In [1]:
```python
import torch
import h5py

import numpy as np
import pandas as pd
import matplotlib.pyplot as plt

import os

import torch
from torch import nn
from torch import optim

from PIL import Image
from torchvision import transforms as T
from torch.utils.data import Dataset, DataLoader, TensorDataset, random_spli

from torchvision import models

import gc
from random import shuffle
```

```
/home/harkhymadhe/miniforge3/lib/python3.11/site-packages/torchvision/io/ima
ge.py:13: UserWarning: Failed to load image Python extension: '/home/harkhym
adhe/miniforge3/lib/python3.11/site-packages/torchvision/image.so: undefined
symbol: _ZN3c106detail23torchInternalAssertFailEPKcS2_jS2_RKSs'If you don't
plan on using image functionality from `torchvision.io`, you can ignore this
warning. Otherwise, there might be something wrong with your environment. Di
d you have `libjpeg` or `libpng` installed before building `torchvision` fro
m source?
  warn(
```

In [2]:
```python
# File paths
electron_file = "dataset/SingleElectronPt50_IMGCROPS_n249k_RHv1.hdf5"
photon_file = "dataset/SinglePhotonPt50_IMGCROPS_n249k_RHv1.hdf5"
```

In [3]:
```python
# Load data files
electron_data = h5py.File(name = electron_file)
photon_data = h5py.File(name = photon_file)
```

In [4]:
```python
electron_data.keys()
```

Out[4]:
```
<KeysViewHDF5 ['X', 'y']>
```

In [5]:
```python
# Feature shape
electron_data['X'].shape
```

Out[5]:
```
(249000, 32, 32, 2)
```

In [6]:
```python
# Target shape
electron_data['y'].shape
```

Out[6]:
```
(249000,)
```

In [7]:
```
# Feature shape
photon_data['X'].shape
```

Out[7]:
```
(249000, 32, 32, 2)
```

In [8]:
```
# Target shape
photon_data['y'].shape
```

Out[8]:
```
(249000,)
```

In [9]:
```
# Target shape
photon_data['y'].shape
```

Out[9]:
```
(249000,)
```

In [10]:
```
def h5_to_numpy(h5_file):
    X, y = h5_file["X"], h5_file["y"]
    return np.array(X), np.array(y)
```

In [11]:
```
electron_data = h5_to_numpy(electron_data)
photon_data = h5_to_numpy(photon_data)
```

In [12]:
```
data = np.concatenate([electron_data[0], photon_data[0]], axis = 0)
targets = np.concatenate([electron_data[1].reshape(-1, 1), photon_data[1].re
```

In [13]:
```
del electron_data
del photon_data
```

In [14]:
```
gc.collect()
```

Out[14]:
```
0
```

In [15]:
```
targets.dtype
```

Out[15]:
```
dtype('float32')
```

In [16]:
```
data[:10].shape
```

Out[16]:
```
(10, 32, 32, 2)
```

In [17]:
```
np.unique(targets)
```

Out[17]:
```
array([0., 1.], dtype=float32)
```

In [18]:
```
targets[:10]
```

```
Out[18]: array([[1.],
       [1.],
       [1.],
       [1.],
       [1.],
       [1.],
       [1.],
       [1.],
       [1.],
       [1.]], dtype=float32)
```

```
In [19]: targets[-20:]
```

```
Out[19]: array([[0.],
       [0.],
       [0.],
       [0.],
       [0.],
       [0.],
       [0.],
       [0.],
       [0.],
       [0.],
       [0.],
       [0.],
       [0.],
       [0.],
       [0.],
       [0.],
       [0.],
       [0.],
       [0.],
       [0.]], dtype=float32)
```

```
In [20]: targets[::2]
```

```
Out[20]: array([[1.],
       [1.],
       [1.],
       ...,
       [0.],
       [0.],
       [0.]], dtype=float32)
```

```
In [21]: from sklearn.model_selection import train_test_split
```

```
In [22]: y_train, y_test = train_test_split(pd.DataFrame(targets), test_size = .2, sh
```

```
In [23]: train_indices = y_train.index.values
```

```
In [24]: test_indices = y_test.index.values
```

```
In [25]: train_indices
```

Out[25]: array([229073, 114023, 181431, ..., 135714, 39443, 385558])

