

# MLP\_as\_tp

February 20, 2025

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[2]: import numpy as np
import matplotlib.pyplot as plt
from tensorflow.keras.datasets import mnist

def init_params(nx, nh, ny):
    np.random.seed(42)
    params = {
        'W1': np.random.normal(0, 0.3, (nh, nx)),
        'b1': np.zeros((nh, 1)),
        'W2': np.random.normal(0, 0.3, (ny, nh)),
        'b2': np.zeros((ny, 1))
    }
    return params

def softmax(Z):
    expZ = np.exp(Z - np.max(Z, axis=0, keepdims=True))
    return expZ / np.sum(expZ, axis=0, keepdims=True)

def forward(params, X):
    Z1 = np.dot(params['W1'], X) + params['b1']
    A1 = np.tanh(Z1)
    Z2 = np.dot(params['W2'], A1) + params['b2']
    A2 = softmax(Z2)
    return A2, {'Z1': Z1, 'A1': A1, 'Z2': Z2, 'A2': A2}

def loss_accuracy(Yhat, Y):
    m = Y.shape[1]
    loss = -np.sum(Y * np.log(Yhat + 1e-8)) / m
    predictions = np.argmax(Yhat, axis=0)
    labels = np.argmax(Y, axis=0)
    accuracy = np.mean(predictions == labels)
    return loss, accuracy

def backward(X, params, outputs, Y):
    m = X.shape[1]
    dZ2 = outputs['A2'] - Y
    dW2 = np.dot(dZ2, outputs['A1'].T) / m
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db2 = np.sum(dZ2, axis=1, keepdims=True) / m
dA1 = np.dot(params['W2'].T, dZ2)
dZ1 = dA1 * (1 - np.tanh(outputs['Z1'])) ** 2
dW1 = np.dot(dZ1, X.T) / m
db1 = np.sum(dZ1, axis=1, keepdims=True) / m
grads = {'dW1': dW1, 'db1': db1, 'dW2': dW2, 'db2': db2}
return grads

def sgd(params, grads, eta):
    for key in params.keys():
        params[key] -= eta * grads['d' + key]

# Step 6: Training Loop
def train_mlp(X_train, Y_train, X_val, Y_val, nx, nh, ny, epochs, batch_size, eta):
    params = init_params(nx, nh, ny)
    losses = []
    accuracies = []
    for epoch in range(epochs):
        permutation = np.random.permutation(X_train.shape[1])
        X_train = X_train[:, permutation]
        Y_train = Y_train[:, permutation]

        for i in range(0, X_train.shape[1], batch_size):
            X_batch = X_train[:, i:i + batch_size]
            Y_batch = Y_train[:, i:i + batch_size]
            Yhat, outputs = forward(params, X_batch)
            loss, _ = loss_accuracy(Yhat, Y_batch)
            grads = backward(X_batch, params, outputs, Y_batch)
            sgd(params, grads, eta)

            Yhat_val, _ = forward(params, X_val)
            val_loss, val_accuracy = loss_accuracy(Yhat_val, Y_val)
            losses.append(val_loss)
            accuracies.append(val_accuracy)
            print(f"Epoch {epoch + 1}/{epochs}, Loss: {val_loss:.4f}, Accuracy:{val_accuracy:.4f}")

    plt.plot(losses, label="Loss")
    plt.plot(accuracies, label="Accuracy")
    plt.xlabel("Epochs")
    plt.ylabel("Value")
    plt.legend()
    plt.show()

# Step 7: Load MNIST data and train the MLP
(X_train, Y_train), (X_test, Y_test) = mnist.load_data()

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X_train = X_train.reshape(X_train.shape[0], -1).T / 255.0
X_test = X_test.reshape(X_test.shape[0], -1).T / 255.0
Y_train = np.eye(10)[Y_train].T
Y_test = np.eye(10)[Y_test].T

train_mlp(X_train, Y_train, X_test, Y_test, nx=784, nh=128, ny=10, epochs=500,
batch_size=128, eta=0.1)

