Deep Learning

August 7, 2023

1 Deep Learning

[1]:
```
import torch
import torch.nn as nn
import torch.nn.functional as F

import numpy as np
import matplotlib.pyplot as plt
import seaborn as sns
import pandas as pd
```

[2]:
```
%matplotlib inline
```

1.1 Loading data

[3]:
```
df = pd.read_csv("./processed_data/processed_data/ecg_processed_data.csv",␣
↪index_col=0)
```

[4]:
```
df.head()
```

[4]:

	Record ID	Segment Start	Segment End	0	1	2	\
0	100	13	213	0.059449	0.055308	0.052035	
1	100	307	507	0.084239	0.087566	0.088956	
2	100	563	763	-0.006937	-0.005690	-0.005184	
3	100	883	1083	0.072086	0.073128	0.073026	
4	100	1168	1368	0.084762	0.083995	0.082327	

	3	4	5	6	…	191	192	193	\
0	0.049666	0.047961	0.046922	0.046801	…	0.029812	0.031902	0.033233	
1	0.088621	0.086919	0.084459	0.081823	…	0.020380	0.020170	0.020049	
2	-0.005172	-0.005405	-0.005802	-0.006385	…	-0.083923	-0.084476	-0.084798	
3	0.071802	0.069731	0.067336	0.065156	…	0.040917	0.040820	0.040605	
4	0.080127	0.077701	0.075216	0.072963	…	0.024691	0.025225	0.025977	

	194	195	196	197	198	199	\
0	0.033981	0.034276	0.034166	0.033702	0.033134	0.032648	
1	0.020272	0.020719	0.020971	0.020866	0.020622	0.020434	

```
2 -0.084841 -0.084325 -0.082953 -0.080644 -0.077424 -0.073181
3  0.040177  0.039328  0.038051  0.036671  0.035565  0.034817
4  0.027249  0.029211  0.031715  0.034364  0.036462  0.037443

   Annotation Class
0                N
1                N
2                N
3                N
4                N

[5 rows x 204 columns]
```

[5]:
```
df.describe().transpose()
```

[5]:

	count	mean	std	min	…
Record ID	99174.0	170.801752	51.985347	100.000000	
Segment Start	99174.0	325045.609051	188363.760147	9.000000	
Segment End	99174.0	325245.609051	188363.760147	209.000000	
0	99174.0	-0.042127	0.119547	-1.900955	
1	99174.0	-0.042054	0.118728	-1.887876	
…	…	…	…	…	
195	99174.0	0.068449	0.243398	-2.685320	
196	99174.0	0.065637	0.240538	-2.715343	
197	99174.0	0.062668	0.237743	-2.734072	
198	99174.0	0.059560	0.234978	-2.743276	
199	99174.0	0.056335	0.232210	-2.742996	

	25%	50%	75%	max
Record ID	114.000000	203.000000	215.000000	234.000000
Segment Start	160745.000000	326069.500000	488528.500000	649793.000000
Segment End	160945.000000	326269.500000	488728.500000	649993.000000
0	-0.097349	-0.045074	0.006416	2.195452
1	-0.097490	-0.044461	0.006934	2.207827
…	…	…	…	…
195	-0.058351	-0.001114	0.128255	2.462435
196	-0.058428	-0.001539	0.122874	2.480217
197	-0.058666	-0.002161	0.117917	2.494743
198	-0.059124	-0.003069	0.112630	2.506468
199	-0.059530	-0.004525	0.107668	2.515870

[203 rows x 8 columns]

[6]:
```
df.info()
```

```
<class 'pandas.core.frame.DataFrame'>
Index: 99174 entries, 0 to 99173
```

```
Columns: 204 entries, Record ID to Annotation Class
dtypes: float64(200), int64(3), object(1)
memory usage: 155.1+ MB
```

1.2 Preprocessing

[7]:
```
X = df[[str(i) for i in range(0, 200)]].values
```

[8]:
```
X
```

[8]:
```
array([[ 0.05944944,  0.05530813,  0.05203533, …,  0.03370211,
         0.03313351,  0.03264835],
       [ 0.08423915,  0.08756617,  0.08895633, …,  0.02086591,
         0.02062246,  0.02043396],
       [-0.00693746, -0.00568975, -0.00518379, …, -0.08064385,
        -0.07742402, -0.07318052],
       …,
       [-0.0464351 , -0.04455849, -0.04386177, …, -0.08220224,
        -0.08951841, -0.09635549],
       [-0.09173968, -0.09411179, -0.09693917, …,  0.01425364,
         0.01084743,  0.0081831 ],
       [ 0.07593816,  0.07788971,  0.07865438, …,  0.05425404,
         0.04719546,  0.0410799 ]])
```

[9]:
```
X.shape
```

[9]:
```
(99174, 200)
```

[10]:
```
y = df["Annotation Class"].astype("category")
```

[11]:
```
y.describe()
```

[11]:
```
count     99174
unique        5
top           N
freq      73439
Name: Annotation Class, dtype: object
```

[12]:
```
y.info()
```

```
<class 'pandas.core.series.Series'>
Index: 99174 entries, 0 to 99173
Series name: Annotation Class
Non-Null Count  Dtype
--------------  -----
99174 non-null  category
dtypes: category(1)
memory usage: 871.9 KB
```

[13]:
```
y.cat.codes
```

[13]:
```
0        2
1        2
2        2
3        2
4        2
        ..
99169    2
99170    2
99171    2
99172    2
99173    2
Length: 99174, dtype: int8
```

[14]:
```
y.cat.categories
```

[14]:
```
Index(['/', 'L', 'N', 'R', 'V'], dtype='object')
```

[15]:
```
y_code = y.cat.codes.values
```

[16]:
```
y_code
```

[16]:
```
array([2, 2, 2, …, 2, 2, 2], dtype=int8)
```

[17]:
```
y_code.shape
```

[17]:
```
(99174,)
```

[18]:
```
y_code
```

[18]:
```
array([2, 2, 2, …, 2, 2, 2], dtype=int8)
```

[19]:
```
from sklearn.model_selection import train_test_split
```

[20]:
```
X_train, X_test, y_train, y_test = train_test_split(
    X, y_code, test_size=0.2, random_state=101, stratify=y, shuffle=True
)
```

[21]:
```
X_train, X_val, y_train, y_val = train_test_split(
    X_train, y_train, test_size=0.2, random_state=101, stratify=y_train,␣
 ↪shuffle=True
)
```

[22]:
```
X_train_tensor = torch.FloatTensor(X_train)
X_val_tensor = torch.FloatTensor(X_val)
X_test_tensor = torch.FloatTensor(X_test)
```

```
y_train_tensor = torch.LongTensor(y_train)
y_val_tensor = torch.LongTensor(y_val)
y_test_tensor = torch.LongTensor(y_test)
```

[23]:
```
X_train_tensor.shape
```

[23]:
```
torch.Size([63471, 200])
```

[24]:
```
X_val_tensor.shape
```

[24]:
```
torch.Size([15868, 200])
```

1.3 ANN

[25]:
```
from ecg_deep_learning_models.models import ECGANNModel, ECGCNNModel,␣
 ↪ECGLSTMModel
from ecg_deep_learning_models.utils import (
    count_parameters,
    train_model,
    eval_model,
    show_metrics,profile
)
```

[26]:
```
ecg_ann_model = ECGANNModel(layers=[100, 50])
ecg_ann_model_1 = ECGANNModel(layers=[100, 50, 25])
```

[27]:
```
count_parameters(ecg_ann_model)
```

```
 20000
   100
  5000
    50
   250
     5
------
 25405
```

[28]:
```
count_parameters(ecg_ann_model_1)
```

```
 20000
   100
  5000
    50
  1250
    25
   125
     5
```

```
------
 26555
```

[29]:
```
ecg_ann_model
```

[29]:
```
ECGANNModel(
  (layers): Sequential(
    (0): Linear(in_features=200, out_features=100, bias=True)
    (1): ReLU(inplace=True)
    (2): Dropout(p=0.5, inplace=False)
    (3): Linear(in_features=100, out_features=50, bias=True)
    (4): ReLU(inplace=True)
    (5): Dropout(p=0.5, inplace=False)
    (6): Linear(in_features=50, out_features=5, bias=True)
  )
)
```

[30]:
```
ecg_ann_model_1
```

[30]:
```
ECGANNModel(
  (layers): Sequential(
    (0): Linear(in_features=200, out_features=100, bias=True)
    (1): ReLU(inplace=True)
    (2): Dropout(p=0.5, inplace=False)
    (3): Linear(in_features=100, out_features=50, bias=True)
    (4): ReLU(inplace=True)
    (5): Dropout(p=0.5, inplace=False)
    (6): Linear(in_features=50, out_features=25, bias=True)
    (7): ReLU(inplace=True)
    (8): Dropout(p=0.5, inplace=False)
    (9): Linear(in_features=25, out_features=5, bias=True)
  )
)
```

[31]:
```
X_train_tensor.shape
```

[31]:
```
torch.Size([63471, 200])
```

[32]:
```
ecg_ann_model.parameters()
```

[32]:
```
<generator object Module.parameters at 0x7f2b4abd34a0>
```

[33]:
```
ecg_ann_model_1.parameters()
```

[33]:
```
<generator object Module.parameters at 0x7f2b4abd3820>
```

[34]:
```
ecg_ann_model.parameters
```

[34]:
```
<bound method Module.parameters of ECGANNModel(
  (layers): Sequential(
    (0): Linear(in_features=200, out_features=100, bias=True)
    (1): ReLU(inplace=True)
    (2): Dropout(p=0.5, inplace=False)
    (3): Linear(in_features=100, out_features=50, bias=True)
    (4): ReLU(inplace=True)
    (5): Dropout(p=0.5, inplace=False)
    (6): Linear(in_features=50, out_features=5, bias=True)
  )
)>
```

[35]:
```
ecg_ann_model_1.parameters
```

[35]:
```
<bound method Module.parameters of ECGANNModel(
  (layers): Sequential(
    (0): Linear(in_features=200, out_features=100, bias=True)
    (1): ReLU(inplace=True)
    (2): Dropout(p=0.5, inplace=False)
    (3): Linear(in_features=100, out_features=50, bias=True)
    (4): ReLU(inplace=True)
    (5): Dropout(p=0.5, inplace=False)
    (6): Linear(in_features=50, out_features=25, bias=True)
    (7): ReLU(inplace=True)
    (8): Dropout(p=0.5, inplace=False)
    (9): Linear(in_features=25, out_features=5, bias=True)
  )
)>
```