In [26]:
```
test_indices
```

Out[26]: array([130698, 27109, 452500, ..., 270272, 306726, 254625])

In [27]:
```
# Set device
DEVICE = torch.device("cuda" if torch.cuda.is_available() else "cpu")
```

In [28]:
```
data = torch.tensor(data).to(DEVICE)
targets = torch.tensor(targets, dtype = torch.int64).to(DEVICE)
```

In [29]:
```
# Split into train and test samples
train_data, test_data = data[train_indices], data[test_indices]
train_targets, test_targets = targets[train_indices], targets[test_indices]
```

In [30]:
```
del data
del targets
```

In [31]:
```
gc.collect()
```

Out[31]: 11

In [32]:
```
# Generate train and test datasets
train_dataset = TensorDataset(train_data.permute(0, 3, 1, 2), train_targets)
test_dataset = TensorDataset(test_data.permute(0, 3, 1, 2), test_targets)
```

In [33]:
```
BATCH_SIZE = 128

train_dl = DataLoader(train_dataset, batch_size=BATCH_SIZE, shuffle=True)
test_dl = DataLoader(test_dataset, batch_size=BATCH_SIZE, shuffle=False)
```

In [34]:
```
gc.collect()
```

Out[34]: 0

In [ ]:

In [35]:
```
model = models.resnet18(pretrained=True)
```

```
/home/harkhymadhe/miniforge3/lib/python3.11/site-packages/torchvision/model
s/_utils.py:208: UserWarning: The parameter 'pretrained' is deprecated since
0.13 and may be removed in the future, please use 'weights' instead.
  warnings.warn(
/home/harkhymadhe/miniforge3/lib/python3.11/site-packages/torchvision/model
s/_utils.py:223: UserWarning: Arguments other than a weight enum or `None` f
or 'weights' are deprecated since 0.13 and may be removed in the future. The
current behavior is equivalent to passing `weights=ResNet18_Weights.IMAGENET
1K_V1`. You can also use `weights=ResNet18_Weights.DEFAULT` to get the most
up-to-date weights.
  warnings.warn(msg)
```