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Epoch 1/500, Loss: 0.3877, Accuracy: 0.8855  
 Epoch 2/500, Loss: 0.3206, Accuracy: 0.9036  
 Epoch 3/500, Loss: 0.2817, Accuracy: 0.9165  
 Epoch 4/500, Loss: 0.2587, Accuracy: 0.9248  
 Epoch 5/500, Loss: 0.2440, Accuracy: 0.9273  
 Epoch 6/500, Loss: 0.2290, Accuracy: 0.9354  
 Epoch 7/500, Loss: 0.2179, Accuracy: 0.9374  
 Epoch 8/500, Loss: 0.2095, Accuracy: 0.9390  
 Epoch 9/500, Loss: 0.2010, Accuracy: 0.9426  
 Epoch 10/500, Loss: 0.1939, Accuracy: 0.9440  
 Epoch 11/500, Loss: 0.1871, Accuracy: 0.9458  
 Epoch 12/500, Loss: 0.1817, Accuracy: 0.9469  
 Epoch 13/500, Loss: 0.1767, Accuracy: 0.9499  
 Epoch 14/500, Loss: 0.1729, Accuracy: 0.9495  
 Epoch 15/500, Loss: 0.1679, Accuracy: 0.9512  
 Epoch 16/500, Loss: 0.1651, Accuracy: 0.9517  
 Epoch 17/500, Loss: 0.1611, Accuracy: 0.9534  
 Epoch 18/500, Loss: 0.1590, Accuracy: 0.9534  
 Epoch 19/500, Loss: 0.1560, Accuracy: 0.9546  
 Epoch 20/500, Loss: 0.1531, Accuracy: 0.9538  
 Epoch 21/500, Loss: 0.1505, Accuracy: 0.9555  
 Epoch 22/500, Loss: 0.1488, Accuracy: 0.9562  
 Epoch 23/500, Loss: 0.1469, Accuracy: 0.9551  
 Epoch 24/500, Loss: 0.1453, Accuracy: 0.9550  
 Epoch 25/500, Loss: 0.1432, Accuracy: 0.9574  
 Epoch 26/500, Loss: 0.1409, Accuracy: 0.9573  
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 Epoch 29/500, Loss: 0.1360, Accuracy: 0.9585  
 Epoch 30/500, Loss: 0.1362, Accuracy: 0.9580  
 Epoch 31/500, Loss: 0.1340, Accuracy: 0.9586  
 Epoch 32/500, Loss: 0.1338, Accuracy: 0.9582  
 Epoch 33/500, Loss: 0.1329, Accuracy: 0.9577  
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 Epoch 35/500, Loss: 0.1313, Accuracy: 0.9597  
 Epoch 36/500, Loss: 0.1298, Accuracy: 0.9591  
 Epoch 37/500, Loss: 0.1290, Accuracy: 0.9595  
 Epoch 38/500, Loss: 0.1278, Accuracy: 0.9607  
 Epoch 39/500, Loss: 0.1273, Accuracy: 0.9605  
 Epoch 40/500, Loss: 0.1269, Accuracy: 0.9603

Epoch 41/500, Loss: 0.1273, Accuracy: 0.9600  
Epoch 42/500, Loss: 0.1257, Accuracy: 0.9608  
Epoch 43/500, Loss: 0.1247, Accuracy: 0.9611  
Epoch 44/500, Loss: 0.1251, Accuracy: 0.9602  
Epoch 45/500, Loss: 0.1240, Accuracy: 0.9613  
Epoch 46/500, Loss: 0.1244, Accuracy: 0.9617  
Epoch 47/500, Loss: 0.1232, Accuracy: 0.9624  
Epoch 48/500, Loss: 0.1234, Accuracy: 0.9621  
Epoch 49/500, Loss: 0.1234, Accuracy: 0.9611  
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Epoch 80/500, Loss: 0.1188, Accuracy: 0.9637  
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Epoch 84/500, Loss: 0.1193, Accuracy: 0.9637  
Epoch 85/500, Loss: 0.1184, Accuracy: 0.9642  
Epoch 86/500, Loss: 0.1183, Accuracy: 0.9649  
Epoch 87/500, Loss: 0.1186, Accuracy: 0.9645  
Epoch 88/500, Loss: 0.1191, Accuracy: 0.9635