[36]:
```
train_accuracies, test_accuracies, train_mean_losses, test_mean_losses =␣
 ↪train_model(
    model=ecg_ann_model,
    X_train=X_train_tensor,
    y_train=y_train_tensor,
    X_test=X_val_tensor,
    y_test=y_val_tensor,
    learning_rate=0.001,
    batch_size=100,
    val_batch_size=100,
    epochs=100,
)
```

```
epoch:1 Train Loss:        0.45 Train Accuracy:       86.30     Test Loss:
0.18  Test Accuracy:       94.93       Tolerance Count:0
epoch:2 Train Loss:        0.23 Train Accuracy:       93.15     Test Loss:
0.12  Test Accuracy:       96.43       Tolerance Count:0
epoch:3 Train Loss:        0.19 Train Accuracy:       94.37     Test Loss:
```

```
0.10  Test Accuracy:       97.42       Tolerance Count:0
epoch:4 Train Loss:        0.17 Train Accuracy:       95.12     Test Loss:
0.09  Test Accuracy:       97.59       Tolerance Count:0
epoch:5 Train Loss:        0.15 Train Accuracy:       95.65     Test Loss:
0.08  Test Accuracy:       97.72       Tolerance Count:0
epoch:6 Train Loss:        0.15 Train Accuracy:       95.82     Test Loss:
0.07  Test Accuracy:       98.02       Tolerance Count:0
epoch:7 Train Loss:        0.14 Train Accuracy:       96.08     Test Loss:
0.07  Test Accuracy:       98.13       Tolerance Count:0
epoch:8 Train Loss:        0.13 Train Accuracy:       96.30     Test Loss:
0.07  Test Accuracy:       98.24       Tolerance Count:0
epoch:9 Train Loss:        0.13 Train Accuracy:       96.29     Test Loss:
0.06  Test Accuracy:       98.34       Tolerance Count:0
epoch:10        Train Loss:        0.12 Train Accuracy:       96.55     Test
Loss:        0.06  Test Accuracy:       98.33       Tolerance Count:0
epoch:11        Train Loss:        0.12 Train Accuracy:       96.62     Test
Loss:        0.06  Test Accuracy:       98.49       Tolerance Count:0
epoch:12        Train Loss:        0.11 Train Accuracy:       96.83     Test
Loss:        0.06  Test Accuracy:       98.51       Tolerance Count:0
epoch:13        Train Loss:        0.11 Train Accuracy:       96.85     Test
Loss:        0.05  Test Accuracy:       98.48       Tolerance Count:0
epoch:14        Train Loss:        0.11 Train Accuracy:       96.83     Test
Loss:        0.06  Test Accuracy:       98.54       Tolerance Count:0
epoch:15        Train Loss:        0.10 Train Accuracy:       97.01     Test
Loss:        0.06  Test Accuracy:       98.66       Tolerance Count:0
epoch:16        Train Loss:        0.11 Train Accuracy:       96.96     Test
Loss:        0.05  Test Accuracy:       98.56       Tolerance Count:0
epoch:17        Train Loss:        0.10 Train Accuracy:       97.13     Test
Loss:        0.05  Test Accuracy:       98.59       Tolerance Count:0
epoch:18        Train Loss:        0.10 Train Accuracy:       97.09     Test
Loss:        0.05  Test Accuracy:       98.59       Tolerance Count:0
epoch:19        Train Loss:        0.10 Train Accuracy:       97.13     Test
Loss:        0.05  Test Accuracy:       98.61       Tolerance Count:0
epoch:20        Train Loss:        0.10 Train Accuracy:       97.01     Test
Loss:        0.05  Test Accuracy:       98.71       Tolerance Count:0
epoch:21        Train Loss:        0.10 Train Accuracy:       97.15     Test
Loss:        0.05  Test Accuracy:       98.68       Tolerance Count:0
epoch:22        Train Loss:        0.10 Train Accuracy:       97.17     Test
Loss:        0.05  Test Accuracy:       98.70       Tolerance Count:0
epoch:23        Train Loss:        0.10 Train Accuracy:       97.21     Test
Loss:        0.05  Test Accuracy:       98.65       Tolerance Count:0
epoch:24        Train Loss:        0.10 Train Accuracy:       97.22     Test
Loss:        0.05  Test Accuracy:       98.78       Tolerance Count:0
epoch:25        Train Loss:        0.09 Train Accuracy:       97.39     Test
Loss:        0.05  Test Accuracy:       98.78       Tolerance Count:0
epoch:26        Train Loss:        0.10 Train Accuracy:       97.18     Test
Loss:        0.05  Test Accuracy:       98.76       Tolerance Count:0
epoch:27        Train Loss:        0.10 Train Accuracy:       97.31     Test
```

```
Loss:       0.05  Test Accuracy:       98.78       Tolerance Count:0
epoch:28       Train Loss:       0.09 Train Accuracy:       97.32     Test
Loss:       0.05  Test Accuracy:       98.73       Tolerance Count:0
epoch:29       Train Loss:       0.09 Train Accuracy:       97.28     Test
Loss:       0.05  Test Accuracy:       98.76       Tolerance Count:0
epoch:30       Train Loss:       0.09 Train Accuracy:       97.34     Test
Loss:       0.05  Test Accuracy:       98.78       Tolerance Count:0
epoch:31       Train Loss:       0.09 Train Accuracy:       97.40     Test
Loss:       0.05  Test Accuracy:       98.71       Tolerance Count:0
epoch:32       Train Loss:       0.09 Train Accuracy:       97.36     Test
Loss:       0.05  Test Accuracy:       98.70       Tolerance Count:0
epoch:33       Train Loss:       0.09 Train Accuracy:       97.33     Test
Loss:       0.05  Test Accuracy:       98.80       Tolerance Count:0
epoch:34       Train Loss:       0.09 Train Accuracy:       97.42     Test
Loss:       0.05  Test Accuracy:       98.71       Tolerance Count:0
epoch:35       Train Loss:       0.09 Train Accuracy:       97.40     Test
Loss:       0.05  Test Accuracy:       98.74       Tolerance Count:0
epoch:36       Train Loss:       0.09 Train Accuracy:       97.39     Test
Loss:       0.04  Test Accuracy:       98.82       Tolerance Count:0
epoch:37       Train Loss:       0.09 Train Accuracy:       97.46     Test
Loss:       0.04  Test Accuracy:       98.84       Tolerance Count:0
epoch:38       Train Loss:       0.09 Train Accuracy:       97.47     Test
Loss:       0.04  Test Accuracy:       98.79       Tolerance Count:0
epoch:39       Train Loss:       0.09 Train Accuracy:       97.52     Test
Loss:       0.04  Test Accuracy:       98.75       Tolerance Count:0
epoch:40       Train Loss:       0.09 Train Accuracy:       97.45     Test
Loss:       0.04  Test Accuracy:       98.84       Tolerance Count:0
epoch:41       Train Loss:       0.09 Train Accuracy:       97.56     Test
Loss:       0.04  Test Accuracy:       98.87       Tolerance Count:0
epoch:42       Train Loss:       0.09 Train Accuracy:       97.52     Test
Loss:       0.04  Test Accuracy:       98.78       Tolerance Count:0
epoch:43       Train Loss:       0.09 Train Accuracy:       97.52     Test
Loss:       0.04  Test Accuracy:       98.81       Tolerance Count:0
epoch:44       Train Loss:       0.08 Train Accuracy:       97.52     Test
Loss:       0.04  Test Accuracy:       98.86       Tolerance Count:0
epoch:45       Train Loss:       0.09 Train Accuracy:       97.56     Test
Loss:       0.04  Test Accuracy:       98.90       Tolerance Count:0
epoch:46       Train Loss:       0.08 Train Accuracy:       97.59     Test
Loss:       0.04  Test Accuracy:       98.83       Tolerance Count:0
epoch:47       Train Loss:       0.08 Train Accuracy:       97.60     Test
Loss:       0.04  Test Accuracy:       98.82       Tolerance Count:0
epoch:48       Train Loss:       0.08 Train Accuracy:       97.54     Test
Loss:       0.05  Test Accuracy:       98.77       Tolerance Count:0
epoch:49       Train Loss:       0.08 Train Accuracy:       97.49     Test
Loss:       0.04  Test Accuracy:       98.84       Tolerance Count:0
epoch:50       Train Loss:       0.08 Train Accuracy:       97.60     Test
Loss:       0.04  Test Accuracy:       98.86       Tolerance Count:0
epoch:51       Train Loss:       0.08 Train Accuracy:       97.53     Test
```