In [36]:
```
model
```

Out[36]:
```
ResNet(
  (conv1): Conv2d(3, 64, kernel_size=(7, 7), stride=(2, 2), padding=(3, 3),
bias=False)
  (bn1): BatchNorm2d(64, eps=1e-05, momentum=0.1, affine=True, track_runnin
g_stats=True)
  (relu): ReLU(inplace=True)
  (maxpool): MaxPool2d(kernel_size=3, stride=2, padding=1, dilation=1, ceil
_mode=False)
  (layer1): Sequential(
    (0): BasicBlock(
      (conv1): Conv2d(64, 64, kernel_size=(3, 3), stride=(1, 1), padding=
(1, 1), bias=False)
      (bn1): BatchNorm2d(64, eps=1e-05, momentum=0.1, affine=True, track_ru
nning_stats=True)
      (relu): ReLU(inplace=True)
      (conv2): Conv2d(64, 64, kernel_size=(3, 3), stride=(1, 1), padding=
(1, 1), bias=False)
      (bn2): BatchNorm2d(64, eps=1e-05, momentum=0.1, affine=True, track_ru
nning_stats=True)
    )
    (1): BasicBlock(
      (conv1): Conv2d(64, 64, kernel_size=(3, 3), stride=(1, 1), padding=
(1, 1), bias=False)
      (bn1): BatchNorm2d(64, eps=1e-05, momentum=0.1, affine=True, track_ru
nning_stats=True)
      (relu): ReLU(inplace=True)
      (conv2): Conv2d(64, 64, kernel_size=(3, 3), stride=(1, 1), padding=
(1, 1), bias=False)
      (bn2): BatchNorm2d(64, eps=1e-05, momentum=0.1, affine=True, track_ru
nning_stats=True)
    )
  )
  (layer2): Sequential(
    (0): BasicBlock(
      (conv1): Conv2d(64, 128, kernel_size=(3, 3), stride=(2, 2), padding=
(1, 1), bias=False)
      (bn1): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True, track_r
unning_stats=True)
      (relu): ReLU(inplace=True)
      (conv2): Conv2d(128, 128, kernel_size=(3, 3), stride=(1, 1), padding=
(1, 1), bias=False)
      (bn2): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True, track_r
unning_stats=True)
      (downsample): Sequential(
        (0): Conv2d(64, 128, kernel_size=(1, 1), stride=(2, 2), bias=False)
        (1): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True, track_r
unning_stats=True)
      )
    )
    (1): BasicBlock(
      (conv1): Conv2d(128, 128, kernel_size=(3, 3), stride=(1, 1), padding=
(1, 1), bias=False)
      (bn1): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True, track_r
unning_stats=True)
      (relu): ReLU(inplace=True)
      (conv2): Conv2d(128, 128, kernel_size=(3, 3), stride=(1, 1), padding=
```

```
(1, 1), bias=False)
      (bn2): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True, track_r
unning_stats=True)
    )
  )
  (layer3): Sequential(
    (0): BasicBlock(
      (conv1): Conv2d(128, 256, kernel_size=(3, 3), stride=(2, 2), padding=
(1, 1), bias=False)
      (bn1): BatchNorm2d(256, eps=1e-05, momentum=0.1, affine=True, track_r
unning_stats=True)
      (relu): ReLU(inplace=True)
      (conv2): Conv2d(256, 256, kernel_size=(3, 3), stride=(1, 1), padding=
(1, 1), bias=False)
      (bn2): BatchNorm2d(256, eps=1e-05, momentum=0.1, affine=True, track_r
unning_stats=True)
      (downsample): Sequential(
        (0): Conv2d(128, 256, kernel_size=(1, 1), stride=(2, 2), bias=Fals
e)
        (1): BatchNorm2d(256, eps=1e-05, momentum=0.1, affine=True, track_r
unning_stats=True)
      )
    )
    (1): BasicBlock(
      (conv1): Conv2d(256, 256, kernel_size=(3, 3), stride=(1, 1), padding=
(1, 1), bias=False)
      (bn1): BatchNorm2d(256, eps=1e-05, momentum=0.1, affine=True, track_r
unning_stats=True)
      (relu): ReLU(inplace=True)
      (conv2): Conv2d(256, 256, kernel_size=(3, 3), stride=(1, 1), padding=
(1, 1), bias=False)
      (bn2): BatchNorm2d(256, eps=1e-05, momentum=0.1, affine=True, track_r
unning_stats=True)
    )
  )
  (layer4): Sequential(
    (0): BasicBlock(
      (conv1): Conv2d(256, 512, kernel_size=(3, 3), stride=(2, 2), padding=
(1, 1), bias=False)
      (bn1): BatchNorm2d(512, eps=1e-05, momentum=0.1, affine=True, track_r
unning_stats=True)
      (relu): ReLU(inplace=True)
      (conv2): Conv2d(512, 512, kernel_size=(3, 3), stride=(1, 1), padding=
(1, 1), bias=False)
      (bn2): BatchNorm2d(512, eps=1e-05, momentum=0.1, affine=True, track_r
unning_stats=True)
      (downsample): Sequential(
        (0): Conv2d(256, 512, kernel_size=(1, 1), stride=(2, 2), bias=Fals
e)
        (1): BatchNorm2d(512, eps=1e-05, momentum=0.1, affine=True, track_r
unning_stats=True)
      )
    )
    (1): BasicBlock(
      (conv1): Conv2d(512, 512, kernel_size=(3, 3), stride=(1, 1), padding=
(1, 1), bias=False)
```

```
      (bn1): BatchNorm2d(512, eps=1e-05, momentum=0.1, affine=True, track_r
unning_stats=True)
      (relu): ReLU(inplace=True)
      (conv2): Conv2d(512, 512, kernel_size=(3, 3), stride=(1, 1), padding=
(1, 1), bias=False)
      (bn2): BatchNorm2d(512, eps=1e-05, momentum=0.1, affine=True, track_r
unning_stats=True)
    )
  )
  (avgpool): AdaptiveAvgPool2d(output_size=(1, 1))
  (fc): Linear(in_features=512, out_features=1000, bias=True)
)
```