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Epoch 271/500, Loss: 0.1332, Accuracy: 0.9662  
Epoch 272/500, Loss: 0.1332, Accuracy: 0.9663  
Epoch 273/500, Loss: 0.1332, Accuracy: 0.9661  
Epoch 274/500, Loss: 0.1333, Accuracy: 0.9662  
Epoch 275/500, Loss: 0.1335, Accuracy: 0.9659  
Epoch 276/500, Loss: 0.1334, Accuracy: 0.9663  
Epoch 277/500, Loss: 0.1335, Accuracy: 0.9662  
Epoch 278/500, Loss: 0.1335, Accuracy: 0.9661  
Epoch 279/500, Loss: 0.1336, Accuracy: 0.9661  
Epoch 280/500, Loss: 0.1336, Accuracy: 0.9660

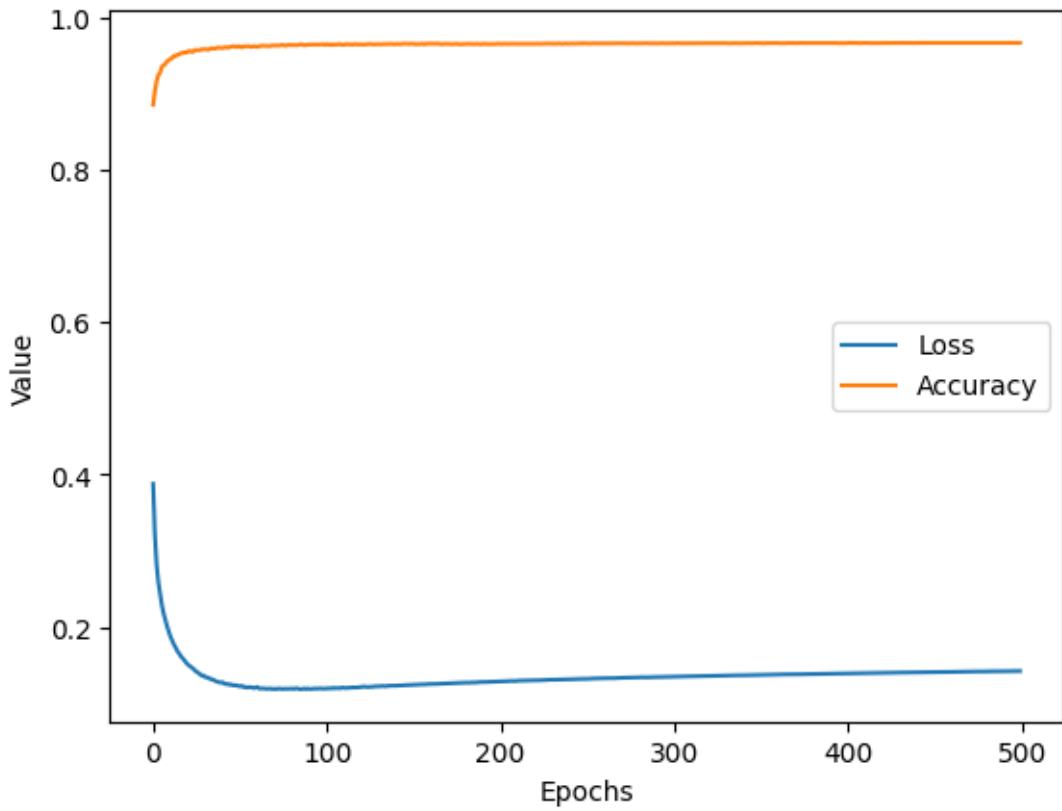
Epoch 281/500, Loss: 0.1337, Accuracy: 0.9663  
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Epoch 285/500, Loss: 0.1337, Accuracy: 0.9664  
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Epoch 292/500, Loss: 0.1342, Accuracy: 0.9663  
Epoch 293/500, Loss: 0.1345, Accuracy: 0.9661  
Epoch 294/500, Loss: 0.1342, Accuracy: 0.9664  
Epoch 295/500, Loss: 0.1343, Accuracy: 0.9661  
Epoch 296/500, Loss: 0.1345, Accuracy: 0.9660  
Epoch 297/500, Loss: 0.1345, Accuracy: 0.9662  
Epoch 298/500, Loss: 0.1345, Accuracy: 0.9661  
Epoch 299/500, Loss: 0.1345, Accuracy: 0.9661  
Epoch 300/500, Loss: 0.1346, Accuracy: 0.9664  
Epoch 301/500, Loss: 0.1348, Accuracy: 0.9660  
Epoch 302/500, Loss: 0.1347, Accuracy: 0.9662  
Epoch 303/500, Loss: 0.1347, Accuracy: 0.9665  
Epoch 304/500, Loss: 0.1348, Accuracy: 0.9662  
Epoch 305/500, Loss: 0.1348, Accuracy: 0.9662  
Epoch 306/500, Loss: 0.1350, Accuracy: 0.9663  
Epoch 307/500, Loss: 0.1350, Accuracy: 0.9662  
Epoch 308/500, Loss: 0.1351, Accuracy: 0.9664  
Epoch 309/500, Loss: 0.1350, Accuracy: 0.9664  
Epoch 310/500, Loss: 0.1351, Accuracy: 0.9663  
Epoch 311/500, Loss: 0.1353, Accuracy: 0.9663  
Epoch 312/500, Loss: 0.1353, Accuracy: 0.9664  
Epoch 313/500, Loss: 0.1353, Accuracy: 0.9663  
Epoch 314/500, Loss: 0.1353, Accuracy: 0.9662  
Epoch 315/500, Loss: 0.1354, Accuracy: 0.9661  
Epoch 316/500, Loss: 0.1354, Accuracy: 0.9664  
Epoch 317/500, Loss: 0.1355, Accuracy: 0.9662  
Epoch 318/500, Loss: 0.1355, Accuracy: 0.9662  
Epoch 319/500, Loss: 0.1356, Accuracy: 0.9663  
Epoch 320/500, Loss: 0.1356, Accuracy: 0.9662  
Epoch 321/500, Loss: 0.1356, Accuracy: 0.9664  
Epoch 322/500, Loss: 0.1357, Accuracy: 0.9664  
Epoch 323/500, Loss: 0.1357, Accuracy: 0.9663  
Epoch 324/500, Loss: 0.1358, Accuracy: 0.9663  
Epoch 325/500, Loss: 0.1358, Accuracy: 0.9662  
Epoch 326/500, Loss: 0.1359, Accuracy: 0.9662  
Epoch 327/500, Loss: 0.1360, Accuracy: 0.9663  
Epoch 328/500, Loss: 0.1359, Accuracy: 0.9664

Epoch 329/500, Loss: 0.1360, Accuracy: 0.9663  
Epoch 330/500, Loss: 0.1361, Accuracy: 0.9664  
Epoch 331/500, Loss: 0.1361, Accuracy: 0.9665  
Epoch 332/500, Loss: 0.1362, Accuracy: 0.9660  
Epoch 333/500, Loss: 0.1362, Accuracy: 0.9663  
Epoch 334/500, Loss: 0.1363, Accuracy: 0.9661  
Epoch 335/500, Loss: 0.1363, Accuracy: 0.9664  
Epoch 336/500, Loss: 0.1364, Accuracy: 0.9663  
Epoch 337/500, Loss: 0.1363, Accuracy: 0.9664  
Epoch 338/500, Loss: 0.1365, Accuracy: 0.9661  
Epoch 339/500, Loss: 0.1364, Accuracy: 0.9662  
Epoch 340/500, Loss: 0.1365, Accuracy: 0.9663  
Epoch 341/500, Loss: 0.1365, Accuracy: 0.9664  
Epoch 342/500, Loss: 0.1366, Accuracy: 0.9663  
Epoch 343/500, Loss: 0.1366, Accuracy: 0.9664  
Epoch 344/500, Loss: 0.1367, Accuracy: 0.9665  
Epoch 345/500, Loss: 0.1367, Accuracy: 0.9664  
Epoch 346/500, Loss: 0.1367, Accuracy: 0.9662  
Epoch 347/500, Loss: 0.1368, Accuracy: 0.9666  
Epoch 348/500, Loss: 0.1367, Accuracy: 0.9666  
Epoch 349/500, Loss: 0.1369, Accuracy: 0.9665  
Epoch 350/500, Loss: 0.1370, Accuracy: 0.9664  
Epoch 351/500, Loss: 0.1370, Accuracy: 0.9664  
Epoch 352/500, Loss: 0.1370, Accuracy: 0.9663  
Epoch 353/500, Loss: 0.1371, Accuracy: 0.9662  
Epoch 354/500, Loss: 0.1372, Accuracy: 0.9665  
Epoch 355/500, Loss: 0.1371, Accuracy: 0.9664  
Epoch 356/500, Loss: 0.1371, Accuracy: 0.9665  
Epoch 357/500, Loss: 0.1373, Accuracy: 0.9665  
Epoch 358/500, Loss: 0.1373, Accuracy: 0.9664  
Epoch 359/500, Loss: 0.1374, Accuracy: 0.9664  
Epoch 360/500, Loss: 0.1373, Accuracy: 0.9665  
Epoch 361/500, Loss: 0.1374, Accuracy: 0.9666  
Epoch 362/500, Loss: 0.1374, Accuracy: 0.9662  
Epoch 363/500, Loss: 0.1374, Accuracy: 0.9664  
Epoch 364/500, Loss: 0.1377, Accuracy: 0.9663  
Epoch 365/500, Loss: 0.1376, Accuracy: 0.9663  
Epoch 366/500, Loss: 0.1376, Accuracy: 0.9666  
Epoch 367/500, Loss: 0.1377, Accuracy: 0.9666  
Epoch 368/500, Loss: 0.1377, Accuracy: 0.9664  
Epoch 369/500, Loss: 0.1377, Accuracy: 0.9664  
Epoch 370/500, Loss: 0.1377, Accuracy: 0.9664  
Epoch 371/500, Loss: 0.1379, Accuracy: 0.9665  
Epoch 372/500, Loss: 0.1379, Accuracy: 0.9663  
Epoch 373/500, Loss: 0.1378, Accuracy: 0.9667  
Epoch 374/500, Loss: 0.1379, Accuracy: 0.9666  
Epoch 375/500, Loss: 0.1379, Accuracy: 0.9667  
Epoch 376/500, Loss: 0.1379, Accuracy: 0.9666

Epoch 377/500, Loss: 0.1381, Accuracy: 0.9666  
Epoch 378/500, Loss: 0.1381, Accuracy: 0.9666  
Epoch 379/500, Loss: 0.1382, Accuracy: 0.9665  
Epoch 380/500, Loss: 0.1381, Accuracy: 0.9667  
Epoch 381/500, Loss: 0.1382, Accuracy: 0.9664  
Epoch 382/500, Loss: 0.1382, Accuracy: 0.9668  
Epoch 383/500, Loss: 0.1383, Accuracy: 0.9664  
Epoch 384/500, Loss: 0.1383, Accuracy: 0.9667  
Epoch 385/500, Loss: 0.1384, Accuracy: 0.9664  
Epoch 386/500, Loss: 0.1384, Accuracy: 0.9666  
Epoch 387/500, Loss: 0.1385, Accuracy: 0.9665  
Epoch 388/500, Loss: 0.1386, Accuracy: 0.9667  
Epoch 389/500, Loss: 0.1386, Accuracy: 0.9666  
Epoch 390/500, Loss: 0.1385, Accuracy: 0.9666  
Epoch 391/500, Loss: 0.1386, Accuracy: 0.9665  
Epoch 392/500, Loss: 0.1386, Accuracy: 0.9666  
Epoch 393/500, Loss: 0.1386, Accuracy: 0.9666  
Epoch 394/500, Loss: 0.1388, Accuracy: 0.9665  
Epoch 395/500, Loss: 0.1388, Accuracy: 0.9666  
Epoch 396/500, Loss: 0.1389, Accuracy: 0.9662  
Epoch 397/500, Loss: 0.1388, Accuracy: 0.9665  
Epoch 398/500, Loss: 0.1388, Accuracy: 0.9665  
Epoch 399/500, Loss: 0.1388, Accuracy: 0.9666  
Epoch 400/500, Loss: 0.1389, Accuracy: 0.9664  
Epoch 401/500, Loss: 0.1389, Accuracy: 0.9670  
Epoch 402/500, Loss: 0.1390, Accuracy: 0.9666  
Epoch 403/500, Loss: 0.1390, Accuracy: 0.9669  
Epoch 404/500, Loss: 0.1390, Accuracy: 0.9666  
Epoch 405/500, Loss: 0.1391, Accuracy: 0.9667  
Epoch 406/500, Loss: 0.1390, Accuracy: 0.9665  
Epoch 407/500, Loss: 0.1392, Accuracy: 0.9665  
Epoch 408/500, Loss: 0.1392, Accuracy: 0.9665  
Epoch 409/500, Loss: 0.1393, Accuracy: 0.9664  
Epoch 410/500, Loss: 0.1391, Accuracy: 0.9668  
Epoch 411/500, Loss: 0.1393, Accuracy: 0.9667  
Epoch 412/500, Loss: 0.1394, Accuracy: 0.9668  
Epoch 413/500, Loss: 0.1394, Accuracy: 0.9667  
Epoch 414/500, Loss: 0.1394, Accuracy: 0.9666  
Epoch 415/500, Loss: 0.1394, Accuracy: 0.9665  
Epoch 416/500, Loss: 0.1395, Accuracy: 0.9665  
Epoch 417/500, Loss: 0.1395, Accuracy: 0.9664  
Epoch 418/500, Loss: 0.1394, Accuracy: 0.9665  
Epoch 419/500, Loss: 0.1396, Accuracy: 0.9666  
Epoch 420/500, Loss: 0.1397, Accuracy: 0.9664  
Epoch 421/500, Loss: 0.1396, Accuracy: 0.9667  
Epoch 422/500, Loss: 0.1397, Accuracy: 0.9666  
Epoch 423/500, Loss: 0.1398, Accuracy: 0.9666  
Epoch 424/500, Loss: 0.1399, Accuracy: 0.9664

Epoch 425/500, Loss: 0.1398, Accuracy: 0.9666  
Epoch 426/500, Loss: 0.1398, Accuracy: 0.9666  
Epoch 427/500, Loss: 0.1399, Accuracy: 0.9667  
Epoch 428/500, Loss: 0.1398, Accuracy: 0.9669  
Epoch 429/500, Loss: 0.1399, Accuracy: 0.9666  
Epoch 430/500, Loss: 0.1400, Accuracy: 0.9667  
Epoch 431/500, Loss: 0.1400, Accuracy: 0.9668  
Epoch 432/500, Loss: 0.1399, Accuracy: 0.9668  
Epoch 433/500, Loss: 0.1401, Accuracy: 0.9667  
Epoch 434/500, Loss: 0.1401, Accuracy: 0.9666  
Epoch 435/500, Loss: 0.1402, Accuracy: 0.9668  
Epoch 436/500, Loss: 0.1401, Accuracy: 0.9667  
Epoch 437/500, Loss: 0.1402, Accuracy: 0.9667  
Epoch 438/500, Loss: 0.1403, Accuracy: 0.9667  
Epoch 439/500, Loss: 0.1402, Accuracy: 0.9666  
Epoch 440/500, Loss: 0.1402, Accuracy: 0.9668  
Epoch 441/500, Loss: 0.1403, Accuracy: 0.9668  
Epoch 442/500, Loss: 0.1403, Accuracy: 0.9668  
Epoch 443/500, Loss: 0.1404, Accuracy: 0.9667  
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Epoch 445/500, Loss: 0.1405, Accuracy: 0.9667  
Epoch 446/500, Loss: 0.1406, Accuracy: 0.9667  
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Epoch 449/500, Loss: 0.1406, Accuracy: 0.9667  
Epoch 450/500, Loss: 0.1407, Accuracy: 0.9667  
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Epoch 452/500, Loss: 0.1408, Accuracy: 0.9667  
Epoch 453/500, Loss: 0.1407, Accuracy: 0.9667  
Epoch 454/500, Loss: 0.1407, Accuracy: 0.9667  
Epoch 455/500, Loss: 0.1408, Accuracy: 0.9666  
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Epoch 459/500, Loss: 0.1409, Accuracy: 0.9666  
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Epoch 461/500, Loss: 0.1409, Accuracy: 0.9668  
Epoch 462/500, Loss: 0.1410, Accuracy: 0.9667  
Epoch 463/500, Loss: 0.1410, Accuracy: 0.9667  
Epoch 464/500, Loss: 0.1411, Accuracy: 0.9667  
Epoch 465/500, Loss: 0.1411, Accuracy: 0.9668  
Epoch 466/500, Loss: 0.1411, Accuracy: 0.9667  
Epoch 467/500, Loss: 0.1411, Accuracy: 0.9667  
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Epoch 469/500, Loss: 0.1413, Accuracy: 0.9668  
Epoch 470/500, Loss: 0.1413, Accuracy: 0.9666  
Epoch 471/500, Loss: 0.1413, Accuracy: 0.9667  
Epoch 472/500, Loss: 0.1413, Accuracy: 0.9666