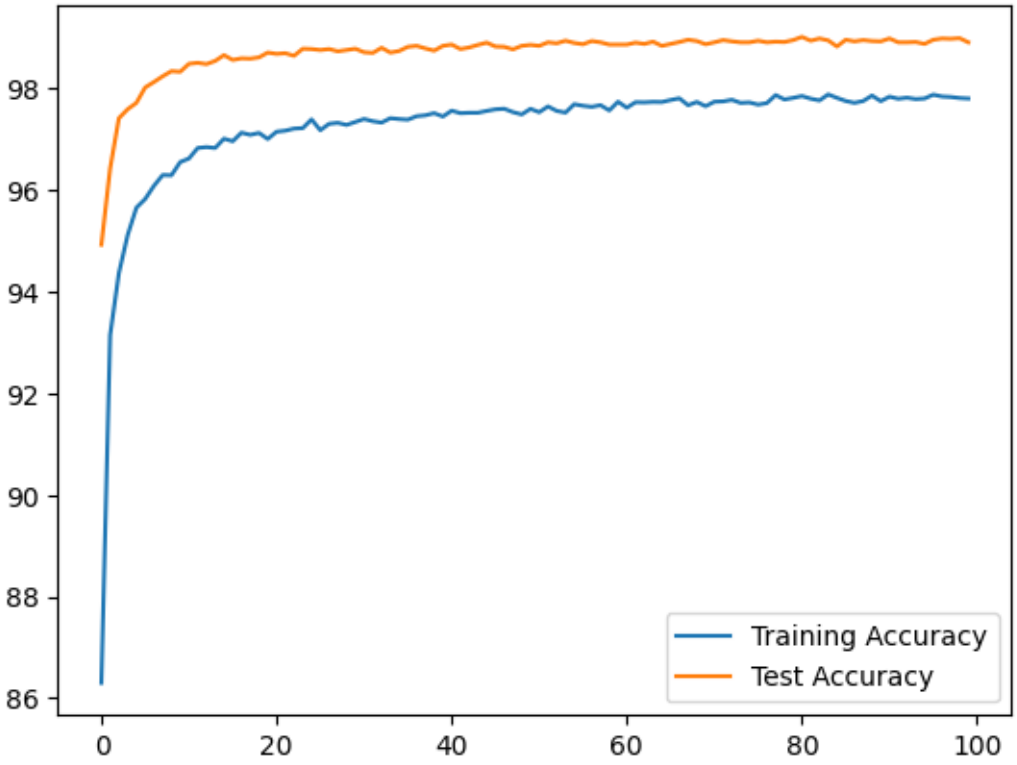
```
Loss:       0.04  Test Accuracy:       98.84       Tolerance Count:0
epoch:52       Train Loss:       0.08 Train Accuracy:       97.65     Test
Loss:       0.04  Test Accuracy:       98.91       Tolerance Count:0
epoch:53       Train Loss:       0.09 Train Accuracy:       97.56     Test
Loss:       0.04  Test Accuracy:       98.89       Tolerance Count:0
epoch:54       Train Loss:       0.09 Train Accuracy:       97.53     Test
Loss:       0.04  Test Accuracy:       98.94       Tolerance Count:0
epoch:55       Train Loss:       0.08 Train Accuracy:       97.69     Test
Loss:       0.04  Test Accuracy:       98.90       Tolerance Count:0
epoch:56       Train Loss:       0.08 Train Accuracy:       97.66     Test
Loss:       0.04  Test Accuracy:       98.87       Tolerance Count:0
epoch:57       Train Loss:       0.08 Train Accuracy:       97.64     Test
Loss:       0.04  Test Accuracy:       98.93       Tolerance Count:0
epoch:58       Train Loss:       0.08 Train Accuracy:       97.67     Test
Loss:       0.04  Test Accuracy:       98.91       Tolerance Count:0
epoch:59       Train Loss:       0.08 Train Accuracy:       97.57     Test
Loss:       0.04  Test Accuracy:       98.87       Tolerance Count:0
epoch:60       Train Loss:       0.08 Train Accuracy:       97.74     Test
Loss:       0.04  Test Accuracy:       98.87       Tolerance Count:0
epoch:61       Train Loss:       0.08 Train Accuracy:       97.62     Test
Loss:       0.04  Test Accuracy:       98.87       Tolerance Count:0
epoch:62       Train Loss:       0.08 Train Accuracy:       97.73     Test
Loss:       0.04  Test Accuracy:       98.90       Tolerance Count:0
epoch:63       Train Loss:       0.08 Train Accuracy:       97.73     Test
Loss:       0.04  Test Accuracy:       98.88       Tolerance Count:0
epoch:64       Train Loss:       0.08 Train Accuracy:       97.74     Test
Loss:       0.04  Test Accuracy:       98.92       Tolerance Count:0
epoch:65       Train Loss:       0.08 Train Accuracy:       97.73     Test
Loss:       0.04  Test Accuracy:       98.84       Tolerance Count:0
epoch:66       Train Loss:       0.08 Train Accuracy:       97.77     Test
Loss:       0.04  Test Accuracy:       98.88       Tolerance Count:0
epoch:67       Train Loss:       0.08 Train Accuracy:       97.81     Test
Loss:       0.04  Test Accuracy:       98.92       Tolerance Count:0
epoch:68       Train Loss:       0.08 Train Accuracy:       97.67     Test
Loss:       0.04  Test Accuracy:       98.96       Tolerance Count:0
epoch:69       Train Loss:       0.08 Train Accuracy:       97.74     Test
Loss:       0.04  Test Accuracy:       98.93       Tolerance Count:0
epoch:70       Train Loss:       0.08 Train Accuracy:       97.65     Test
Loss:       0.04  Test Accuracy:       98.87       Tolerance Count:0
epoch:71       Train Loss:       0.08 Train Accuracy:       97.74     Test
Loss:       0.04  Test Accuracy:       98.91       Tolerance Count:0
epoch:72       Train Loss:       0.08 Train Accuracy:       97.75     Test
Loss:       0.04  Test Accuracy:       98.95       Tolerance Count:0
epoch:73       Train Loss:       0.08 Train Accuracy:       97.78     Test
Loss:       0.04  Test Accuracy:       98.93       Tolerance Count:0
epoch:74       Train Loss:       0.08 Train Accuracy:       97.72     Test
Loss:       0.04  Test Accuracy:       98.91       Tolerance Count:0
epoch:75       Train Loss:       0.08 Train Accuracy:       97.73     Test
```

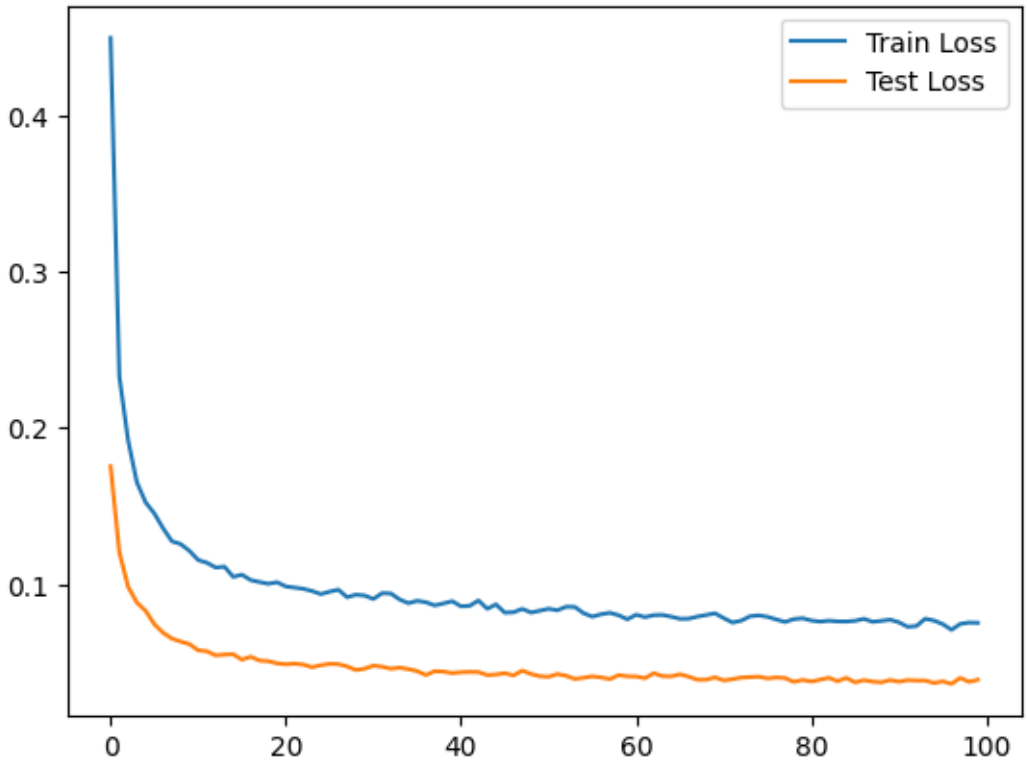
```
Loss:       0.04  Test Accuracy:       98.91       Tolerance Count:0
epoch:76       Train Loss:       0.08 Train Accuracy:       97.68     Test
Loss:       0.04  Test Accuracy:       98.94       Tolerance Count:0
epoch:77       Train Loss:       0.08 Train Accuracy:       97.71     Test
Loss:       0.04  Test Accuracy:       98.91       Tolerance Count:0
epoch:78       Train Loss:       0.08 Train Accuracy:       97.87     Test
Loss:       0.04  Test Accuracy:       98.92       Tolerance Count:0
epoch:79       Train Loss:       0.08 Train Accuracy:       97.78     Test
Loss:       0.04  Test Accuracy:       98.92       Tolerance Count:0
epoch:80       Train Loss:       0.08 Train Accuracy:       97.82     Test
Loss:       0.04  Test Accuracy:       98.95       Tolerance Count:0
epoch:81       Train Loss:       0.08 Train Accuracy:       97.85     Test
Loss:       0.04  Test Accuracy:       99.02       Tolerance Count:0
epoch:82       Train Loss:       0.08 Train Accuracy:       97.80     Test
Loss:       0.04  Test Accuracy:       98.94       Tolerance Count:0
epoch:83       Train Loss:       0.08 Train Accuracy:       97.77     Test
Loss:       0.04  Test Accuracy:       98.99       Tolerance Count:0
epoch:84       Train Loss:       0.08 Train Accuracy:       97.88     Test
Loss:       0.04  Test Accuracy:       98.95       Tolerance Count:0
epoch:85       Train Loss:       0.08 Train Accuracy:       97.82     Test
Loss:       0.04  Test Accuracy:       98.83       Tolerance Count:0
epoch:86       Train Loss:       0.08 Train Accuracy:       97.75     Test
Loss:       0.04  Test Accuracy:       98.96       Tolerance Count:0
epoch:87       Train Loss:       0.08 Train Accuracy:       97.72     Test
Loss:       0.04  Test Accuracy:       98.93       Tolerance Count:0
epoch:88       Train Loss:       0.08 Train Accuracy:       97.75     Test
Loss:       0.04  Test Accuracy:       98.95       Tolerance Count:0
epoch:89       Train Loss:       0.08 Train Accuracy:       97.86     Test
Loss:       0.04  Test Accuracy:       98.93       Tolerance Count:0
epoch:90       Train Loss:       0.08 Train Accuracy:       97.75     Test
Loss:       0.04  Test Accuracy:       98.93       Tolerance Count:0
epoch:91       Train Loss:       0.08 Train Accuracy:       97.84     Test
Loss:       0.04  Test Accuracy:       98.99       Tolerance Count:0
epoch:92       Train Loss:       0.07 Train Accuracy:       97.80     Test
Loss:       0.04  Test Accuracy:       98.91       Tolerance Count:0
epoch:93       Train Loss:       0.07 Train Accuracy:       97.82     Test
Loss:       0.04  Test Accuracy:       98.91       Tolerance Count:0
epoch:94       Train Loss:       0.08 Train Accuracy:       97.79     Test
Loss:       0.04  Test Accuracy:       98.92       Tolerance Count:0
epoch:95       Train Loss:       0.08 Train Accuracy:       97.80     Test
Loss:       0.04  Test Accuracy:       98.88       Tolerance Count:0
epoch:96       Train Loss:       0.07 Train Accuracy:       97.88     Test
Loss:       0.04  Test Accuracy:       98.96       Tolerance Count:0
epoch:97       Train Loss:       0.07 Train Accuracy:       97.84     Test
Loss:       0.04  Test Accuracy:       98.99       Tolerance Count:0
epoch:98       Train Loss:       0.07 Train Accuracy:       97.83     Test
Loss:       0.04  Test Accuracy:       98.98       Tolerance Count:0
epoch:99       Train Loss:       0.08 Train Accuracy:       97.81     Test
```

```
Loss:        0.04  Test Accuracy:       98.99       Tolerance Count:0
epoch:100       Train Loss:        0.08 Train Accuracy:       97.80     Test
Loss:        0.04  Test Accuracy:       98.91       Tolerance Count:0

Duration: 761 seconds
```