In [37]:
```
class ParticleModel(nn.Module):
    def __init__(self, model, freeze = False, out_features = 2, channels = 2
        super().__init__()
        self.backbone = model
        self.freeze = freeze

        self.channels = channels
        self.height = height
        self.width = width

        self.out_features = out_features
        self.layer_norm = nn.LayerNorm([self.channels, self.height, self.wic

        if self.freeze:
            for param in self.backbone.parameters():
                param.requires_grad_(False)

        self.backbone.conv1 = nn.Conv2d(self.channels, 64, kernel_size=(7, 7
        fc = nn.Linear(in_features=model.fc.in_features, out_features=self.c

        self.backbone.fc = fc

    def forward(self, x):
        x = self.layer_norm(x)
        return self.backbone(x)
```

In [38]:
```
def initialize_weights(model):
    for (name, weights) in filter(lambda x: x[1].requires_grad, model.named_
        if name.split(".")[1] not in ["fc", "conv1"]:
            continue
        try:
            nn.init.kaiming_normal_(weights)
        except:
            nn.init.normal_(weights, 0., 0.05)

    return model

def get_l2_loss(model):
    return sum([x ** 2 for x in model.parameters()])
```

In [39]:
```
model = ParticleModel(model = model)
```

```
In [40]: model.to(DEVICE)

model = initialize_weights(model)
```

```
In [42]: EPOCHS = 20
l2_lambda = 4e-4

criterion = nn.CrossEntropyLoss().to(DEVICE)

# Optimizer hyperparameters
LR = 1e-3
FACTOR = 100
AMSGRAD = False
BETAS = (.9, .999)
```

In this notebook, the pretrained weights will be finetuned. This is in contrast to the previous one, where the weights were kept frozen. Also, the learing rate is increased from 1e-4 to 1e-3.

```
In [43]: opt = optim.Adam(
    params = [{
        "params" : model.backbone.fc.parameters(),
        "lr": LR
    }],
    lr=LR/FACTOR,
    amsgrad = AMSGRAD,
    betas = BETAS
)
```

```
In [44]: def get_l2_loss(model):
    l2_loss = torch.tensor(0.).cuda()
    l2_loss += sum(map(lambda x: x.pow(2).sum(), filter(lambda x: x.requires
    return l2_loss
```

```
In [45]: def collate_function_dl(batch):

    #xs = batch[0].clone()
    #ys = batch[1].clone()

    xs = [item[0].unsqueeze(0) for item in batch]
    ys = [item[1] for item in batch]

    xs = torch.cat(xs, dim=0)

    y = torch.tensor(ys).view(-1, 1)

    Xs = [torch.rot90(xs, k = _, dims = [-2, -1]) for _ in range(4)]

    return torch.cat(Xs, dim = 0), torch.cat([y for _ in range(4)], dim = 0)

def collate_function(batch):

    xs = batch[0].clone()
```

```
    ys = batch[1].clone().view(-1, 1)

    Xs = [torch.rot90(xs, k = _, dims = [-2, -1]) for _ in range(4)]

    return torch.cat(Xs, dim = 0), torch.cat([ys for _ in range(4)], dim = 0
```

In [46]:

```
from sklearn.metrics import accuracy_score
```

In [47]:

```
def training_loop(epochs, model, optimizer):
    TRAIN_LOSSES, TEST_LOSSES = [], []
    TRAIN_ACCS, TEST_ACCS = [], []

    for epoch in range(1, epochs + 1):
        train_losses, test_losses = [], []
        train_accs, test_accs = [], []

        model.train() # Set up training mode

        for batch in iter(train_dl):
            # X, y = collate_function(batch)
            X, y = batch
            X, y = X.to(DEVICE), y.view(-1).to(DEVICE)

            with torch.cuda.amp.autocast():
                y_pred = model(X)

            # Uncomment the line below if the criterion is nn.NLLLoss()
            # y_pred = torch.log_softmax(y_pred, dim = -1)

            train_loss = criterion(y_pred, y) # Compare actual targets and p
            train_loss.backward() # Backpropagate the loss

            optimizer.step()
            optimizer.zero_grad()

            train_losses.append(train_loss.item())

            train_acc = accuracy_score(y.cpu().numpy(), y_pred.max(dim = -1)
            train_accs.append(train_acc)

        with torch.no_grad(): # Turn off computational graph
            model.eval() # Set model to evaluation mode
            for batch in iter(test_dl):
                # X_, y_ = collate_function(batch)
                X_, y_ = batch
                X_, y_ = X_.to(DEVICE), y_.view(-1).to(DEVICE)

                with torch.cuda.amp.autocast():
                    y_pred_ = model(X_)

                # Uncomment the line below if the criterion is nn.NLLLoss()
                # y_pred_ = torch.log_softmax(y_pred_, dim = -1)

                test_loss = criterion(y_pred_, y_) # Compare actual targets
                test_losses.append(test_loss.item())
```

```python
                test_acc = accuracy_score(y_.cpu().numpy(), y_pred_.max(dim
                test_accs.append(test_acc)

        avg_train_loss = sum(train_losses) / len(train_losses)
        avg_test_loss = sum(test_losses) / len(test_losses)

        avg_train_acc = sum(train_accs) / len(train_accs)
        avg_test_acc = sum(test_accs) / len(test_accs)

        print(
            f"Epoch: {epoch} | Train loss: {avg_train_loss: .3f} | Test loss
            f"Train accuracy: {avg_train_acc: .3f} | Test accuracy: {avg_tes
        )

        TRAIN_LOSSES.append(avg_train_loss)
        TEST_LOSSES.append(avg_test_loss)

        TRAIN_ACCS.append(avg_train_acc)
        TEST_ACCS.append(avg_test_acc)

    # Clear CUDA cache
    torch.cuda.empty_cache()
    torch.clear_autocast_cache()

    return {
        "loss": [TRAIN_LOSSES, TEST_LOSSES],
        "accuracy": [TRAIN_ACCS, TEST_ACCS],
        "model": model
    }
```

In [48]:

```python
# Train Resnet-18 with finetuning
model_results = training_loop(epochs = EPOCHS, optimizer = opt, model = mode
```

```
/home/harkhymadhe/miniforge3/lib/python3.11/site-packages/torch/nn/modules/c
onv.py:456: UserWarning: Applied workaround for CuDNN issue, install nvrtc.s
o (Triggered internally at /home/conda/feedstock_root/build_artifacts/libtor
ch_1706726118919/work/aten/src/ATen/native/cudnn/Conv_v8.cpp:80.)
  return F.conv2d(input, weight, bias, self.stride,
```

```
Epoch: 1 | Train loss:  0.720 | Test loss:  0.696 | Train accuracy:  0.521 |
Test accuracy:  0.526 |
Epoch: 2 | Train loss:  0.702 | Test loss:  0.698 | Train accuracy:  0.526 |
Test accuracy:  0.530 |
Epoch: 3 | Train loss:  0.702 | Test loss:  0.698 | Train accuracy:  0.525 |
Test accuracy:  0.531 |
Epoch: 4 | Train loss:  0.702 | Test loss:  0.697 | Train accuracy:  0.526 |
Test accuracy:  0.533 |
Epoch: 5 | Train loss:  0.702 | Test loss:  0.698 | Train accuracy:  0.526 |
Test accuracy:  0.530 |
Epoch: 6 | Train loss:  0.701 | Test loss:  0.712 | Train accuracy:  0.526 |
Test accuracy:  0.519 |
Epoch: 7 | Train loss:  0.702 | Test loss:  0.697 | Train accuracy:  0.524 |
Test accuracy:  0.531 |
Epoch: 8 | Train loss:  0.702 | Test loss:  0.705 | Train accuracy:  0.524 |
Test accuracy:  0.523 |
Epoch: 9 | Train loss:  0.702 | Test loss:  0.721 | Train accuracy:  0.525 |
Test accuracy:  0.515 |
Epoch: 10 | Train loss:  0.702 | Test loss:  0.700 | Train accuracy:  0.526
| Test accuracy:  0.524 |
Epoch: 11 | Train loss:  0.703 | Test loss:  0.714 | Train accuracy:  0.525
| Test accuracy:  0.516 |
Epoch: 12 | Train loss:  0.702 | Test loss:  0.701 | Train accuracy:  0.526
| Test accuracy:  0.523 |
Epoch: 13 | Train loss:  0.702 | Test loss:  0.694 | Train accuracy:  0.525
| Test accuracy:  0.535 |
Epoch: 14 | Train loss:  0.701 | Test loss:  0.701 | Train accuracy:  0.526
| Test accuracy:  0.523 |
Epoch: 15 | Train loss:  0.703 | Test loss:  0.702 | Train accuracy:  0.525
| Test accuracy:  0.523 |
Epoch: 16 | Train loss:  0.702 | Test loss:  0.703 | Train accuracy:  0.525
| Test accuracy:  0.526 |
Epoch: 17 | Train loss:  0.702 | Test loss:  0.706 | Train accuracy:  0.525
| Test accuracy:  0.520 |
Epoch: 18 | Train loss:  0.702 | Test loss:  0.697 | Train accuracy:  0.526
| Test accuracy:  0.531 |
Epoch: 19 | Train loss:  0.702 | Test loss:  0.699 | Train accuracy:  0.524
| Test accuracy:  0.527 |
Epoch: 20 | Train loss:  0.702 | Test loss:  0.703 | Train accuracy:  0.524
| Test accuracy:  0.521 |
```

In [ ]:

```

```

In [49]:

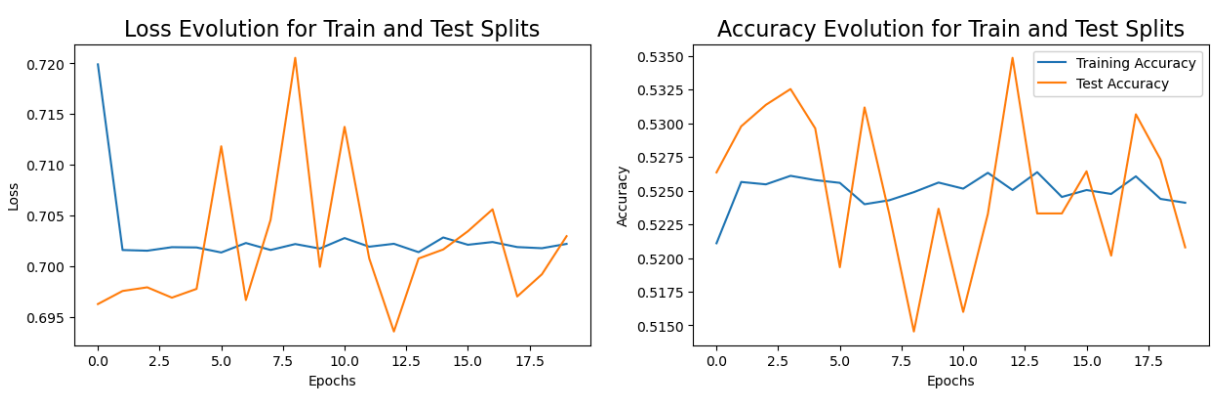
```python
def visualize_results(history, key = None):
    if key is not None:
        TRAIN_RESULTS, TEST_RESULTS = history[key]

        plt.figure(figsize = (10, 3))

        plt.plot(range(EPOCHS), TRAIN_RESULTS, label = f"Training {key.capit
        plt.plot(range(EPOCHS), TEST_RESULTS, label = f"Test {key.capitalize

        plt.xlabel("Epochs")
        plt.ylabel(key.capitalize())

        plt.title(key.capitalize() + " Evolution for Train and Test Splits",
```

```
        plt.legend()
        plt.show(); plt.close("all")
    else:
        TRAIN_LOSSES, TEST_LOSSES = history["loss"]
        TRAIN_ACCS, TEST_ACCS = history["accuracy"]

        fig, ax = plt.subplots(1, 2, figsize = (15, 4))

        ax[0].plot(range(EPOCHS), TRAIN_LOSSES, label = "Training Loss")
        ax[0].plot(range(EPOCHS), TEST_LOSSES, label = "Test Loss")

        ax[0].set_xlabel("Epochs")
        ax[0].set_ylabel("Loss")

        ax[0].set_title("Loss Evolution for Train and Test Splits", fontsize

        ax[1].plot(range(EPOCHS), TRAIN_ACCS, label = "Training Accuracy")
        ax[1].plot(range(EPOCHS), TEST_ACCS, label = "Test Accuracy")

        ax[1].set_xlabel("Epochs")
        ax[1].set_ylabel("Accuracy")

        ax[1].set_title("Accuracy Evolution for Train and Test Splits", font

        plt.legend()
        plt.show(); plt.close("all")

    return
```

In [ ]:

In [50]:

```
# VGG-13 with finetuning
visualize_results(model_results)
```



In [ ]:

In [ ]: