - val_loss: 0.3186 - val_accuracy: 0.9117
Epoch 23/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2204 - ac
curacy: 0.9347 - val_loss: 0.3107 - val_accuracy: 0.9122
Epoch 24/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2182 - ac
curacy: 0.9351 - val_loss: 0.3269 - val_accuracy: 0.9117
Epoch 25/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2178 - ac
curacy: 0.9341 - val_loss: 0.3236 - val_accuracy: 0.9088
Epoch 26/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2074 - ac
curacy: 0.9373 - val_loss: 0.3077 - val_accuracy: 0.9117
Epoch 27/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2103 - ac
curacy: 0.9370 - val_loss: 0.3283 - val_accuracy: 0.9078
Epoch 28/50
750/750 [==============================] - 1s 2ms/step - loss: 0.2036 - ac
```

```
curacy: 0.9391 - val_loss: 0.3342 - val_accuracy: 0.9090
Epoch 29/50
750/750 [==============================] - 2s 2ms/step - loss: 0.2034 - ac
curacy: 0.9389 - val_loss: 0.3200 - val_accuracy: 0.9120
Epoch 30/50
750/750 [==============================] - 2s 2ms/step - loss: 0.1978 - ac
curacy: 0.9409 - val_loss: 0.3182 - val_accuracy: 0.9102
Epoch 31/50
750/750 [==============================] - 1s 2ms/step - loss: 0.1968 - ac
curacy: 0.9403 - val_loss: 0.3211 - val_accuracy: 0.9098
Epoch 32/50
750/750 [==============================] - 1s 2ms/step - loss: 0.1963 - ac
curacy: 0.9414 - val_loss: 0.3178 - val_accuracy: 0.9093
Epoch 33/50
750/750 [==============================] - 1s 2ms/step - loss: 0.1913 - ac
curacy: 0.9434 - val_loss: 0.3209 - val_accuracy: 0.9100
Epoch 34/50
750/750 [==============================] - 1s 2ms/step - loss: 0.1911 - ac
curacy: 0.9436 - val_loss: 0.3286 - val_accuracy: 0.9088
Epoch 35/50
750/750 [==============================] - 1s 2ms/step - loss: 0.1912 - ac
curacy: 0.9442 - val_loss: 0.3140 - val_accuracy: 0.9110
Epoch 36/50
750/750 [==============================] - 1s 2ms/step - loss: 0.1878 - ac
curacy: 0.9442 - val_loss: 0.3205 - val_accuracy: 0.9133
Epoch 37/50
750/750 [==============================] - 1s 2ms/step - loss: 0.1880 - ac
curacy: 0.9446 - val_loss: 0.3169 - val_accuracy: 0.9128
Epoch 38/50
750/750 [==============================] - 2s 2ms/step - loss: 0.1855 - ac
curacy: 0.9448 - val_loss: 0.3350 - val_accuracy: 0.9110
Epoch 39/50
750/750 [==============================] - 1s 2ms/step - loss: 0.1812 - ac
curacy: 0.9472 - val_loss: 0.3262 - val_accuracy: 0.9098
Epoch 40/50
750/750 [==============================] - 1s 2ms/step - loss: 0.1838 - ac
curacy: 0.9460 - val_loss: 0.3311 - val_accuracy: 0.9108
Epoch 41/50
750/750 [==============================] - 1s 2ms/step - loss: 0.1812 - ac
curacy: 0.9462 - val_loss: 0.3278 - val_accuracy: 0.9095
Epoch 42/50
750/750 [==============================] - 1s 2ms/step - loss: 0.1775 - ac
curacy: 0.9476 - val_loss: 0.3242 - val_accuracy: 0.9113
Epoch 43/50
750/750 [==============================] - 1s 2ms/step - loss: 0.1762 - ac
curacy: 0.9485 - val_loss: 0.3378 - val_accuracy: 0.9095
Epoch 44/50
750/750 [==============================] - 1s 2ms/step - loss: 0.1707 - ac
curacy: 0.9496 - val_loss: 0.3370 - val_accuracy: 0.9093
Epoch 45/50
750/750 [==============================] - 1s 2ms/step - loss: 0.1733 - ac
curacy: 0.9488 - val_loss: 0.3430 - val_accuracy: 0.9078
Epoch 46/50
```

```
750/750 [==============================] - 2s 2ms/step - loss: 0.1688 - ac
curacy: 0.9508 - val_loss: 0.3444 - val_accuracy: 0.9062
Epoch 47/50
750/750 [==============================] - 1s 2ms/step - loss: 0.1668 - ac
curacy: 0.9507 - val_loss: 0.3392 - val_accuracy: 0.9087
Epoch 48/50
750/750 [==============================] - 1s 2ms/step - loss: 0.1698 - ac
curacy: 0.9503 - val_loss: 0.3351 - val_accuracy: 0.9097
Epoch 49/50
750/750 [==============================] - 1s 2ms/step - loss: 0.1692 - ac
curacy: 0.9494 - val_loss: 0.3467 - val_accuracy: 0.9067
Epoch 50/50
750/750 [==============================] - 1s 2ms/step - loss: 0.1659 - ac
curacy: 0.9510 - val_loss: 0.3472 - val_accuracy: 0.9122
188/188 [==============================] - 0s 1ms/step - loss: 0.3386 - ac
curacy: 0.9048
Test accuracy with hyperparameters {'hidden_layers': [16, 32, 64], 'learni
ng_rate': 0.005, 'activation': 'sigmoid', 'rate': 0}: 0.9048333168029785
```

Loss vs Epoch ({'hidden_layers': [16, 32, 64], 'learning_rate': 0.005, 'activation': 'sigmoid', 'rate': 0})

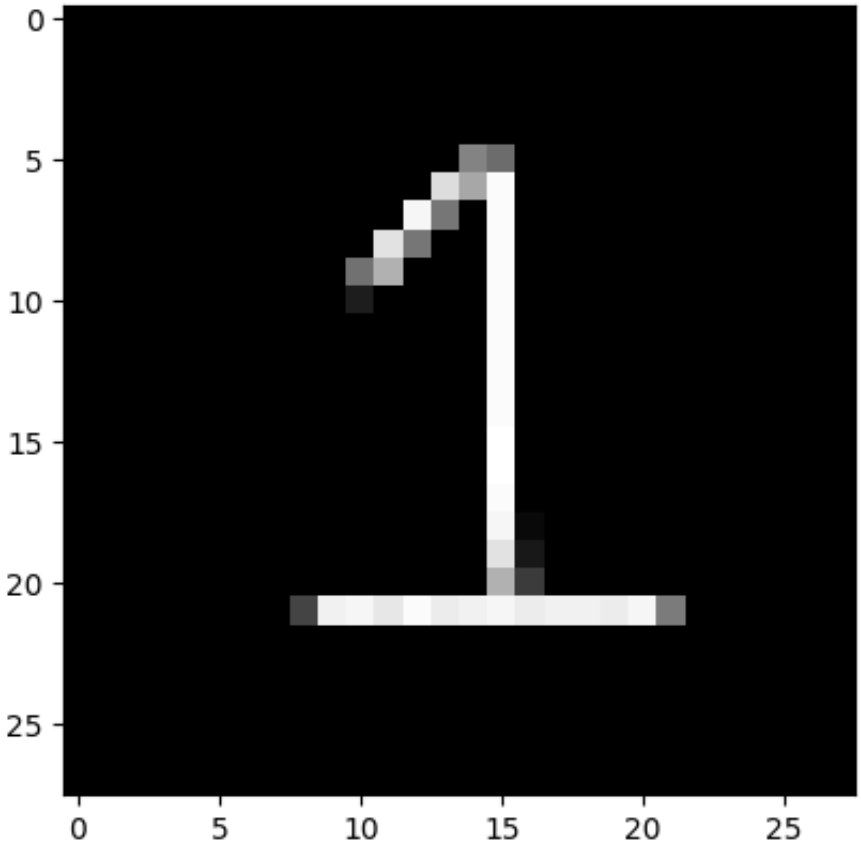




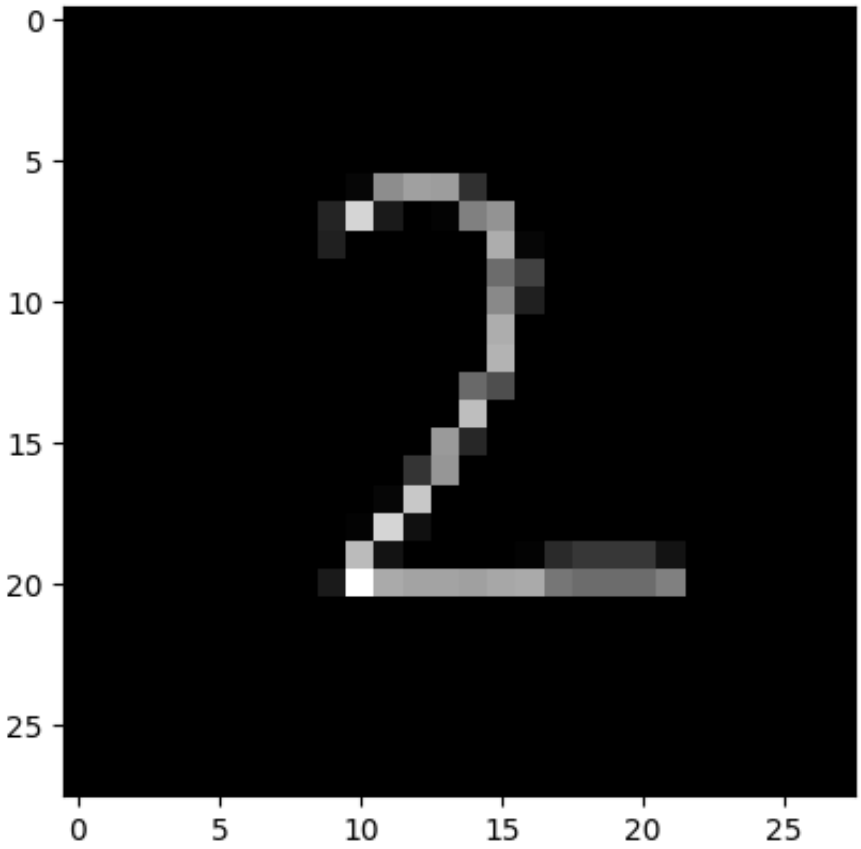
Out[33]: [0.9048333168029785, 82.61834287643433]

In [34]:
```
for i in range(1, 6):
    img = cv2.imread(str(i)+'.png')
    img = img[:, :, 2]
    img = cv2.resize(img, (28, 28), interpolation=cv2.INTER_AREA)
    img = 255-img
    imgplot = plt.imshow(img, cmap="gray")
    img = transform(img)
    img = np.expand_dims(img, axis=0)
    print(img.shape)
    pred = model.predict(img)
    print(np.argmax(pred))
    plt.show()
```

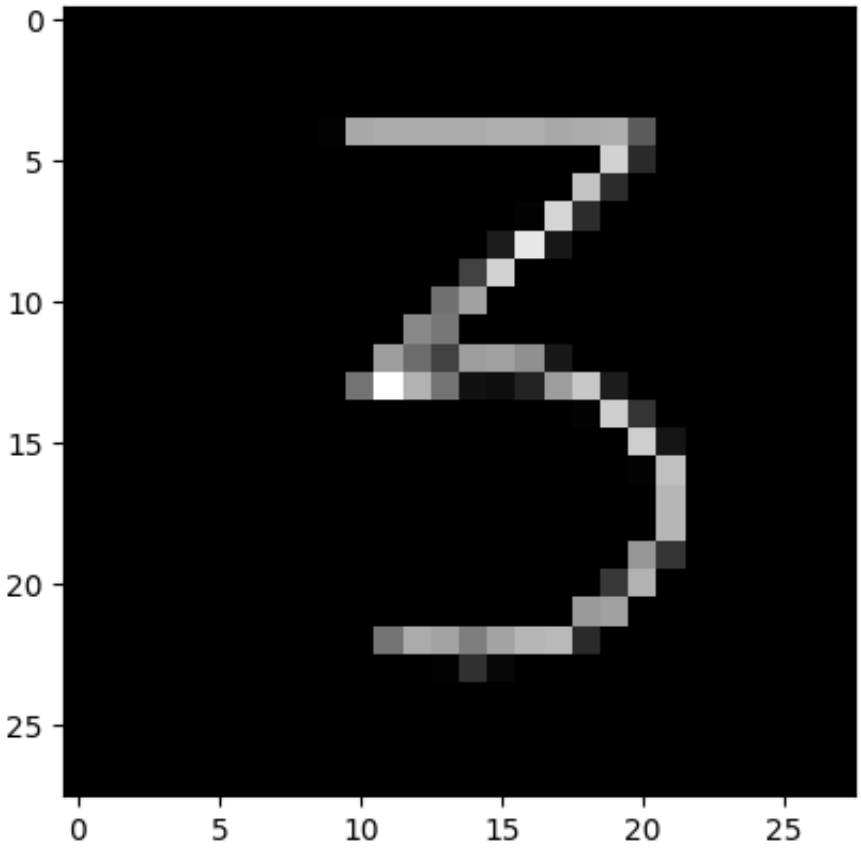
```
(1, 1024)
1/1 [==============================] - 0s 65ms/step
1
```



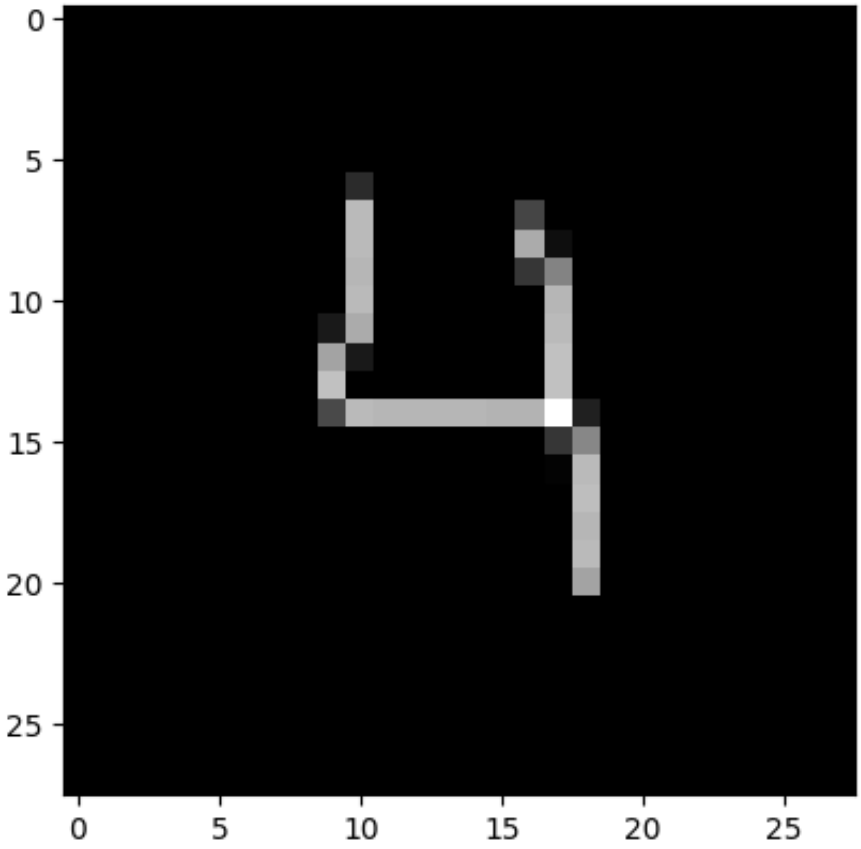

```
(1, 1024)
1/1 [==============================] - 0s 13ms/step
5
```



```
(1, 1024)
1/1 [==============================] - 0s 13ms/step
4
```




```
(1, 1024)
1/1 [==============================] - 0s 17ms/step
4
```




```
(1, 1024)
1/1 [==============================] - 0s 14ms/step
5
```