[38]:
```
show_metrics(train_accuracies, test_accuracies, train_mean_losses,␣
 ↪test_mean_losses)
eval_model(ecg_ann_model, X_test_tensor, y_test_tensor)
profile(ecg_ann_model,tuple([200]))
```






```
              precision    recall  f1-score   support

           0       1.00      1.00      1.00       724
           1       0.98      0.99      0.98      1594
           2       1.00      0.99      0.99     14734
           3       0.99      1.00      0.99      1442
           4       0.95      0.96      0.96      1341

    accuracy                           0.99     19835
   macro avg       0.98      0.99      0.98     19835
weighted avg       0.99      0.99      0.99     19835

[[  723     0     0     0     1]
 [    0  1575    12     0     7]
 [    0    23 14637    14    60]
 [    0     0     5  1436     1]
 [    1    16    34     1  1289]]

Duration: 1 seconds
Warning: module Dropout is treated as a zero-op.
Warning: module ECGANNModel is treated as a zero-op.
ECGANNModel(
```

```
  25.41 k, 100.000% Params, 25.55 KMac, 100.000% MACs,
  (layers): Sequential(
    25.41 k, 100.000% Params, 25.55 KMac, 100.000% MACs,
    (0): Linear(20.1 k, 79.118% Params, 20.1 KMac, 78.654% MACs,
in_features=200, out_features=100, bias=True)
    (1): ReLU(0, 0.000% Params, 100.0 Mac, 0.391% MACs, inplace=True)
    (2): Dropout(0, 0.000% Params, 0.0 Mac, 0.000% MACs, p=0.5, inplace=False)
    (3): Linear(5.05 k, 19.878% Params, 5.05 KMac, 19.761% MACs,
in_features=100, out_features=50, bias=True)
    (4): ReLU(0, 0.000% Params, 50.0 Mac, 0.196% MACs, inplace=True)
    (5): Dropout(0, 0.000% Params, 0.0 Mac, 0.000% MACs, p=0.5, inplace=False)
    (6): Linear(255, 1.004% Params, 255.0 Mac, 0.998% MACs, in_features=50,
out_features=5, bias=True)
  )
)
Computational complexity: 25.55 KMac
Computational complexity: 51.1 KFlops
Number of parameters: 25.41 k
```

[39]:
```
train_accuracies, test_accuracies, train_mean_losses, test_mean_losses =␣
 ↪train_model(
    model=ecg_ann_model_1,
    X_train=X_train_tensor,
    y_train=y_train_tensor,
    X_test=X_val_tensor,
    y_test=y_val_tensor,
    learning_rate=0.001,
    batch_size=100,
    val_batch_size=100,
    epochs=100,
)
```

```
epoch:1 Train Loss:        0.58 Train Accuracy:       80.00     Test Loss:
0.24  Test Accuracy:       93.06       Tolerance Count:0
epoch:2 Train Loss:        0.32 Train Accuracy:       89.26     Test Loss:
0.16  Test Accuracy:       95.75       Tolerance Count:0
epoch:3 Train Loss:        0.27 Train Accuracy:       91.75     Test Loss:
0.13  Test Accuracy:       96.30       Tolerance Count:0
epoch:4 Train Loss:        0.24 Train Accuracy:       92.80     Test Loss:
0.11  Test Accuracy:       96.80       Tolerance Count:0
epoch:5 Train Loss:        0.22 Train Accuracy:       93.53     Test Loss:
0.10  Test Accuracy:       97.18       Tolerance Count:0
epoch:6 Train Loss:        0.21 Train Accuracy:       93.87     Test Loss:
0.09  Test Accuracy:       97.32       Tolerance Count:0
epoch:7 Train Loss:        0.20 Train Accuracy:       94.32     Test Loss:
0.09  Test Accuracy:       97.52       Tolerance Count:0
epoch:8 Train Loss:        0.18 Train Accuracy:       94.61     Test Loss:
0.08  Test Accuracy:       97.83       Tolerance Count:0
```

```
epoch:9 Train Loss:        0.18 Train Accuracy:       94.79     Test Loss:
0.08  Test Accuracy:       97.85       Tolerance Count:0
epoch:10        Train Loss:        0.17 Train Accuracy:       95.02     Test
Loss:        0.07  Test Accuracy:       97.92       Tolerance Count:0
epoch:11        Train Loss:        0.16 Train Accuracy:       95.28     Test
Loss:        0.08  Test Accuracy:       97.93       Tolerance Count:0
epoch:12        Train Loss:        0.16 Train Accuracy:       95.38     Test
Loss:        0.07  Test Accuracy:       97.91       Tolerance Count:0
epoch:13        Train Loss:        0.16 Train Accuracy:       95.44     Test
Loss:        0.07  Test Accuracy:       98.12       Tolerance Count:0
epoch:14        Train Loss:        0.15 Train Accuracy:       95.69     Test
Loss:        0.06  Test Accuracy:       98.22       Tolerance Count:0
epoch:15        Train Loss:        0.15 Train Accuracy:       95.74     Test
Loss:        0.06  Test Accuracy:       98.18       Tolerance Count:0
epoch:16        Train Loss:        0.15 Train Accuracy:       95.82     Test
Loss:        0.06  Test Accuracy:       98.34       Tolerance Count:0
epoch:17        Train Loss:        0.14 Train Accuracy:       95.98     Test
Loss:        0.06  Test Accuracy:       98.34       Tolerance Count:0
epoch:18        Train Loss:        0.14 Train Accuracy:       95.90     Test
Loss:        0.06  Test Accuracy:       98.31       Tolerance Count:0
epoch:19        Train Loss:        0.14 Train Accuracy:       96.06     Test
Loss:        0.06  Test Accuracy:       98.35       Tolerance Count:0
epoch:20        Train Loss:        0.14 Train Accuracy:       96.08     Test
Loss:        0.06  Test Accuracy:       98.42       Tolerance Count:0
epoch:21        Train Loss:        0.13 Train Accuracy:       96.25     Test
Loss:        0.05  Test Accuracy:       98.53       Tolerance Count:0
epoch:22        Train Loss:        0.14 Train Accuracy:       96.16     Test
Loss:        0.05  Test Accuracy:       98.48       Tolerance Count:0
epoch:23        Train Loss:        0.14 Train Accuracy:       96.13     Test
Loss:        0.05  Test Accuracy:       98.55       Tolerance Count:0
epoch:24        Train Loss:        0.13 Train Accuracy:       96.23     Test
Loss:        0.06  Test Accuracy:       98.44       Tolerance Count:0
epoch:25        Train Loss:        0.13 Train Accuracy:       96.21     Test
Loss:        0.06  Test Accuracy:       98.20       Tolerance Count:0
epoch:26        Train Loss:        0.13 Train Accuracy:       96.36     Test
Loss:        0.05  Test Accuracy:       98.41       Tolerance Count:0
epoch:27        Train Loss:        0.13 Train Accuracy:       96.51     Test
Loss:        0.05  Test Accuracy:       98.53       Tolerance Count:0
epoch:28        Train Loss:        0.13 Train Accuracy:       96.53     Test
Loss:        0.05  Test Accuracy:       98.60       Tolerance Count:0
epoch:29        Train Loss:        0.13 Train Accuracy:       96.45     Test
Loss:        0.05  Test Accuracy:       98.59       Tolerance Count:0
epoch:30        Train Loss:        0.13 Train Accuracy:       96.44     Test
Loss:        0.05  Test Accuracy:       98.51       Tolerance Count:0
epoch:31        Train Loss:        0.12 Train Accuracy:       96.58     Test
Loss:        0.05  Test Accuracy:       98.55       Tolerance Count:0
epoch:32        Train Loss:        0.13 Train Accuracy:       96.50     Test
Loss:        0.05  Test Accuracy:       98.60       Tolerance Count:0
```