Epoch 473/500, Loss: 0.1413, Accuracy: 0.9668  
Epoch 474/500, Loss: 0.1414, Accuracy: 0.9667  
Epoch 475/500, Loss: 0.1414, Accuracy: 0.9666  
Epoch 476/500, Loss: 0.1415, Accuracy: 0.9667  
Epoch 477/500, Loss: 0.1414, Accuracy: 0.9668  
Epoch 478/500, Loss: 0.1414, Accuracy: 0.9666  
Epoch 479/500, Loss: 0.1415, Accuracy: 0.9668  
Epoch 480/500, Loss: 0.1416, Accuracy: 0.9667  
Epoch 481/500, Loss: 0.1416, Accuracy: 0.9666  
Epoch 482/500, Loss: 0.1416, Accuracy: 0.9667  
Epoch 483/500, Loss: 0.1417, Accuracy: 0.9667  
Epoch 484/500, Loss: 0.1416, Accuracy: 0.9668  
Epoch 485/500, Loss: 0.1418, Accuracy: 0.9666  
Epoch 486/500, Loss: 0.1417, Accuracy: 0.9667  
Epoch 487/500, Loss: 0.1417, Accuracy: 0.9668  
Epoch 488/500, Loss: 0.1418, Accuracy: 0.9667  
Epoch 489/500, Loss: 0.1418, Accuracy: 0.9668  
Epoch 490/500, Loss: 0.1418, Accuracy: 0.9667  
Epoch 491/500, Loss: 0.1418, Accuracy: 0.9667  
Epoch 492/500, Loss: 0.1419, Accuracy: 0.9666  
Epoch 493/500, Loss: 0.1419, Accuracy: 0.9668  
Epoch 494/500, Loss: 0.1420, Accuracy: 0.9666  
Epoch 495/500, Loss: 0.1420, Accuracy: 0.9667  
Epoch 496/500, Loss: 0.1420, Accuracy: 0.9667  
Epoch 497/500, Loss: 0.1420, Accuracy: 0.9667  
Epoch 498/500, Loss: 0.1421, Accuracy: 0.9668  
Epoch 499/500, Loss: 0.1421, Accuracy: 0.9667  
Epoch 500/500, Loss: 0.1421, Accuracy: 0.9668



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