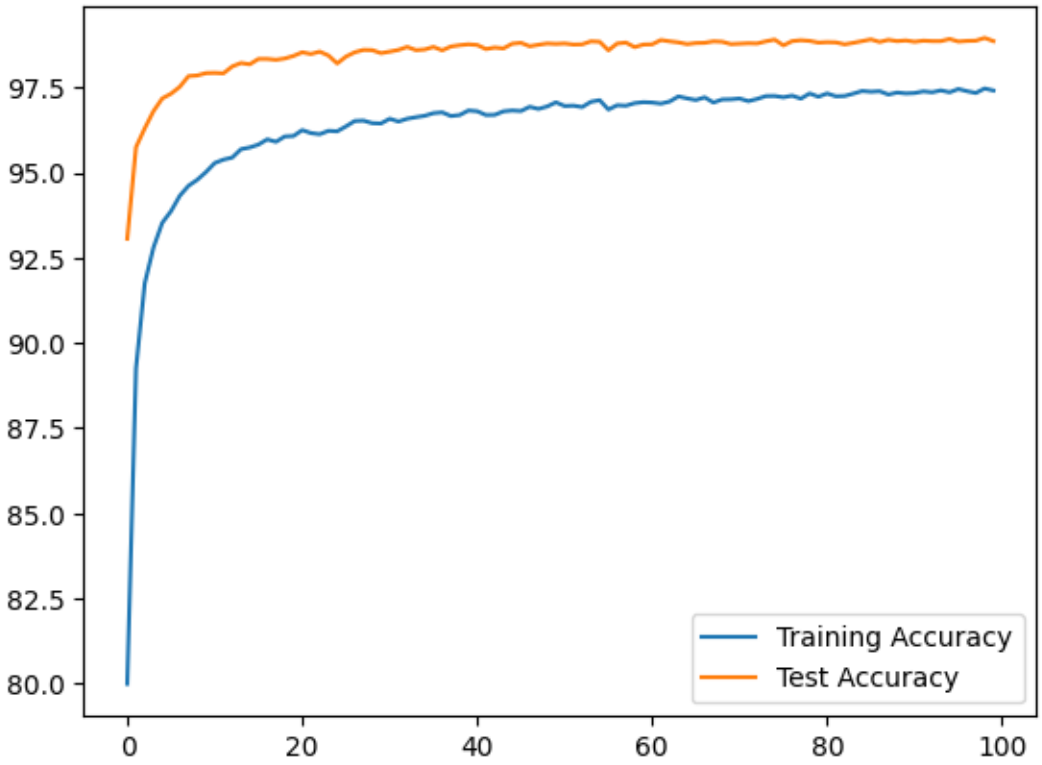
```
epoch:33        Train Loss:        0.12 Train Accuracy:       96.58     Test
Loss:        0.05  Test Accuracy:       98.69       Tolerance Count:0
epoch:34        Train Loss:        0.13 Train Accuracy:       96.63     Test
Loss:        0.05  Test Accuracy:       98.59       Tolerance Count:0
epoch:35        Train Loss:        0.12 Train Accuracy:       96.67     Test
Loss:        0.05  Test Accuracy:       98.61       Tolerance Count:0
epoch:36        Train Loss:        0.12 Train Accuracy:       96.74     Test
Loss:        0.05  Test Accuracy:       98.69       Tolerance Count:0
epoch:37        Train Loss:        0.12 Train Accuracy:       96.77     Test
Loss:        0.05  Test Accuracy:       98.59       Tolerance Count:0
epoch:38        Train Loss:        0.12 Train Accuracy:       96.66     Test
Loss:        0.05  Test Accuracy:       98.70       Tolerance Count:0
epoch:39        Train Loss:        0.12 Train Accuracy:       96.69     Test
Loss:        0.05  Test Accuracy:       98.74       Tolerance Count:0
epoch:40        Train Loss:        0.12 Train Accuracy:       96.82     Test
Loss:        0.04  Test Accuracy:       98.76       Tolerance Count:0
epoch:41        Train Loss:        0.12 Train Accuracy:       96.80     Test
Loss:        0.05  Test Accuracy:       98.75       Tolerance Count:0
epoch:42        Train Loss:        0.12 Train Accuracy:       96.69     Test
Loss:        0.05  Test Accuracy:       98.63       Tolerance Count:0
epoch:43        Train Loss:        0.12 Train Accuracy:       96.69     Test
Loss:        0.05  Test Accuracy:       98.67       Tolerance Count:0
epoch:44        Train Loss:        0.12 Train Accuracy:       96.80     Test
Loss:        0.05  Test Accuracy:       98.65       Tolerance Count:0
epoch:45        Train Loss:        0.12 Train Accuracy:       96.82     Test
Loss:        0.04  Test Accuracy:       98.78       Tolerance Count:0
epoch:46        Train Loss:        0.11 Train Accuracy:       96.81     Test
Loss:        0.04  Test Accuracy:       98.81       Tolerance Count:0
epoch:47        Train Loss:        0.12 Train Accuracy:       96.93     Test
Loss:        0.05  Test Accuracy:       98.71       Tolerance Count:0
epoch:48        Train Loss:        0.12 Train Accuracy:       96.87     Test
Loss:        0.05  Test Accuracy:       98.75       Tolerance Count:0
epoch:49        Train Loss:        0.11 Train Accuracy:       96.94     Test
Loss:        0.05  Test Accuracy:       98.79       Tolerance Count:0
epoch:50        Train Loss:        0.11 Train Accuracy:       97.06     Test
Loss:        0.04  Test Accuracy:       98.78       Tolerance Count:0
epoch:51        Train Loss:        0.11 Train Accuracy:       96.95     Test
Loss:        0.04  Test Accuracy:       98.79       Tolerance Count:0
epoch:52        Train Loss:        0.11 Train Accuracy:       96.97     Test
Loss:        0.04  Test Accuracy:       98.76       Tolerance Count:0
epoch:53        Train Loss:        0.12 Train Accuracy:       96.92     Test
Loss:        0.04  Test Accuracy:       98.76       Tolerance Count:0
epoch:54        Train Loss:        0.11 Train Accuracy:       97.08     Test
Loss:        0.04  Test Accuracy:       98.85       Tolerance Count:0
epoch:55        Train Loss:        0.11 Train Accuracy:       97.13     Test
Loss:        0.04  Test Accuracy:       98.84       Tolerance Count:0
epoch:56        Train Loss:        0.12 Train Accuracy:       96.85     Test
Loss:        0.05  Test Accuracy:       98.59       Tolerance Count:0
```

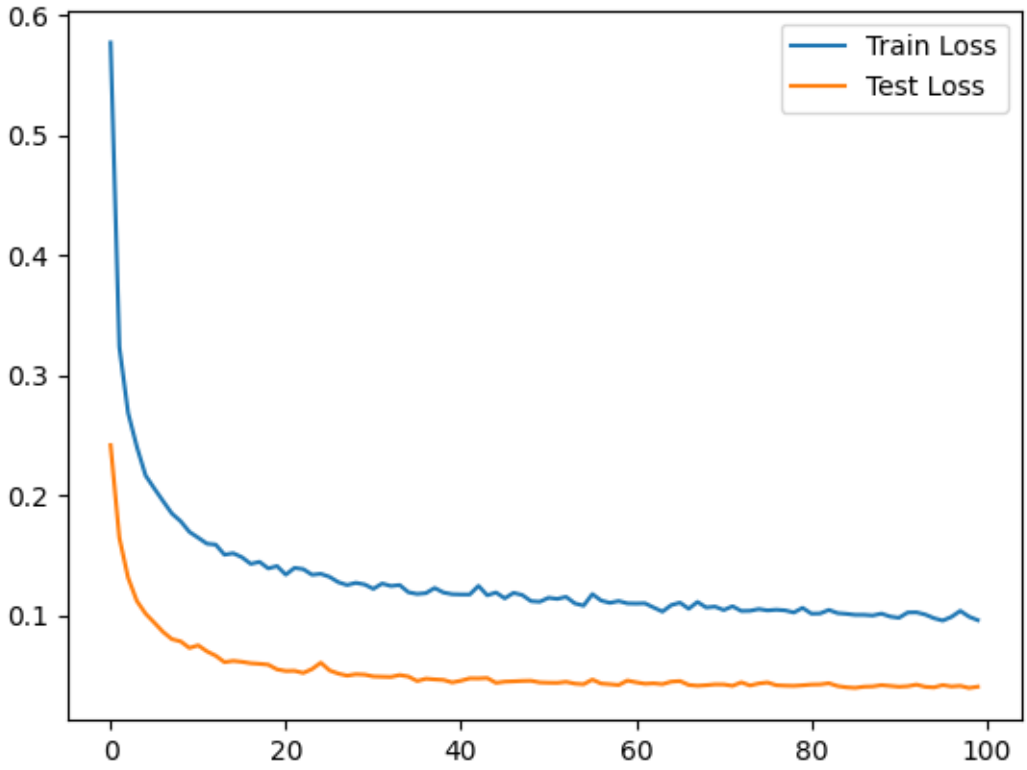
```
epoch:57        Train Loss:        0.11 Train Accuracy:       96.98     Test
Loss:       0.04  Test Accuracy:       98.79       Tolerance Count:0
epoch:58        Train Loss:        0.11 Train Accuracy:       96.96     Test
Loss:       0.04  Test Accuracy:       98.82       Tolerance Count:0
epoch:59        Train Loss:        0.11 Train Accuracy:       97.04     Test
Loss:       0.04  Test Accuracy:       98.68       Tolerance Count:0
epoch:60        Train Loss:        0.11 Train Accuracy:       97.07     Test
Loss:       0.05  Test Accuracy:       98.76       Tolerance Count:0
epoch:61        Train Loss:        0.11 Train Accuracy:       97.06     Test
Loss:       0.04  Test Accuracy:       98.76       Tolerance Count:0
epoch:62        Train Loss:        0.11 Train Accuracy:       97.03     Test
Loss:       0.04  Test Accuracy:       98.89       Tolerance Count:0
epoch:63        Train Loss:        0.11 Train Accuracy:       97.09     Test
Loss:       0.04  Test Accuracy:       98.85       Tolerance Count:0
epoch:64        Train Loss:        0.10 Train Accuracy:       97.24     Test
Loss:       0.04  Test Accuracy:       98.82       Tolerance Count:0
epoch:65        Train Loss:        0.11 Train Accuracy:       97.18     Test
Loss:       0.04  Test Accuracy:       98.77       Tolerance Count:0
epoch:66        Train Loss:        0.11 Train Accuracy:       97.13     Test
Loss:       0.05  Test Accuracy:       98.80       Tolerance Count:0
epoch:67        Train Loss:        0.11 Train Accuracy:       97.21     Test
Loss:       0.04  Test Accuracy:       98.81       Tolerance Count:0
epoch:68        Train Loss:        0.11 Train Accuracy:       97.06     Test
Loss:       0.04  Test Accuracy:       98.85       Tolerance Count:0
epoch:69        Train Loss:        0.11 Train Accuracy:       97.15     Test
Loss:       0.04  Test Accuracy:       98.84       Tolerance Count:0
epoch:70        Train Loss:        0.11 Train Accuracy:       97.15     Test
Loss:       0.04  Test Accuracy:       98.77       Tolerance Count:0
epoch:71        Train Loss:        0.10 Train Accuracy:       97.17     Test
Loss:       0.04  Test Accuracy:       98.78       Tolerance Count:0
epoch:72        Train Loss:        0.11 Train Accuracy:       97.10     Test
Loss:       0.04  Test Accuracy:       98.80       Tolerance Count:0
epoch:73        Train Loss:        0.10 Train Accuracy:       97.16     Test
Loss:       0.04  Test Accuracy:       98.79       Tolerance Count:0
epoch:74        Train Loss:        0.10 Train Accuracy:       97.25     Test
Loss:       0.04  Test Accuracy:       98.85       Tolerance Count:0
epoch:75        Train Loss:        0.11 Train Accuracy:       97.25     Test
Loss:       0.04  Test Accuracy:       98.90       Tolerance Count:0
epoch:76        Train Loss:        0.10 Train Accuracy:       97.21     Test
Loss:       0.04  Test Accuracy:       98.73       Tolerance Count:0
epoch:77        Train Loss:        0.10 Train Accuracy:       97.26     Test
Loss:       0.04  Test Accuracy:       98.86       Tolerance Count:0
epoch:78        Train Loss:        0.10 Train Accuracy:       97.17     Test
Loss:       0.04  Test Accuracy:       98.88       Tolerance Count:0
epoch:79        Train Loss:        0.10 Train Accuracy:       97.32     Test
Loss:       0.04  Test Accuracy:       98.87       Tolerance Count:0
epoch:80        Train Loss:        0.11 Train Accuracy:       97.23     Test
Loss:       0.04  Test Accuracy:       98.82       Tolerance Count:0
```

```
epoch:81        Train Loss:        0.10 Train Accuracy:       97.32     Test
Loss:        0.04  Test Accuracy:       98.83       Tolerance Count:0
epoch:82        Train Loss:        0.10 Train Accuracy:       97.24     Test
Loss:        0.04  Test Accuracy:       98.82       Tolerance Count:0
epoch:83        Train Loss:        0.10 Train Accuracy:       97.25     Test
Loss:        0.04  Test Accuracy:       98.76       Tolerance Count:0
epoch:84        Train Loss:        0.10 Train Accuracy:       97.32     Test
Loss:        0.04  Test Accuracy:       98.81       Tolerance Count:0
epoch:85        Train Loss:        0.10 Train Accuracy:       97.40     Test
Loss:        0.04  Test Accuracy:       98.86       Tolerance Count:0
epoch:86        Train Loss:        0.10 Train Accuracy:       97.37     Test
Loss:        0.04  Test Accuracy:       98.91       Tolerance Count:0
epoch:87        Train Loss:        0.10 Train Accuracy:       97.39     Test
Loss:        0.04  Test Accuracy:       98.83       Tolerance Count:0
epoch:88        Train Loss:        0.10 Train Accuracy:       97.29     Test
Loss:        0.04  Test Accuracy:       98.90       Tolerance Count:0
epoch:89        Train Loss:        0.10 Train Accuracy:       97.35     Test
Loss:        0.04  Test Accuracy:       98.86       Tolerance Count:0
epoch:90        Train Loss:        0.10 Train Accuracy:       97.32     Test
Loss:        0.04  Test Accuracy:       98.88       Tolerance Count:0
epoch:91        Train Loss:        0.10 Train Accuracy:       97.34     Test
Loss:        0.04  Test Accuracy:       98.84       Tolerance Count:0
epoch:92        Train Loss:        0.10 Train Accuracy:       97.38     Test
Loss:        0.04  Test Accuracy:       98.87       Tolerance Count:0
epoch:93        Train Loss:        0.10 Train Accuracy:       97.36     Test
Loss:        0.04  Test Accuracy:       98.86       Tolerance Count:0
epoch:94        Train Loss:        0.10 Train Accuracy:       97.41     Test
Loss:        0.04  Test Accuracy:       98.86       Tolerance Count:0
epoch:95        Train Loss:        0.10 Train Accuracy:       97.36     Test
Loss:        0.04  Test Accuracy:       98.92       Tolerance Count:0
epoch:96        Train Loss:        0.10 Train Accuracy:       97.45     Test
Loss:        0.04  Test Accuracy:       98.85       Tolerance Count:0
epoch:97        Train Loss:        0.10 Train Accuracy:       97.39     Test
Loss:        0.04  Test Accuracy:       98.87       Tolerance Count:0
epoch:98        Train Loss:        0.10 Train Accuracy:       97.34     Test
Loss:        0.04  Test Accuracy:       98.87       Tolerance Count:0
epoch:99        Train Loss:        0.10 Train Accuracy:       97.47     Test
Loss:        0.04  Test Accuracy:       98.95       Tolerance Count:0
epoch:100       Train Loss:        0.10 Train Accuracy:       97.41     Test
Loss:        0.04  Test Accuracy:       98.86       Tolerance Count:0

Duration: 828 seconds
```

[40]:
```
show_metrics(train_accuracies, test_accuracies, train_mean_losses,␣
 ↪test_mean_losses)
eval_model(ecg_ann_model_1, X_test_tensor, y_test_tensor)
profile(ecg_ann_model_1,tuple([200]))
```


97.5
95.0
92.5
90.0
87.5
85.0
82.5
80.0
0
20
40
60
80
100
Training Accuracy
Test Accuracy


0.6
0.5
0.4
0.3
0.2
0.1
0
20
40
60
80
100
Train Loss
Test Loss

```
              precision    recall  f1-score   support

           0       0.99      1.00      0.99       717
           1       0.97      0.99      0.98      1582
           2       0.99      0.99      0.99     14689
           3       0.99      1.00      0.99      1436
           4       0.96      0.93      0.94      1411

    accuracy                           0.99     19835
   macro avg       0.98      0.98      0.98     19835
weighted avg       0.99      0.99      0.99     19835

[[  716     0     1     0     0]
 [    0  1567    12     0     3]
 [    1    19 14610    12    47]
 [    0     0     4  1430     2]
 [    7    28    61     9  1306]]

Duration: 1 seconds
Warning: module Dropout is treated as a zero-op.
Warning: module ECGANNModel is treated as a zero-op.
ECGANNModel(
  26.55 k, 100.000% Params, 26.73 KMac, 100.000% MACs,
  (layers): Sequential(
    26.55 k, 100.000% Params, 26.73 KMac, 100.000% MACs,
    (0): Linear(20.1 k, 75.692% Params, 20.1 KMac, 75.196% MACs,
in_features=200, out_features=100, bias=True)
    (1): ReLU(0, 0.000% Params, 100.0 Mac, 0.374% MACs, inplace=True)
    (2): Dropout(0, 0.000% Params, 0.0 Mac, 0.000% MACs, p=0.5, inplace=False)
    (3): Linear(5.05 k, 19.017% Params, 5.05 KMac, 18.893% MACs,
in_features=100, out_features=50, bias=True)
    (4): ReLU(0, 0.000% Params, 50.0 Mac, 0.187% MACs, inplace=True)
    (5): Dropout(0, 0.000% Params, 0.0 Mac, 0.000% MACs, p=0.5, inplace=False)
    (6): Linear(1.27 k, 4.801% Params, 1.27 KMac, 4.770% MACs, in_features=50,
out_features=25, bias=True)
    (7): ReLU(0, 0.000% Params, 25.0 Mac, 0.094% MACs, inplace=True)
    (8): Dropout(0, 0.000% Params, 0.0 Mac, 0.000% MACs, p=0.5, inplace=False)
    (9): Linear(130, 0.490% Params, 130.0 Mac, 0.486% MACs, in_features=25,
out_features=5, bias=True)
  )
)
Computational complexity: 26.73 KMac
Computational complexity: 53.46 KFlops
Number of parameters: 26.55 k
```

1.4 CNN

[41]:
```
ecg_cnn_model = ECGCNNModel()
```

[42]:
```
count_parameters(ecg_cnn_model)
```

```
    48
    16
  1536
    32
    32
    32
  6144
    64
 24576
   128
   128
   128
2432000
   100
  5000
    50
   250
     5

------
2470269
```

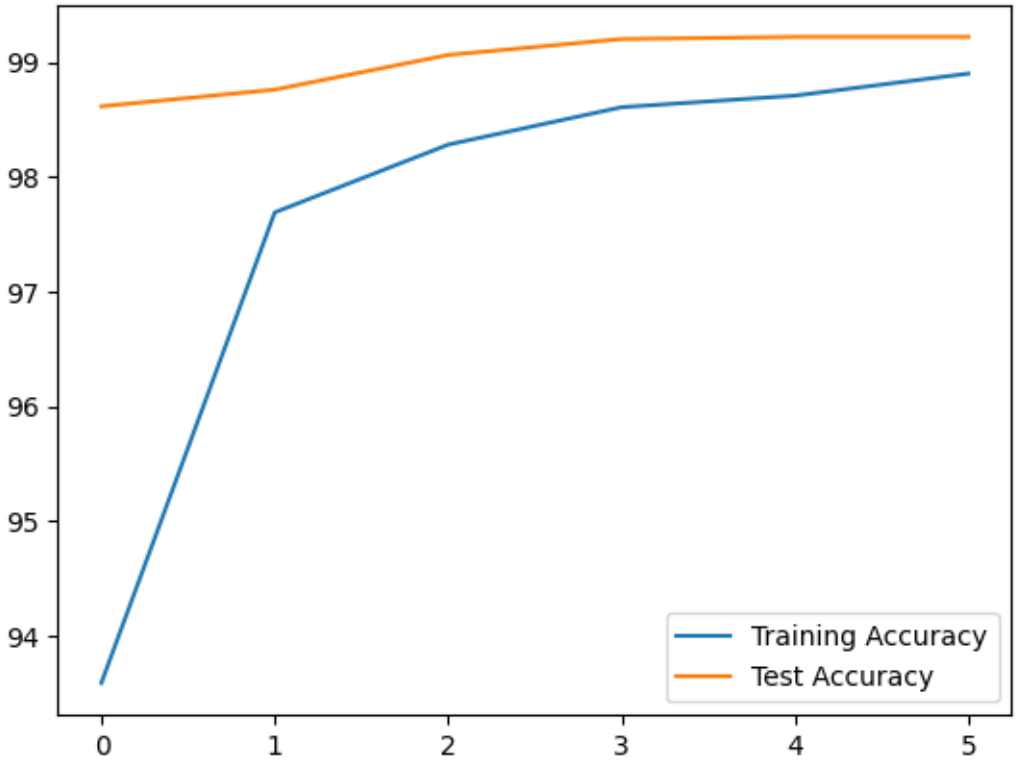
[43]:
```
train_accuracies, test_accuracies, train_mean_losses, test_mean_losses =␣
 ↪train_model(
    model=ecg_cnn_model,
    X_train=X_train_tensor.reshape(-1, 1, 200),
    y_train=y_train_tensor,
    X_test=X_val_tensor.reshape(-1, 1, 200),
    y_test=y_val_tensor,
    learning_rate=0.001,
    batch_size=100,
    val_batch_size=100,
    epochs=6,
)
```

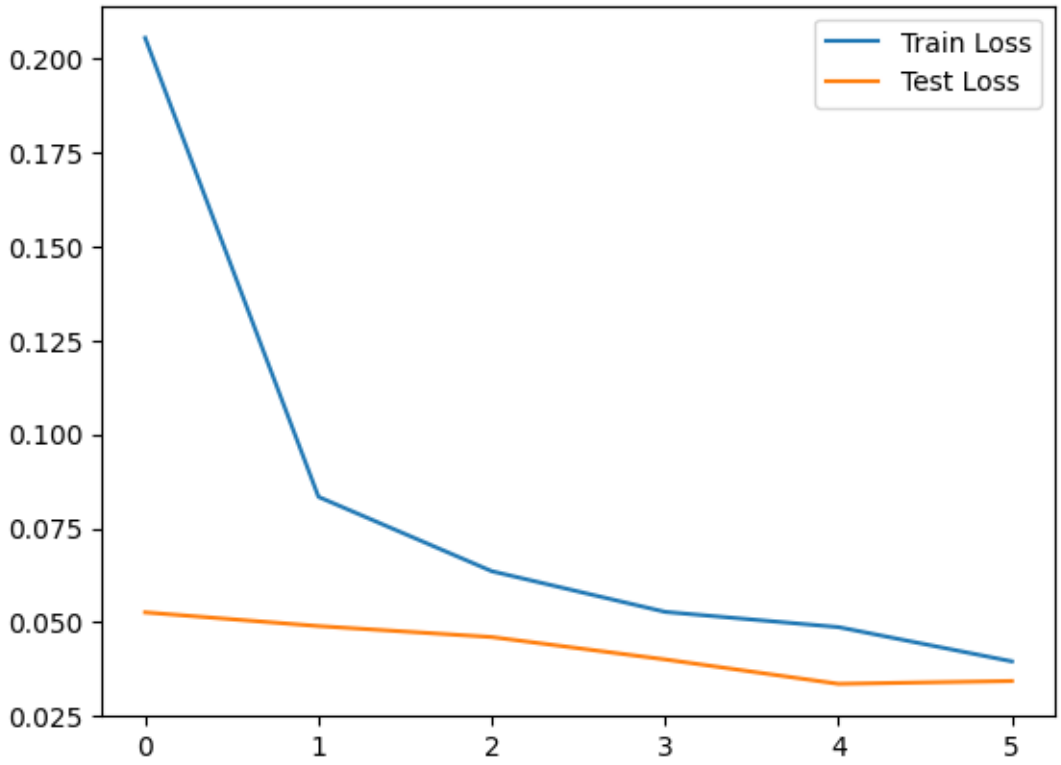
```
epoch:1 Train Loss:        0.21 Train Accuracy:       93.59     Test Loss:
0.05  Test Accuracy:       98.61       Tolerance Count:0
epoch:2 Train Loss:        0.08 Train Accuracy:       97.69     Test Loss:
0.05  Test Accuracy:       98.76       Tolerance Count:0
epoch:3 Train Loss:        0.06 Train Accuracy:       98.28     Test Loss:
0.05  Test Accuracy:       99.06       Tolerance Count:0
epoch:4 Train Loss:        0.05 Train Accuracy:       98.61     Test Loss:
0.04  Test Accuracy:       99.20       Tolerance Count:0
```

```
epoch:5 Train Loss:        0.05 Train Accuracy:       98.71     Test Loss:
0.03  Test Accuracy:       99.22       Tolerance Count:0
epoch:6 Train Loss:        0.04 Train Accuracy:       98.90     Test Loss:
0.03  Test Accuracy:       99.22       Tolerance Count:0

Duration: 840 seconds
```

[46]:
```
show_metrics(train_accuracies, test_accuracies, train_mean_losses,␣
 ↪test_mean_losses)
eval_model(ecg_cnn_model, X_test_tensor.reshape(-1, 1, 200), y_test_tensor)
profile(ecg_cnn_model, tuple([1,200]))
```






```
              precision    recall  f1-score   support

           0       1.00      1.00      1.00       725
           1       0.99      0.99      0.99      1616
           2       1.00      0.99      1.00     14746
           3       1.00      1.00      1.00      1450
           4       0.94      0.98      0.96      1298

    accuracy                           0.99     19835
   macro avg       0.98      0.99      0.99     19835
weighted avg       0.99      0.99      0.99     19835

[[  723     0     2     0     0]
 [    0  1594     5     0    17]
 [    0    10 14659     7    70]
 [    0     0     5  1444     1]
 [    1    10    17     0  1270]]

Duration: 12 seconds
Warning: variables __flops__ or __params__ are already defined for the
moduleConv1d ptflops can affect your code!
Warning: variables __flops__ or __params__ are already defined for the
```

```
moduleReLU ptflops can affect your code!
Warning: variables __flops__ or __params__ are already defined for the
moduleConv1d ptflops can affect your code!
Warning: variables __flops__ or __params__ are already defined for the
moduleReLU ptflops can affect your code!
Warning: variables __flops__ or __params__ are already defined for the
moduleMaxPool1d ptflops can affect your code!
Warning: variables __flops__ or __params__ are already defined for the
moduleBatchNorm1d ptflops can affect your code!
Warning: variables __flops__ or __params__ are already defined for the
moduleConv1d ptflops can affect your code!
Warning: variables __flops__ or __params__ are already defined for the
moduleReLU ptflops can affect your code!
Warning: variables __flops__ or __params__ are already defined for the
moduleConv1d ptflops can affect your code!
Warning: variables __flops__ or __params__ are already defined for the
moduleReLU ptflops can affect your code!
Warning: variables __flops__ or __params__ are already defined for the
moduleMaxPool1d ptflops can affect your code!
Warning: variables __flops__ or __params__ are already defined for the
moduleBatchNorm1d ptflops can affect your code!
Warning: variables __flops__ or __params__ are already defined for the
moduleLinear ptflops can affect your code!
Warning: variables __flops__ or __params__ are already defined for the
moduleReLU ptflops can affect your code!
Warning: variables __flops__ or __params__ are already defined for the
moduleLinear ptflops can affect your code!
Warning: variables __flops__ or __params__ are already defined for the
moduleReLU ptflops can affect your code!
Warning: variables __flops__ or __params__ are already defined for the
moduleLinear ptflops can affect your code!
Warning: module Flatten is treated as a zero-op.
Warning: module Dropout is treated as a zero-op.
Warning: module ECGCNNModel is treated as a zero-op.
ECGCNNModel(
  2.47 M, 100.000% Params, 8.81 MMac, 100.000% MACs,
  (conv_layer): Sequential(
    32.86 k, 1.330% Params, 6.37 MMac, 72.339% MACs,
    (0): Conv1d(64, 0.003% Params, 12.67 KMac, 0.144% MACs, 1, 16,
kernel_size=(3,), stride=(1,))
    (1): ReLU(0, 0.000% Params, 3.17 KMac, 0.036% MACs, inplace=True)
    (2): Conv1d(1.57 k, 0.063% Params, 307.33 KMac, 3.488% MACs, 16, 32,
kernel_size=(3,), stride=(1,))
    (3): ReLU(0, 0.000% Params, 6.27 KMac, 0.071% MACs, inplace=True)
    (4): MaxPool1d(0, 0.000% Params, 6.27 KMac, 0.071% MACs, kernel_size=2,
stride=1, padding=0, dilation=1, ceil_mode=False)
    (5): BatchNorm1d(64, 0.003% Params, 12.48 KMac, 0.142% MACs, 32, eps=1e-05,
momentum=0.1, affine=True, track_running_stats=True)
```

```
    (6): Conv1d(6.21 k, 0.251% Params, 1.2 MMac, 13.596% MACs, 32, 64,
kernel_size=(3,), stride=(1,))
    (7): ReLU(0, 0.000% Params, 12.35 KMac, 0.140% MACs, inplace=True)
    (8): Conv1d(24.7 k, 1.000% Params, 4.72 MMac, 53.544% MACs, 64, 128,
kernel_size=(3,), stride=(1,))
    (9): ReLU(0, 0.000% Params, 24.45 KMac, 0.277% MACs, inplace=True)
    (10): MaxPool1d(0, 0.000% Params, 24.45 KMac, 0.277% MACs, kernel_size=2,
stride=1, padding=0, dilation=1, ceil_mode=False)
    (11): BatchNorm1d(256, 0.010% Params, 48.64 KMac, 0.552% MACs, 128,
eps=1e-05, momentum=0.1, affine=True, track_running_stats=True)
    (12): Flatten(0, 0.000% Params, 0.0 Mac, 0.000% MACs, start_dim=1,
end_dim=-1)
  )
  (fc_layers): Sequential(
    2.44 M, 98.670% Params, 2.44 MMac, 27.661% MACs,
    (0): Linear(2.43 M, 98.455% Params, 2.43 MMac, 27.599% MACs,
in_features=24320, out_features=100, bias=True)
    (1): ReLU(0, 0.000% Params, 100.0 Mac, 0.001% MACs, inplace=True)
    (2): Dropout(0, 0.000% Params, 0.0 Mac, 0.000% MACs, p=0.5, inplace=False)
    (3): Linear(5.05 k, 0.204% Params, 5.05 KMac, 0.057% MACs, in_features=100,
out_features=50, bias=True)
    (4): ReLU(0, 0.000% Params, 50.0 Mac, 0.001% MACs, inplace=True)
    (5): Dropout(0, 0.000% Params, 0.0 Mac, 0.000% MACs, p=0.5, inplace=False)
    (6): Linear(255, 0.010% Params, 255.0 Mac, 0.003% MACs, in_features=50,
out_features=5, bias=True)
  )
)
Computational complexity: 8.81 MMac
Computational complexity: 17.62 MFlops
Number of parameters: 2.47 M
```

1.5 LSTM

[47]:
```
ecg_lstm_model = ECGLSTMModel()
```

[48]:
```
ecg_lstm_model.parameters()
```

[48]:
```
<generator object Module.parameters at 0x7f2b2e99b890>
```

[49]:
```
ecg_lstm_model.parameters
```

[49]:
```
<bound method Module.parameters of ECGLSTMModel(
  (lstm): LSTM(200, 50, num_layers=2, batch_first=True)
  (fc): Sequential(
    (0): Flatten(start_dim=1, end_dim=-1)
    (1): Linear(in_features=50, out_features=25, bias=True)
    (2): ReLU(inplace=True)
```

```
    (3): Dropout(p=0.5, inplace=False)
    (4): Linear(in_features=25, out_features=5, bias=True)
  )
)>
```

[50]:
```
count_parameters(ecg_lstm_model)
```

```
 40000
 10000
   200
   200
 10000
 10000
   200
   200
  1250
    25
   125
     5
------
 72205
```

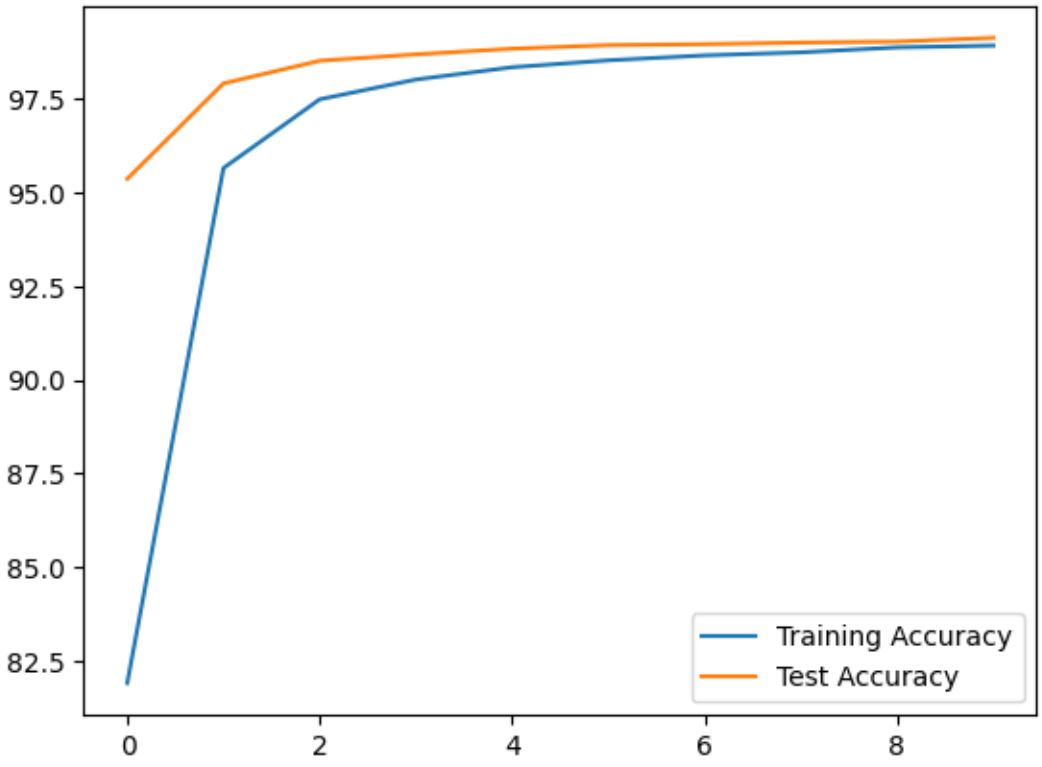
[51]:
```
train_accuracies, test_accuracies, train_mean_losses, test_mean_losses =␣
 ↪train_model(
    model=ecg_lstm_model,
    X_train=X_train_tensor.reshape(-1,1,200),
    y_train=y_train_tensor,
    X_test=X_val_tensor.reshape(-1,1,200),
    y_test=y_val_tensor,
    learning_rate=0.001,
    batch_size=100,
    val_batch_size=100,
    epochs=10, lstm=True
)
```

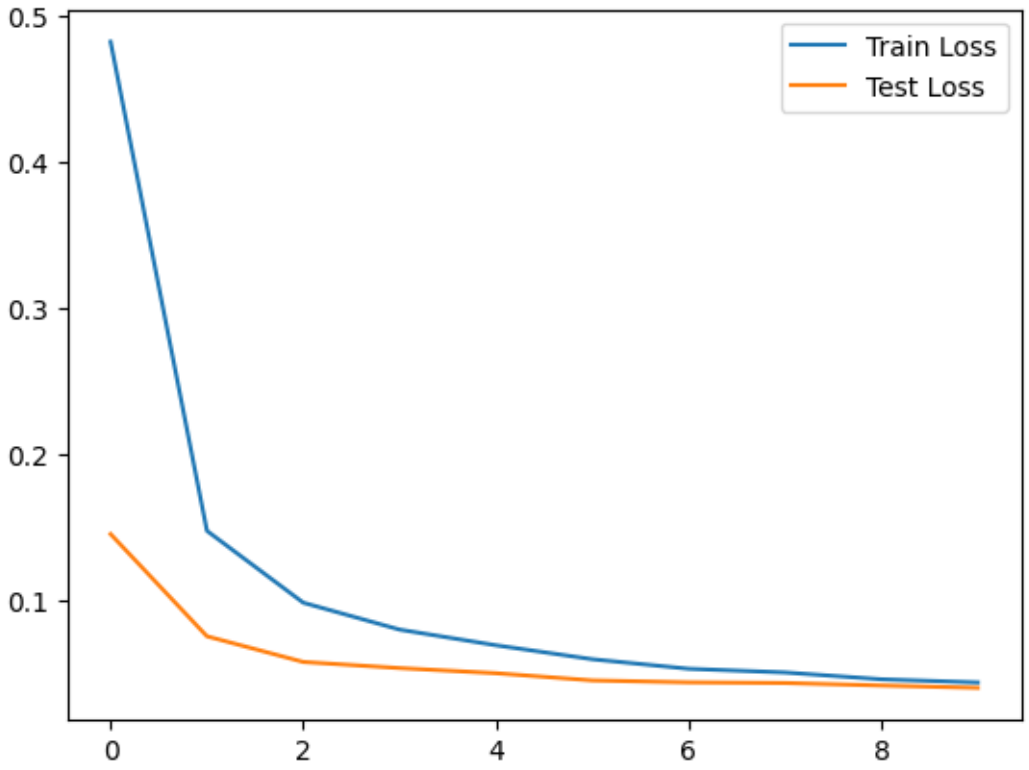
```
epoch:1 Train Loss:        0.48 Train Accuracy:       81.91     Test Loss:
0.15  Test Accuracy:       95.36       Tolerance Count:0
epoch:2 Train Loss:        0.15 Train Accuracy:       95.65     Test Loss:
0.08  Test Accuracy:       97.91       Tolerance Count:0
epoch:3 Train Loss:        0.10 Train Accuracy:       97.48     Test Loss:
0.06  Test Accuracy:       98.51       Tolerance Count:0
epoch:4 Train Loss:        0.08 Train Accuracy:       98.01     Test Loss:
0.05  Test Accuracy:       98.68       Tolerance Count:0
epoch:5 Train Loss:        0.07 Train Accuracy:       98.34     Test Loss:
0.05  Test Accuracy:       98.83       Tolerance Count:0
epoch:6 Train Loss:        0.06 Train Accuracy:       98.52     Test Loss:
0.05  Test Accuracy:       98.93       Tolerance Count:0
```

```
epoch:7 Train Loss:        0.05 Train Accuracy:       98.66     Test Loss:
0.04  Test Accuracy:       98.95       Tolerance Count:0
epoch:8 Train Loss:        0.05 Train Accuracy:       98.74     Test Loss:
0.04  Test Accuracy:       99.00       Tolerance Count:0
epoch:9 Train Loss:        0.05 Train Accuracy:       98.87     Test Loss:
0.04  Test Accuracy:       99.02       Tolerance Count:0
epoch:10        Train Loss:        0.04 Train Accuracy:       98.92     Test
Loss:        0.04  Test Accuracy:       99.12       Tolerance Count:0

Duration: 110 seconds
```

[52]:
```
show_metrics(train_accuracies, test_accuracies, train_mean_losses,␣
 ↪test_mean_losses)
eval_model(ecg_lstm_model, X_test_tensor.reshape(-1, 1, 200), y_test_tensor)
profile(ecg_lstm_model,tuple([ 1, 200]))
```






```
              precision    recall  f1-score   support

           0       1.00      1.00      1.00       724
           1       0.98      0.98      0.98      1627
           2       1.00      0.99      1.00     14714
           3       0.99      0.99      0.99      1454
           4       0.94      0.97      0.96      1316

    accuracy                           0.99     19835
   macro avg       0.98      0.99      0.98     19835
weighted avg       0.99      0.99      0.99     19835

[[  723     0     1     0     0]
 [    0  1587    19     0    21]
 [    0    12 14637     9    56]
 [    0     0    13  1438     3]
 [    1    15    18     4  1278]]

Duration: 1 seconds
Warning: module Flatten is treated as a zero-op.
Warning: module Dropout is treated as a zero-op.
Warning: module ECGLSTMModel is treated as a zero-op.
```

```
ECGLSTMModel(
  72.2 k, 100.000% Params, 73.23 KMac, 100.000% MACs,
  (lstm): LSTM(70.8 k, 98.054% Params, 71.8 KMac, 98.047% MACs, 200, 50,
num_layers=2, batch_first=True)
  (fc): Sequential(
    1.41 k, 1.946% Params, 1.43 KMac, 1.953% MACs,
    (0): Flatten(0, 0.000% Params, 0.0 Mac, 0.000% MACs, start_dim=1,
end_dim=-1)
    (1): Linear(1.27 k, 1.766% Params, 1.27 KMac, 1.741% MACs, in_features=50,
out_features=25, bias=True)
    (2): ReLU(0, 0.000% Params, 25.0 Mac, 0.034% MACs, inplace=True)
    (3): Dropout(0, 0.000% Params, 0.0 Mac, 0.000% MACs, p=0.5, inplace=False)
    (4): Linear(130, 0.180% Params, 130.0 Mac, 0.178% MACs, in_features=25,
out_features=5, bias=True)
  )
)
Computational complexity: 73.23 KMac
Computational complexity: 146.46 KFlops
Number of parameters: 72.2 k
```

[ ]:

[ ]:

[ ]:

[ ]: