ImageClasssification

December 8, 2021

[ ]:
```
#installs
!pip install -U scikit-learn
!pip install seaborn
```

```
Requirement already satisfied: scikit-learn in /usr/local/lib/python3.7/dist-
packages (1.0.1)
Requirement already satisfied: scipy>=1.1.0 in /usr/local/lib/python3.7/dist-
packages (from scikit-learn) (1.4.1)
Requirement already satisfied: threadpoolctl>=2.0.0 in
/usr/local/lib/python3.7/dist-packages (from scikit-learn) (3.0.0)
Requirement already satisfied: joblib>=0.11 in /usr/local/lib/python3.7/dist-
packages (from scikit-learn) (1.1.0)
Requirement already satisfied: numpy>=1.14.6 in /usr/local/lib/python3.7/dist-
packages (from scikit-learn) (1.19.5)
Requirement already satisfied: seaborn in /usr/local/lib/python3.7/dist-packages
(0.11.2)
Requirement already satisfied: scipy>=1.0 in /usr/local/lib/python3.7/dist-
packages (from seaborn) (1.4.1)
Requirement already satisfied: numpy>=1.15 in /usr/local/lib/python3.7/dist-
packages (from seaborn) (1.19.5)
Requirement already satisfied: matplotlib>=2.2 in /usr/local/lib/python3.7/dist-
packages (from seaborn) (3.2.2)
Requirement already satisfied: pandas>=0.23 in /usr/local/lib/python3.7/dist-
packages (from seaborn) (1.1.5)
Requirement already satisfied: kiwisolver>=1.0.1 in
/usr/local/lib/python3.7/dist-packages (from matplotlib>=2.2->seaborn) (1.3.2)
Requirement already satisfied: python-dateutil>=2.1 in
/usr/local/lib/python3.7/dist-packages (from matplotlib>=2.2->seaborn) (2.8.2)
Requirement already satisfied: pyparsing!=2.0.4,!=2.1.2,!=2.1.6,>=2.0.1 in
/usr/local/lib/python3.7/dist-packages (from matplotlib>=2.2->seaborn) (3.0.6)
Requirement already satisfied: cycler>=0.10 in /usr/local/lib/python3.7/dist-
packages (from matplotlib>=2.2->seaborn) (0.11.0)
Requirement already satisfied: pytz>=2017.2 in /usr/local/lib/python3.7/dist-
packages (from pandas>=0.23->seaborn) (2018.9)
Requirement already satisfied: six>=1.5 in /usr/local/lib/python3.7/dist-
packages (from python-dateutil>=2.1->matplotlib>=2.2->seaborn) (1.15.0)
```

[ ]:
```
#imports

import torch
import torch.nn as nn
from torch.utils.data import DataLoader
from torchvision.transforms.transforms import Compose, Normalize, RandomCrop,␣
 ↪RandomHorizontalFlip
from torch.utils.data.dataset import random_split
import torch.optim as optim
import torch.optim.lr_scheduler as lr_scheduler

from torchvision import datasets
from torchvision.transforms import ToTensor
from torchvision.datasets.utils import download_url
from torchvision.datasets import ImageFolder

import torch.nn.functional as F

import matplotlib.pyplot as plt

import copy
import time

from sklearn.metrics import confusion_matrix
import seaborn as sns
```

[ ]:
```
from google.colab import drive
drive.mount('/content/gdrive')
```

```
Mounted at /content/gdrive
```

[ ]:
```
%cd /content/gdrive/MyDrive/Colab\ Notebooks/img_classification
```

```
/content/gdrive/MyDrive/Colab Notebooks/img_classification
```

[ ]:
```
device = 'cpu'
if torch.cuda.is_available():
  device = 'cuda'

torch.cuda.is_available()
```

[ ]:
```
True
```

1 Dataset and Dataloaders

1.1 Datasets

[ ]:
```
data_dir = './data'

stats = ((0.491, 0.482, 0.446), (0.247, 0.243, 0.261))

augmentation_transform = Compose([
        RandomCrop(32, padding=4, padding_mode='reflect'),
        RandomHorizontalFlip(),
        ToTensor(),
        Normalize(*stats, inplace=True)
    ])

train_transform = Compose([
        ToTensor(),
        Normalize(*stats, inplace=True)
    ])

val_transform = Compose([
                        ToTensor(),
                        Normalize(*stats)])

train_ds =  datasets.CIFAR10(
    root=data_dir,
    train=True,
    download=True,
    transform=train_transform
)

val_ds =  datasets.CIFAR10(
    root=data_dir,
    train=False,
    download=False,
    transform=val_transform
)


batch_sizes = [32, 64, 128]
```

```
Files already downloaded and verified
```

1.2 Dataloaders

1.2.1 Device Dataloader

[ ]:
```
loaders = {}

for batch_size in batch_sizes:

  train_dl = DataLoader(train_ds, batch_size, shuffle=True, num_workers=2,␣
 ↪pin_memory=True)
  val_dl = DataLoader(val_ds, batch_size*2, num_workers=2, pin_memory=True)

  train_dl = DeviceDataLoader(train_dl, device)
  val_dl = DeviceDataLoader(val_dl, device)

  loaders[batch_size] = [train_dl, val_dl]
```

[ ]:
```
loaders
```

[ ]:
```
{32: [<__main__.DeviceDataLoader at 0x7f1a2729bd90>,
  <__main__.DeviceDataLoader at 0x7f1a2729b690>],
 64: [<__main__.DeviceDataLoader at 0x7f1a2729b190>,
  <__main__.DeviceDataLoader at 0x7f1a2729ba10>],
 128: [<__main__.DeviceDataLoader at 0x7f1a2729bb10>,
  <__main__.DeviceDataLoader at 0x7f1a2729b7d0>]}
```

[ ]:
```
loaders[32][0].device
```

[ ]:
```
'cuda'
```

[ ]:
```
def get_default_device():
    """Pick GPU if available, else CPU"""
    if torch.cuda.is_available():
        return torch.device('cuda')
    else:
        return torch.device('cpu')

def to_device(data, device):
    """Move tensor(s) to chosen device"""
    if isinstance(data, (list,tuple)):
        return [to_device(x, device) for x in data]
    return data.to(device, non_blocking=True)

class DeviceDataLoader():
    """Wrap a dataloader to move data to a device"""
    def __init__(self, dl, device):
        self.dl = dl
        self.device = device
```

```
    def __iter__(self):
        """Yield a batch of data after moving it to device"""
        for b in self.dl:
            yield to_device(b, self.device)

    def __len__(self):
        """Number of batches"""
        return len(self.dl)
```

2 Models

2.1 Base

[ ]:
```
class ImageClassificationBase(nn.Module):

    def training_step(self, batch):
        imgs, lbls = batch
        out = self(imgs) #Generate predictions
        loss = F.cross_entropy(out, lbls) # Calculate Loss
        return loss

    def validation_step(self, batch):

        imgs, lbls = batch
        out = self(imgs)
        loss = F.cross_entropy(out, lbls)
        acc = accuracy(out, lbls)
        return {"val_loss": loss.detach(), "val_acc": acc}

    def validation_epoch_end(self, outputs):
        batch_losses = [x["val_loss"] for x in outputs]
        epoch_loss = torch.stack(batch_losses).mean()
        batch_accs = [x["val_acc"] for x in outputs]
        epoch_acc = torch.stack(batch_accs).mean()
        return {"val_loss": epoch_loss.item(), "val_acc": epoch_acc.item()}

    def epoch_end(self, epoch, result):
        print(f"Epoch: {epoch}, last_lr: {result['lrs'][-1]}, train_loss:␣
 ↪{result['train_loss']}, val_loss: {result['val_loss']}, val_acc:␣
 ↪{result['val_acc']}")


def accuracy(outputs, lbls):
    _, preds = torch.max(outputs, dim=1)
    return torch.tensor(torch.sum(preds == lbls).item() / len(preds))
```

2.2 Simple CNN

[ ]:
```
class Net(ImageClassificationBase):

    def __init__(self) -> None:
        super().__init__()

        self.network = nn.Sequential(
            nn.Conv2d(3, 32, kernel_size=3, padding=1),
            nn.ReLU(), # activation, iterates all elements and if a value is␣
↪negative, changes to 0 introduces non linearity
            nn.Conv2d(32, 64, kernel_size=3, stride=1, padding=1),
            nn.ReLU(),
            nn.MaxPool2d(2,2),

            nn.Conv2d(64, 128, kernel_size=3, padding=1),
            nn.ReLU(), # activation, iterates all elements and if a value is␣
↪negative, changes to 0 introduces non linearity
            nn.Conv2d(128, 128, kernel_size=3, stride=1, padding=1),
            nn.ReLU(),
            nn.MaxPool2d(2,2),

            nn.Conv2d(128, 256, kernel_size=3, padding=1),
            nn.ReLU(), # activation, iterates all elements and if a value is␣
↪negative, changes to 0 introduces non linearity
            nn.Conv2d(256, 256, kernel_size=3, stride=1, padding=1),
            nn.ReLU(),
            nn.MaxPool2d(2,2),

            nn.Flatten(),
            nn.Linear(256*4*4, 1024),
            nn.ReLU(),
            nn.Linear(1024,512),
            nn.ReLU(),
            nn.Linear(512, 10)
        )

    def forward(self, xb):
        return self.network(xb)

cnnModel = Net()
```

[ ]:
```
device
```

[ ]:
```
'cuda'
```

[ ]:
```
cnnModel.to(device)
cnnModel.cuda
```

[ ]:
```
<bound method Module.cuda of Net(
  (network): Sequential(
    (0): Conv2d(3, 32, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
    (1): ReLU()
    (2): Conv2d(32, 64, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
    (3): ReLU()
    (4): MaxPool2d(kernel_size=2, stride=2, padding=0, dilation=1,
ceil_mode=False)
    (5): Conv2d(64, 128, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
    (6): ReLU()
    (7): Conv2d(128, 128, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
    (8): ReLU()
    (9): MaxPool2d(kernel_size=2, stride=2, padding=0, dilation=1,
ceil_mode=False)
    (10): Conv2d(128, 256, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
    (11): ReLU()
    (12): Conv2d(256, 256, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
    (13): ReLU()
    (14): MaxPool2d(kernel_size=2, stride=2, padding=0, dilation=1,
ceil_mode=False)
    (15): Flatten(start_dim=1, end_dim=-1)
    (16): Linear(in_features=4096, out_features=1024, bias=True)
    (17): ReLU()
    (18): Linear(in_features=1024, out_features=512, bias=True)
    (19): ReLU()
    (20): Linear(in_features=512, out_features=10, bias=True)
  )
)>
```

2.3 ResNet

[ ]:
```
def conv_block(in_channels, out_channels, pool=False):
  layers = [
            nn.Conv2d(in_channels, out_channels, kernel_size=3, padding=1),
            nn.BatchNorm2d(out_channels),
            nn.ReLU(inplace=True)
  ]
  if pool: layers.append(nn.MaxPool2d(2))
  return nn.Sequential(*layers)


class ResNet9(ImageClassificationBase):
  def __init__(self, in_channels, num_classes):
    super().__init__()
```

```
    self.conv1 = conv_block(in_channels, 64)
    self.conv2 = conv_block(64, 128, pool=True)
    self.res1 = nn.Sequential(conv_block(128, 128), conv_block(128, 128))

    self.conv3 = conv_block(128, 256, pool=True)
    self.conv4 = conv_block(256, 512, pool=True)
    self.res2 = nn.Sequential(conv_block(512, 512), conv_block(512, 512))

    self.classifier = nn.Sequential(nn.MaxPool2d(4),
                                    nn.Flatten(),
                                    nn.Linear(512, num_classes))


  def forward(self, X):

    out = self.conv1(X)
    out = self.conv2(out)
    out = self.res1(out) + out
    out = self.conv3(out)
    out = self.conv4(out)
    out = self.res2(out) + out
    out = self.classifier(out)

    return out


resNetModel = ResNet9(3,10)
```

[ ]:
```
resNetModel.to(device)
```

[ ]:
```
ResNet9(
  (conv1): Sequential(
    (0): Conv2d(3, 64, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
    (1): BatchNorm2d(64, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (2): ReLU(inplace=True)
  )
  (conv2): Sequential(
    (0): Conv2d(64, 128, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
    (1): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (2): ReLU(inplace=True)
    (3): MaxPool2d(kernel_size=2, stride=2, padding=0, dilation=1,
ceil_mode=False)
  )
  (res1): Sequential(
```

```
    (0): Sequential(
      (0): Conv2d(128, 128, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
      (1): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
      (2): ReLU(inplace=True)
    )
    (1): Sequential(
      (0): Conv2d(128, 128, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
      (1): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
      (2): ReLU(inplace=True)
    )
  )
  (conv3): Sequential(
    (0): Conv2d(128, 256, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
    (1): BatchNorm2d(256, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (2): ReLU(inplace=True)
    (3): MaxPool2d(kernel_size=2, stride=2, padding=0, dilation=1,
ceil_mode=False)
  )
  (conv4): Sequential(
    (0): Conv2d(256, 512, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
    (1): BatchNorm2d(512, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (2): ReLU(inplace=True)
    (3): MaxPool2d(kernel_size=2, stride=2, padding=0, dilation=1,
ceil_mode=False)
  )
  (res2): Sequential(
    (0): Sequential(
      (0): Conv2d(512, 512, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
      (1): BatchNorm2d(512, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
      (2): ReLU(inplace=True)
    )
    (1): Sequential(
      (0): Conv2d(512, 512, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
      (1): BatchNorm2d(512, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
      (2): ReLU(inplace=True)
    )
  )
  (classifier): Sequential(
    (0): MaxPool2d(kernel_size=4, stride=4, padding=0, dilation=1,
ceil_mode=False)
    (1): Flatten(start_dim=1, end_dim=-1)
```

```
    (2): Linear(in_features=512, out_features=10, bias=True)
  )
)
```

[ ]:
```
resNetModel.__
```

3 Training and Evaluation

[ ]:
```
@torch.no_grad()
def evaluate(model, val_loader):
    model.eval()
    outputs = [model.validation_step(batch) for batch in val_loader]
    return model.validation_epoch_end(outputs)

def get_lr(optimizer):
    for param_group in optimizer.param_groups:
        return param_group['lr']

def fit_one_cycle(epochs, max_lr, model, train_loader, val_loader,
                  weight_decay=0, grad_clip=None, opt_func=torch.optim.SGD):

    best_acc = [0.0, 0]
    torch.cuda.empty_cache()
    history = []

    # Set up cutom optimizer with weight decay
    optimizer = opt_func(model.parameters(), max_lr, weight_decay=weight_decay)
    # Set up one-cycle learning rate scheduler
    sched = torch.optim.lr_scheduler.OneCycleLR(optimizer, max_lr,␣
↪epochs=epochs,
                                                ␣
↪steps_per_epoch=len(train_loader))


    for epoch in range(epochs):

        print(f'Epoch {epoch}/{epochs-1}')
        print('-' * 10)

        # Training Phase
        model.train()
        train_losses = []
        lrs = []

        for batch in train_loader:
            loss = model.training_step(batch)
```

```
            train_losses.append(loss)
            #loss.requires_grad = True
            loss.backward()

            # Gradient clipping
            if grad_clip:
                nn.utils.clip_grad_value_(model.parameters(), grad_clip)

            optimizer.step()
            optimizer.zero_grad()

            # Record & update learning rate
            lrs.append(get_lr(optimizer))
            sched.step()

        # Validation phase
        result = evaluate(model, val_loader)
        result['train_loss'] = torch.stack(train_losses).mean().item()
        result['lrs'] = lrs
        model.epoch_end(epoch, result)
        history.append(result)

        epoch_acc = result['val_acc']

        if epoch_acc > best_acc[0]:
          best_acc[0] = epoch_acc
          best_acc[1] = epoch
          torch.save(model, 'best_modelrn9.pt')

        print(f"Best Acc: {best_acc[0]} in Epoch no. {best_acc[1]}")

    return history
```

[ ]:
```
history = [evaluate(resNetModel, val_dl)]
history
```

[ ]:
```
[{'val_acc': 0.10830078274011612, 'val_loss': 2.304202079772949}]
```

3.1 Hyperparametres

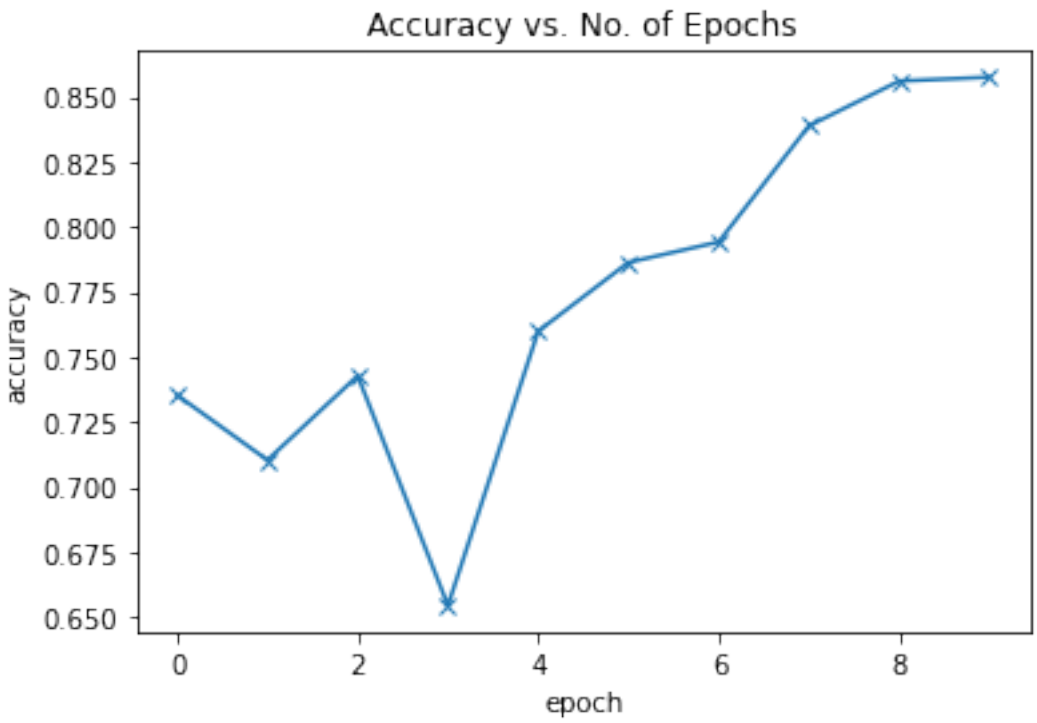
[ ]:
```
epochs = 10
max_lr = 0.01
grad_clip = 0.1
weight_decay = 1e-4
opt_func = torch.optim.Adam
```

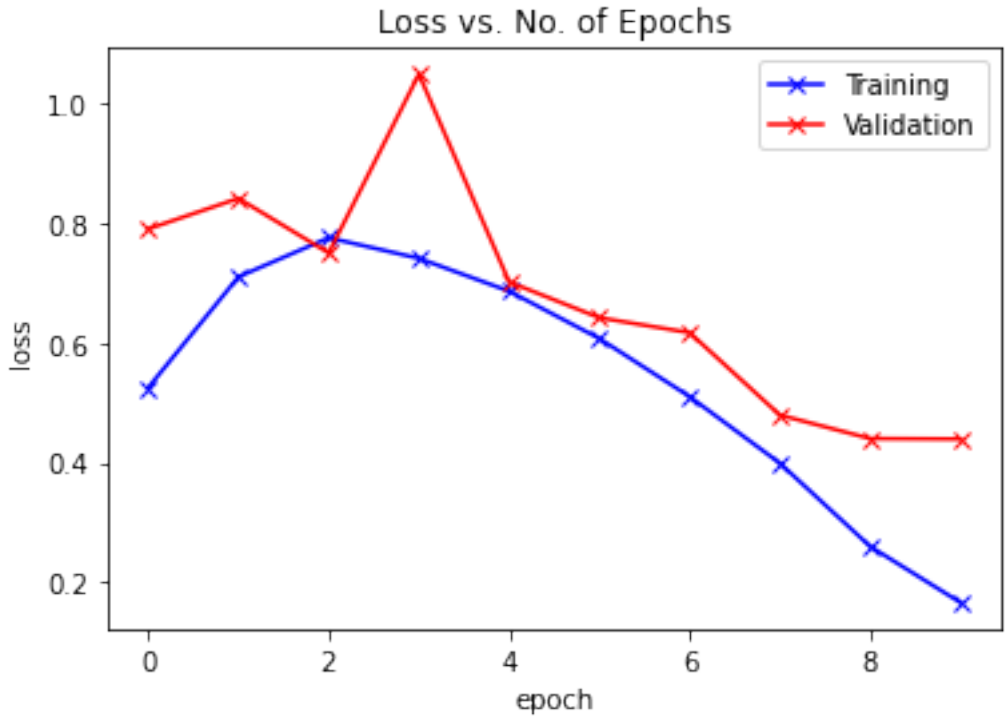
[ ]:
```
def plot_accuracies(history, filename):
    accuracies = [x['val_acc'] for x in history]
    plt.plot(accuracies, '-x')
    plt.xlabel('epoch')
    plt.ylabel('accuracy')
    plt.title('Accuracy vs. No. of Epochs')
    plt.savefig(f'acc_{filename}.png')
    plt.show()


def plot_losses(history, filename):
    train_losses = [ x.get('train_loss') for x in history]
    val_losses = [x['val_loss'] for x in history]
    plt.plot(train_losses, '-bx')
    plt.plot(val_losses, '-rx')
    plt.xlabel('epoch')
    plt.ylabel('loss')
    plt.legend(['Training', 'Validation'])
    plt.title('Loss vs. No. of Epochs')
    plt.savefig(f'loss_{filename}.png')
    plt.show()


def visualize_model(model, val_loader, num_images=6):
    was_training = model.training
    model.eval()
    images_so_far = 0
    fig = plt.figure()

    with torch.no_grad():
        for i, (inputs, labels) in enumerate(val_loader):

            outputs = model(inputs)
            _, preds = torch.max(outputs, 1)

            for j in range(inputs.size()[0]):
                images_so_far += 1
                ax = plt.subplot(num_images//2, 2, images_so_far)
                ax.axis('off')
                ax.set_title('predicted: {}'.format(class_names[preds[j]]))
                imshow(inputs.cpu().data[j])

                if images_so_far == num_images:
                    model.train(mode=was_training)
                    return
        model.train(mode=was_training)
```

[ ]:
```
for key, val in loaders.items():

  print(f"""Parametres
  -----
  Num Epochs: {epochs},
  Batch size: {key},
  """)
  %%time
  history, best_model = fit_one_cycle(epochs, max_lr, resNetModel, val[0],␣
 ↪val[1], grad_clip=grad_clip,
                          weight_decay=weight_decay, opt_func=opt_func)

  plot_accuracies(history, f"resNetModel{key}")
  plot_losses(history, f"resNetModel{key}")

  torch.save(best_model, f"resNet{key}Dict.pt")
```

```
Parametres
  -----
  Num Epochs: 10,
  Batch size: 32,

CPU times: user 4 µs, sys: 1 µs, total: 5 µs
Wall time: 10 µs
Epoch 0/9
----------
Epoch: 0, last_lr: 0.0027981431071167143, train_loss: 0.5248221158981323,
val_loss: 0.7899484038352966, val_acc: 0.7352706789970398
Best Acc: 0.7352706789970398 in Epoch no. 0
Epoch 1/9
----------
Epoch: 1, last_lr: 0.007599071373902852, train_loss: 0.7099831104278564,
val_loss: 0.8410148024559021, val_acc: 0.7102906107902527
Best Acc: 0.7352706789970398 in Epoch no. 0
Epoch 2/9
----------
Epoch: 2, last_lr: 0.01, train_loss: 0.7752159237861633, val_loss:
0.7497961521148682, val_acc: 0.7427348494529724
Best Acc: 0.7427348494529724 in Epoch no. 2
Epoch 3/9
----------
Epoch: 3, last_lr: 0.009504846320134737, train_loss: 0.7408013343811035,
val_loss: 1.0484436750411987, val_acc: 0.6543591022491455
Best Acc: 0.7427348494529724 in Epoch no. 2
Epoch 4/9
----------
Epoch: 4, last_lr: 0.008117456539497631, train_loss: 0.6859750151634216,
```

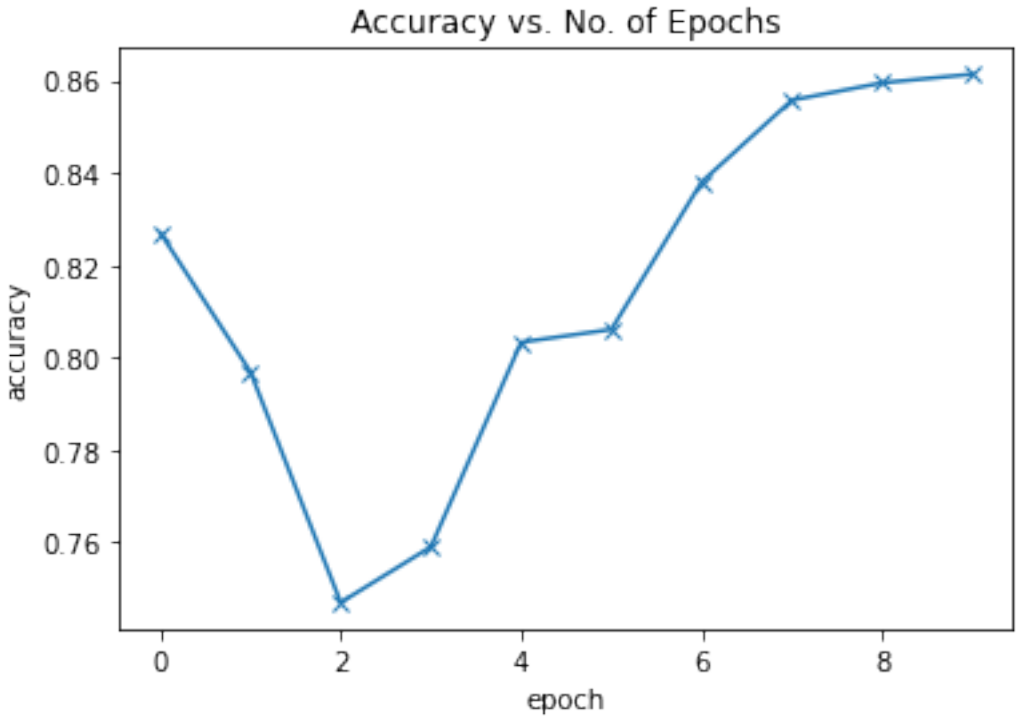
```
val_loss: 0.7013722658157349, val_acc: 0.7598527073860168
Best Acc: 0.7598527073860168 in Epoch no. 4
Epoch 5/9
----------
Epoch: 5, last_lr: 0.0061126202193628925, train_loss: 0.6069056987762451,
val_loss: 0.641569972038269, val_acc: 0.7863256335258484
Best Acc: 0.7863256335258484 in Epoch no. 5
Epoch 6/9
----------
Epoch: 6, last_lr: 0.003887419780637108, train_loss: 0.5099025964736938,
val_loss: 0.6167000532150269, val_acc: 0.7941879034042358
Best Acc: 0.7941879034042358 in Epoch no. 6
Epoch 7/9
----------
Epoch: 7, last_lr: 0.00188258346050237, train_loss: 0.3986726701259613,
val_loss: 0.4790746569633484, val_acc: 0.8388733863830566
Best Acc: 0.8388733863830566 in Epoch no. 7
Epoch 8/9
----------
Epoch: 8, last_lr: 0.0004951936798652628, train_loss: 0.2597155272960663,
val_loss: 0.4398353695869446, val_acc: 0.856090784072876
Best Acc: 0.856090784072876 in Epoch no. 8
Epoch 9/9
----------
Epoch: 9, last_lr: 4e-08, train_loss: 0.1660231500864029, val_loss:
0.4390949010848999, val_acc: 0.8575835824012756
Best Acc: 0.8575835824012756 in Epoch no. 9
```

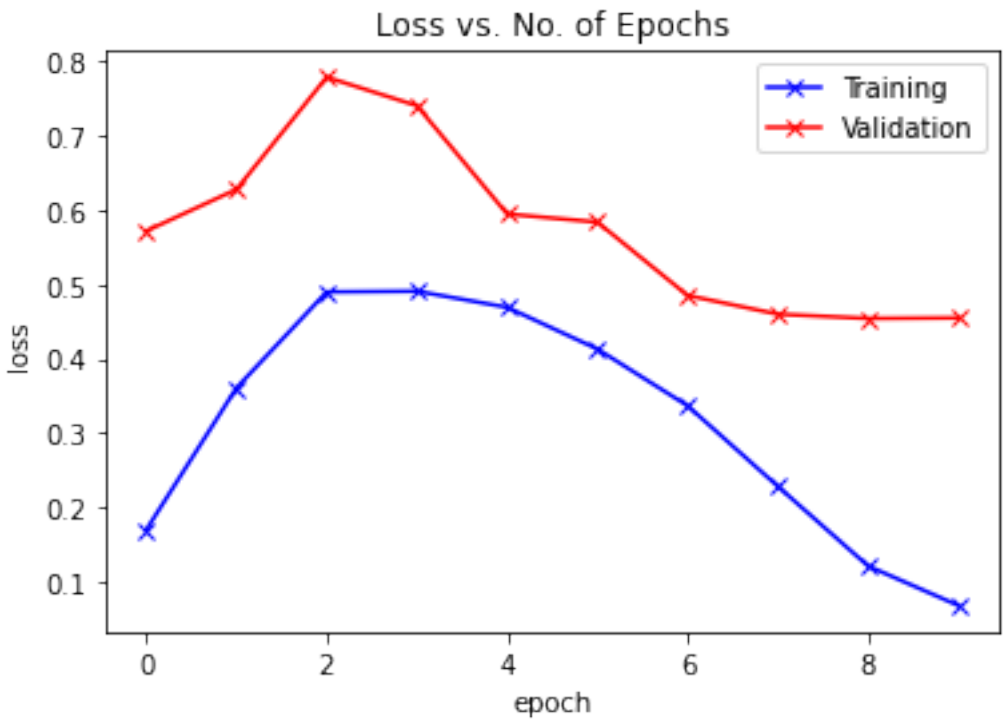

Accuracy vs. No. of Epochs
accuracy
epoch
0.850
0.825
0.800
0.775
0.750
0.725
0.700
0.675
0.650
0
2
4
6
8


Loss vs. No. of Epochs
Training
Validation
loss
epoch
1.0
0.8
0.6
0.4
0.2
0
2
4
6
8

```
Parametres
  -----
  Num Epochs: 10,
  Batch size: 64,

CPU times: user 0 ns, sys: 2 µs, total: 2 µs
Wall time: 6.68 µs
Epoch 0/9
----------
Epoch: 0, last_lr: 0.002796288276714347, train_loss: 0.16991613805294037,
val_loss: 0.5712572932243347, val_acc: 0.8270371556282043
Best Acc: 0.8270371556282043 in Epoch no. 0
Epoch 1/9
----------
Epoch: 1, last_lr: 0.007598143420255434, train_loss: 0.3605975806713104,
val_loss: 0.6271682977676392, val_acc: 0.796875
Best Acc: 0.8270371556282043 in Epoch no. 0
Epoch 2/9
----------
Epoch: 2, last_lr: 0.01, train_loss: 0.4894494116306305, val_loss:
0.7778607606887817, val_acc: 0.7469343543052673
Best Acc: 0.8270371556282043 in Epoch no. 0
Epoch 3/9
----------
Epoch: 3, last_lr: 0.009504846320134737, train_loss: 0.49041029810905457,
val_loss: 0.7395403385162354, val_acc: 0.758999228477478
Best Acc: 0.8270371556282043 in Epoch no. 0
Epoch 4/9
----------
Epoch: 4, last_lr: 0.008117456539497631, train_loss: 0.46883106231689453,
val_loss: 0.5941011309623718, val_acc: 0.8033030033111572
Best Acc: 0.8270371556282043 in Epoch no. 0
Epoch 5/9
----------
Epoch: 5, last_lr: 0.0061126202193628925, train_loss: 0.4128063917160034,
val_loss: 0.5832463502883911, val_acc: 0.8060719966888428
Best Acc: 0.8270371556282043 in Epoch no. 0
Epoch 6/9
----------
Epoch: 6, last_lr: 0.003887419780637108, train_loss: 0.3365459442138672,
val_loss: 0.48472481966018677, val_acc: 0.8380142450332642
Best Acc: 0.8380142450332642 in Epoch no. 6
Epoch 7/9
----------
Epoch: 7, last_lr: 0.00188258346050237, train_loss: 0.22834143042564392,
val_loss: 0.4595971405506134, val_acc: 0.8557159900665283
Best Acc: 0.8557159900665283 in Epoch no. 7
Epoch 8/9
```

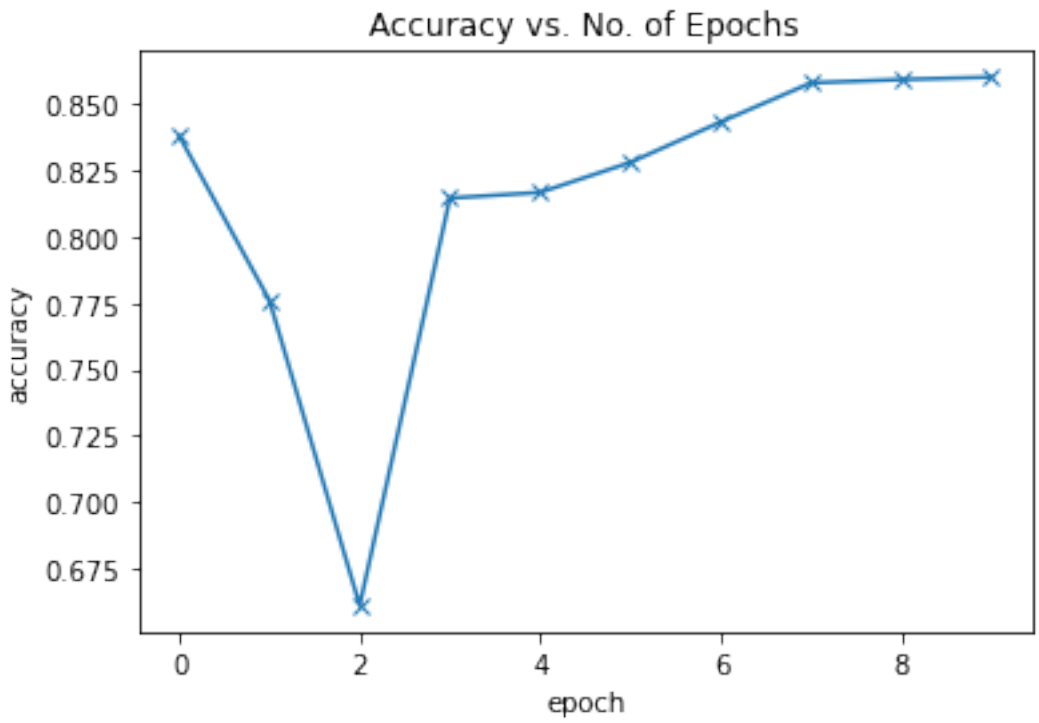
```
----------
Epoch: 8, last_lr: 0.0004951936798652628, train_loss: 0.1213671937584877,
val_loss: 0.4538663327693939, val_acc: 0.8594738841056824
Best Acc: 0.8594738841056824 in Epoch no. 8
Epoch 9/9
----------
Epoch: 9, last_lr: 4e-08, train_loss: 0.06839791685342789, val_loss:
0.4546057879924774, val_acc: 0.8613528609275818
Best Acc: 0.8613528609275818 in Epoch no. 9
```

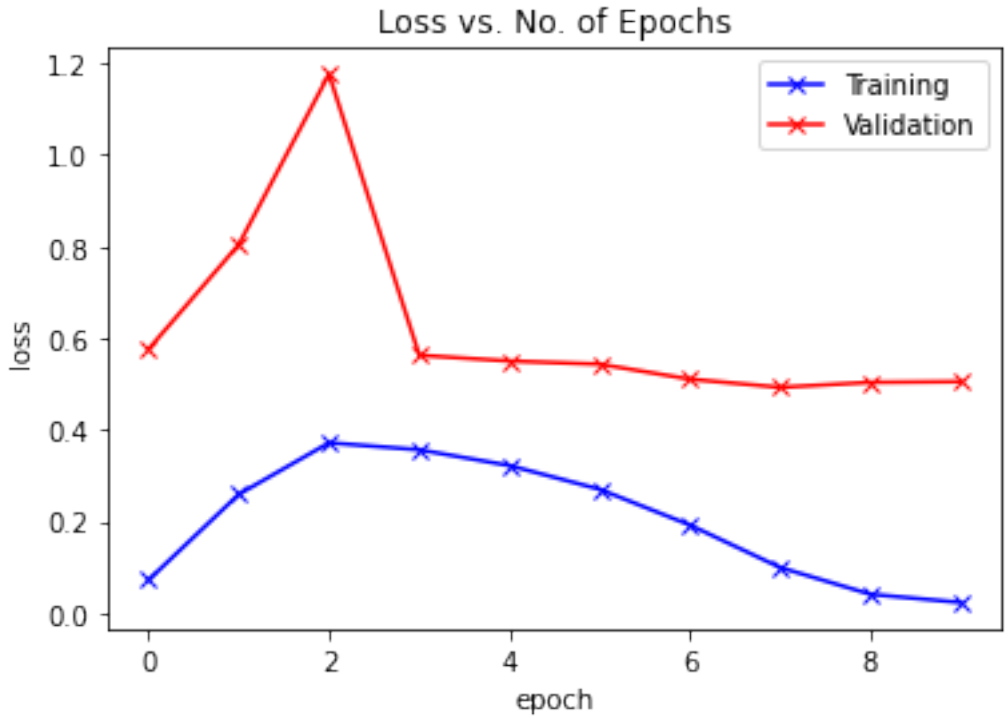





```
Parametres
  -----
  Num Epochs: 10,
  Batch size: 128,

CPU times: user 2 µs, sys: 1e+03 ns, total: 3 µs
Wall time: 5.96 µs
Epoch 0/9
----------
Epoch: 0, last_lr: 0.0027925753062899962, train_loss: 0.07193922996520996,
val_loss: 0.5758343935012817, val_acc: 0.8379882574081421
Best Acc: 0.8379882574081421 in Epoch no. 0
Epoch 1/9
----------
Epoch: 1, last_lr: 0.007596284777545438, train_loss: 0.25895464420318604,
val_loss: 0.8043265342712402, val_acc: 0.7759765386581421
Best Acc: 0.8379882574081421 in Epoch no. 0
Epoch 2/9
----------
Epoch: 2, last_lr: 0.01, train_loss: 0.37148746848106384, val_loss:
1.1762553453445435, val_acc: 0.660937488079071
Best Acc: 0.8379882574081421 in Epoch no. 0
Epoch 3/9
----------
```

```
Epoch: 3, last_lr: 0.009504846320134737, train_loss: 0.35620585083961487,
val_loss: 0.5625473856925964, val_acc: 0.8145507574081421
Best Acc: 0.8379882574081421 in Epoch no. 0
Epoch 4/9
----------
Epoch: 4, last_lr: 0.008117456539497631, train_loss: 0.32177823781967163,
val_loss: 0.5499623417854309, val_acc: 0.816699206829071
Best Acc: 0.8379882574081421 in Epoch no. 0
Epoch 5/9
----------
Epoch: 5, last_lr: 0.0061126202193628925, train_loss: 0.2699469327926636,
val_loss: 0.5431169867515564, val_acc: 0.8280273675918579
Best Acc: 0.8379882574081421 in Epoch no. 0
Epoch 6/9
----------
Epoch: 6, last_lr: 0.003887419780637108, train_loss: 0.19183219969272614,
val_loss: 0.5103043913841248, val_acc: 0.84326171875
Best Acc: 0.84326171875 in Epoch no. 6
Epoch 7/9
----------
Epoch: 7, last_lr: 0.00188258346050237, train_loss: 0.0991458147764206,
val_loss: 0.49252286553382874, val_acc: 0.8580077886581421
Best Acc: 0.8580077886581421 in Epoch no. 7
Epoch 8/9
----------
Epoch: 8, last_lr: 0.0004951936798652628, train_loss: 0.040739886462688446,
val_loss: 0.5034223198890686, val_acc: 0.8592773675918579
Best Acc: 0.8592773675918579 in Epoch no. 8
Epoch 9/9
----------
Epoch: 9, last_lr: 4e-08, train_loss: 0.02280818298459053, val_loss:
0.5049628615379333, val_acc: 0.860156238079071
Best Acc: 0.860156238079071 in Epoch no. 9
```


Accuracy vs. No. of Epochs
accuracy
0.850
0.825
0.800
0.775
0.750
0.725
0.700
0.675
0
2
4
6
8
epoch


Loss vs. No. of Epochs
loss
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
2
4
6
8
epoch
Training
Validation

[ ]:
```
%%time
history += fit_one_cycle(epochs, max_lr, resNetModel, train_dl, val_dl,␣
 ↪grad_clip=grad_clip,
                         weight_decay=weight_decay, opt_func=opt_func)
```

```
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4.514645729738839e-08, 4e-08], train_loss: 0.2512175142765045, val_loss:
0.306847482919693, val_acc: 0.8960937261581421
CPU times: user 6min 45s, sys: 4min 46s, total: 11min 32s
Wall time: 11min 39s
```

4 Validation

4.1 Data augmentation

[ ]:
```
batch_size_ft = 256

train_ds =  datasets.CIFAR10(
    root=data_dir,
    train=True,
    download=True,
    transform=augmentation_transform
)

val_ds =  datasets.CIFAR10(
    root=data_dir,
    train=False,
    download=False,
    transform=val_transform
)

train_dl = DataLoader(train_ds, batch_size_ft, shuffle=True, num_workers=2,␣
 ↪pin_memory=True)
val_dl = DataLoader(val_ds, batch_size_ft*2, num_workers=2, pin_memory=True)
train_dl_ft = DeviceDataLoader(train_dl, device)
val_dl_ft = DeviceDataLoader(val_dl, device)
```

```
Files already downloaded and verified
```

4.2 Prediction

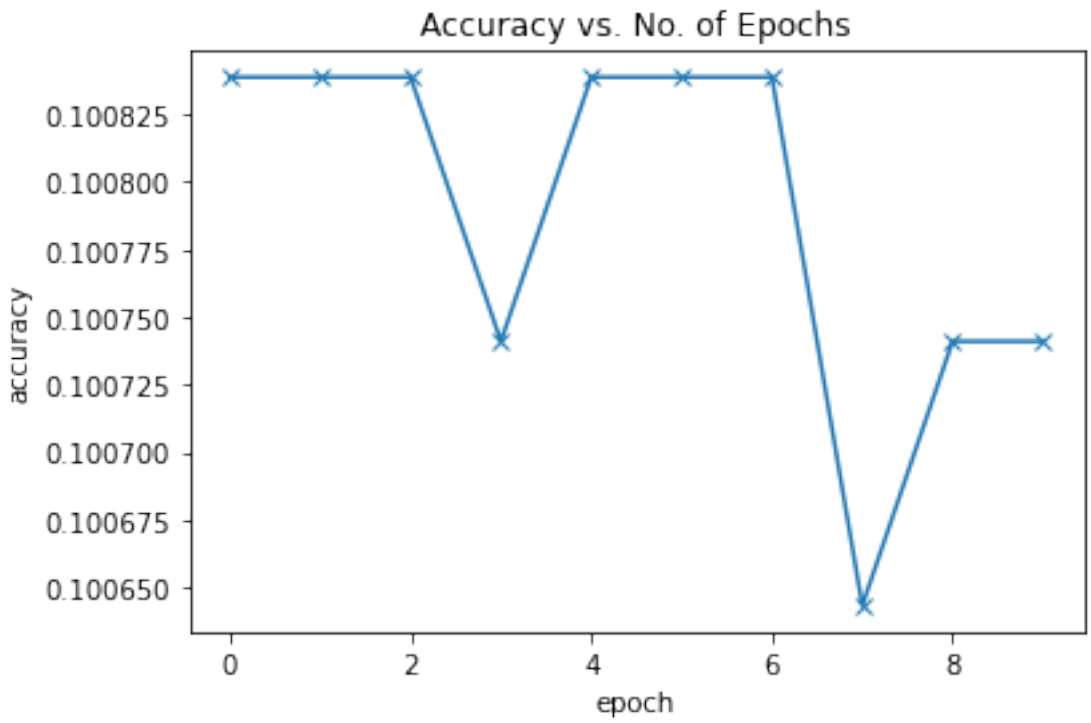
[ ]:
```
def predict(img, model):
    # Convert to a batch of 1
    xb = to_device(img.unsqueeze(0), device)
    # Get predictions from model
    yb = model(xb)
    # Pick index with highest probability
    _, preds  = torch.max(yb, dim=1)
    # Retrieve the class label
    return val_ds.classes[preds[0].item()]
```

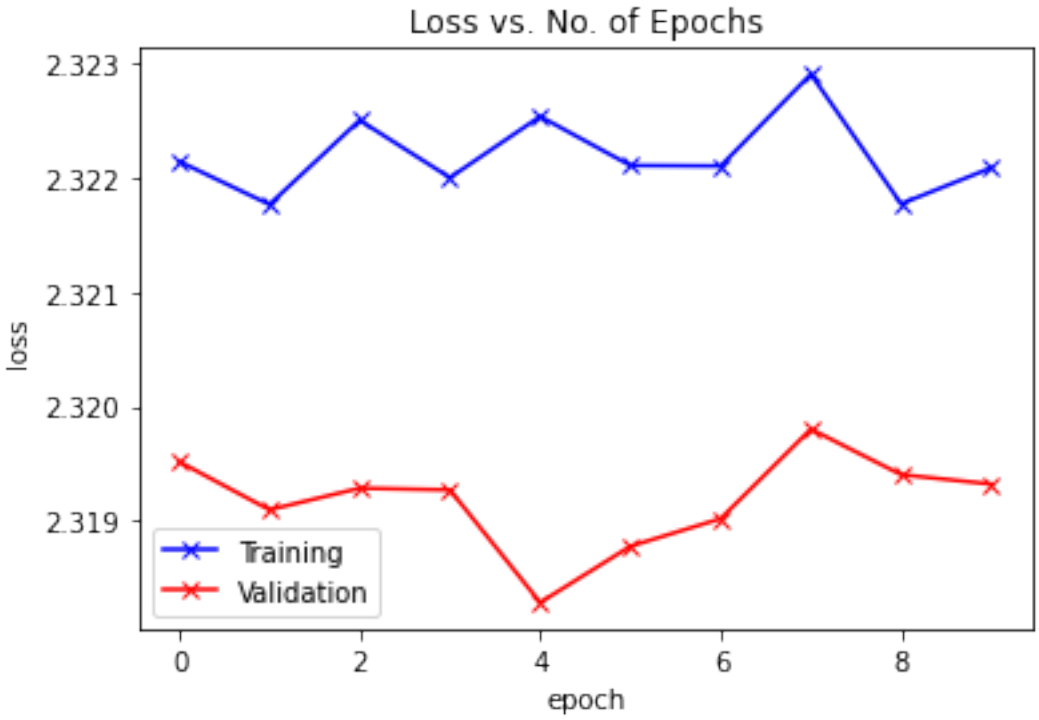
```
#img, label = val_ds[467]
#plt.imshow(img.permute(1, 2, 0))
#print('Label:', val_ds.classes[label], ', Predicted:', predict(img,␣
 ↪resNetFineTunning))
```

[ ]:
```
resNet9 = ResNet9(3, 10)
resNet9.to(device)



history = fit_one_cycle(epochs, max_lr, resNet9, train_dl_ft, val_dl_ft,␣
 ↪grad_clip=grad_clip,
                         opt_func=opt_func)

plot_accuracies(history_ft, 'resNet_best')
plot_losses(history_ft, 'resNest_best')

y = []
y_pred = []

for img, lbl in val_ds:
  y.append(val_ds.classes[lbl])
  y_pred.append(predict(img, resNet9))

confusion_matrix(y, y_pred, labels=val_ds.classes)
```

```
Epoch 0/9
----------
Epoch: 0, last_lr: 0.0027851835584105904, train_loss: 1.2554885149002075,
val_loss: 1.082831859588623, val_acc: 0.6149126887321472
Best Acc: 0.6149126887321472 in Epoch no. 0
Epoch 1/9
----------
Epoch: 1, last_lr: 0.007592580310080607, train_loss: 0.9218870997428894,
val_loss: 1.8074153661727905, val_acc: 0.5475987792015076
Best Acc: 0.6149126887321472 in Epoch no. 0
Epoch 2/9
----------
Epoch: 2, last_lr: 0.01, train_loss: 0.7938281297683716, val_loss:
1.2265682220458984, val_acc: 0.6216853857040405
Best Acc: 0.6216853857040405 in Epoch no. 2
Epoch 3/9
----------
Epoch: 3, last_lr: 0.009504846320134737, train_loss: 0.6052901148796082,
val_loss: 1.1297537088394165, val_acc: 0.6879020929336548
Best Acc: 0.6879020929336548 in Epoch no. 3
Epoch 4/9
```

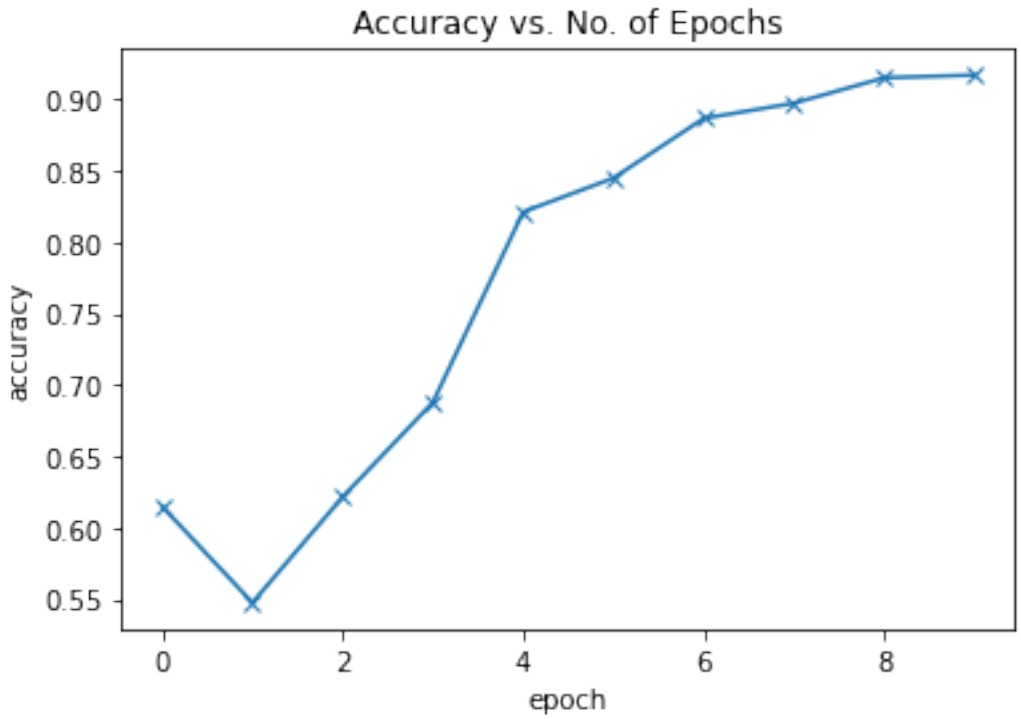
```
----------
Epoch: 4, last_lr: 0.008117456539497631, train_loss: 0.4544855058193207,
val_loss: 0.5621666312217712, val_acc: 0.8212717771530151
Best Acc: 0.8212717771530151 in Epoch no. 4
Epoch 5/9
----------
Epoch: 5, last_lr: 0.0061126202193628925, train_loss: 0.34964555501937866,
val_loss: 0.46824899315834045, val_acc: 0.8449621200561523
Best Acc: 0.8449621200561523 in Epoch no. 5
Epoch 6/9
----------
Epoch: 6, last_lr: 0.003887419780637108, train_loss: 0.28146857023239136,
val_loss: 0.3418613076210022, val_acc: 0.8867474794387817
Best Acc: 0.8867474794387817 in Epoch no. 6
Epoch 7/9
----------
Epoch: 7, last_lr: 0.00188258346050237, train_loss: 0.20665232837200165,
val_loss: 0.3106996715068817, val_acc: 0.897426426410675
Best Acc: 0.897426426410675 in Epoch no. 7
Epoch 8/9
----------
Epoch: 8, last_lr: 0.0004951936798652628, train_loss: 0.15422232449054718,
val_loss: 0.2627998888492584, val_acc: 0.9152171015739441
Best Acc: 0.9152171015739441 in Epoch no. 8
Epoch 9/9
----------
Epoch: 9, last_lr: 4e-08, train_loss: 0.12455056607723236, val_loss:
0.2577187716960907, val_acc: 0.9171243906021118
Best Acc: 0.9171243906021118 in Epoch no. 9
```

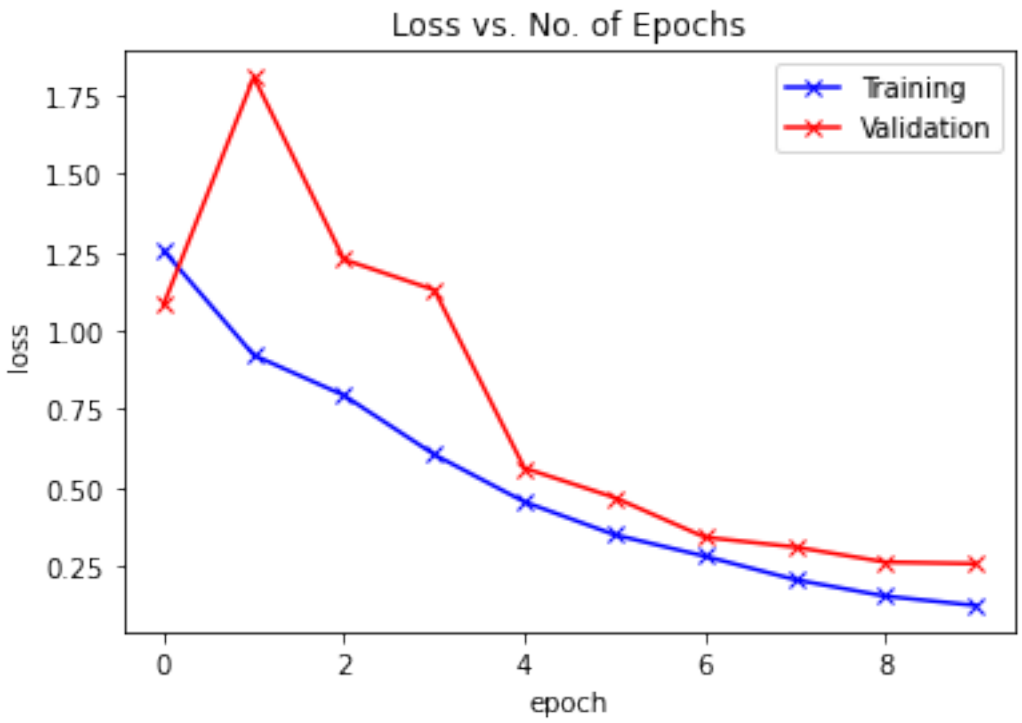

Accuracy vs. No. of Epochs
accuracy
0.100825
0.100800
0.100775
0.100750
0.100725
0.100700
0.100675
0.100650
0
2
4
6
8
epoch


Loss vs. No. of Epochs
loss
2.323
2.322
2.321
2.320
2.319
Training
Validation
0
2
4
6
8
epoch

```
[ ]: array([[938,   3,  15,   7,   1,   1,   1,   3,  21,  10],
            [  6, 977,   0,   1,   0,   0,   0,   0,   3,  13],
            [ 25,   0, 877,  23,  23,  21,  21,   6,   2,   2],
            [  8,   2,  19, 800,  19,  93,  27,  14,   6,  12],
            [  6,   1,  17,  20, 919,  16,   9,  10,   2,   0],
            [  4,   0,  11,  66,  19, 879,   6,  13,   0,   2],
            [  4,   0,  16,  19,   6,   3, 946,   4,   1,   1],
            [  4,   0,   7,  16,  13,  17,   3, 938,   0,   2],
            [ 35,   8,   2,   1,   0,   0,   2,   1, 943,   8],
            [  6,  28,   1,   1,   0,   1,   0,   1,  10, 952]])
```

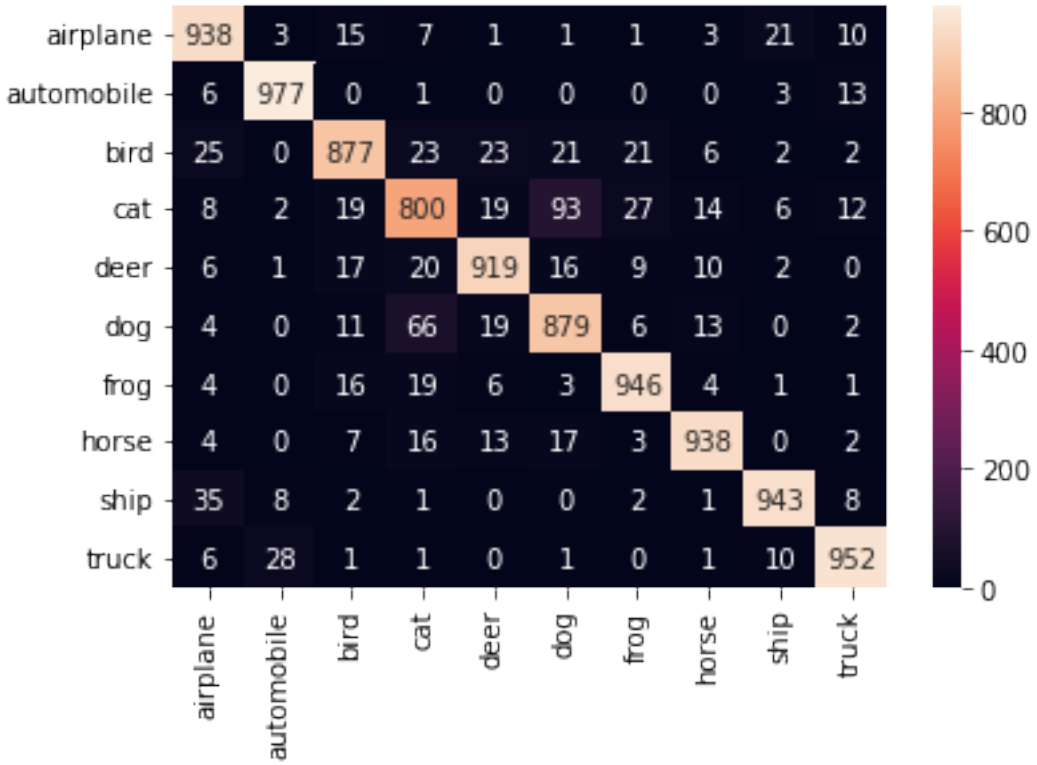
```
[ ]: plot_accuracies(history, 'resNet_best')
     plot_losses(history, 'resNest_best')
```





[ ]:
```
sns.heatmap(confusion_matrix(y, y_pred, labels=val_ds.classes), annot=True,␣
↪xticklabels=val_ds.classes, yticklabels=val_ds.classes, fmt='g')
```

[ ]:
```
<matplotlib.axes._subplots.AxesSubplot at 0x7ff720d144d0>
```



5 Transfer Learning

5.1 Fixed Feature Extractor

5.1.1 tf training function

[ ]:
```
dataloaders = {
    'train': train_dl_ft,
    'val': val_dl_ft
}
```

[ ]:
```
def train_model(model, criterion, optimizer, scheduler, num_epochs=25):
    since = time.time()

    best_model_wts = copy.deepcopy(model.state_dict())
    best_acc = 0.0

    accs = []
    loss = []

    for epoch in range(num_epochs):
        print('Epoch {}/{}'.format(epoch, num_epochs - 1))
```

```
        print('-' * 10)

        # Each epoch has a training and validation phase
        for phase in ['train', 'val']:
            if phase == 'train':
                model.train()  # Set model to training mode
            else:
                model.eval()   # Set model to evaluate mode

            running_loss = 0.0
            running_corrects = 0

            # Iterate over data.
            for inputs, labels in dataloaders[phase]:

                # zero the parameter gradients
                optimizer.zero_grad()

                # forward
                # track history if only in train
                with torch.set_grad_enabled(phase == 'train'):
                    outputs = model(inputs)
                    _, preds = torch.max(outputs, 1)
                    loss = criterion(outputs, labels)

                    # backward + optimize only if in training phase
                    if phase == 'train':
                        loss.backward()
                        optimizer.step()

                # statistics
                running_loss += loss.item() * inputs.size(0)
                running_corrects += torch.sum(preds == labels.data)
            if phase == 'train':
                scheduler.step()

            epoch_loss = running_loss / dataset_sizes[phase]
            epoch_acc = running_corrects.double() / dataset_sizes[phase]

            accs.append(epoch_acc)
            accs.append(epoch_loss)

            print('{} Loss: {:.4f} Acc: {:.4f}'.format(
                phase, epoch_loss, epoch_acc))

            # deep copy the model
            if phase == 'val' and epoch_acc > best_acc:
```

```
                best_acc = epoch_acc
                best_model_wts = copy.deepcopy(model.state_dict())

            print()

        time_elapsed = time.time() - since
        print('Training complete in {:.0f}m {:.0f}s'.format(
            time_elapsed // 60, time_elapsed % 60))
        print('Best val Acc: {:4f}'.format(best_acc))

        # load best model weights
        model.load_state_dict(best_model_wts)
        return accs, loss
```

[ ]:

[ ]:
```
<bound method Module.cuda of ResNet9(
  (conv1): Sequential(
    (0): Conv2d(3, 64, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
    (1): BatchNorm2d(64, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (2): ReLU(inplace=True)
  )
  (conv2): Sequential(
    (0): Conv2d(64, 128, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
    (1): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (2): ReLU(inplace=True)
    (3): MaxPool2d(kernel_size=2, stride=2, padding=0, dilation=1,
ceil_mode=False)
  )
  (res1): Sequential(
    (0): Sequential(
      (0): Conv2d(128, 128, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
      (1): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
      (2): ReLU(inplace=True)
    )
    (1): Sequential(
      (0): Conv2d(128, 128, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
      (1): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
      (2): ReLU(inplace=True)
    )
  )
  (conv3): Sequential(
    (0): Conv2d(128, 256, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
```

```
    (1): BatchNorm2d(256, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (2): ReLU(inplace=True)
    (3): MaxPool2d(kernel_size=2, stride=2, padding=0, dilation=1,
ceil_mode=False)
  )
  (conv4): Sequential(
    (0): Conv2d(256, 512, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
    (1): BatchNorm2d(512, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (2): ReLU(inplace=True)
    (3): MaxPool2d(kernel_size=2, stride=2, padding=0, dilation=1,
ceil_mode=False)
  )
  (res2): Sequential(
    (0): Sequential(
      (0): Conv2d(512, 512, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
      (1): BatchNorm2d(512, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
      (2): ReLU(inplace=True)
    )
    (1): Sequential(
      (0): Conv2d(512, 512, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
      (1): BatchNorm2d(512, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
      (2): ReLU(inplace=True)
    )
  )
  (classifier): Linear(in_features=512, out_features=10, bias=True)
)>
```

[ ]:
```
for param in resNet9.parameters():
    param.requires_grad = False

resNet9.classifier = nn.Linear(512, 10)

criterion = nn.CrossEntropyLoss().
optimizer_conv = optim.SGD(resNet9.classifier.parameters(), lr=0.001,␣
 ↪momentum=0.9)
exp_lr_scheduler = lr_scheduler.StepLR(optimizer_conv, step_size=7, gamma=0.1)


accs, loss = train_model(resNet9, criterion, optimizer_conv,
                         exp_lr_scheduler, num_epochs=20)
```

```
Epoch 0/19
----------
```

```
      ␣
↪---------------------------------------------------------------------------

      RuntimeError                              Traceback (most recent call␣
↪last)

      <ipython-input-107-2d5a6a597405> in <module>()
       15
       16 accs, loss = train_model(resNet9, criterion, optimizer_conv,
   ---> 17                         exp_lr_scheduler, num_epochs=20)


      <ipython-input-106-88adc23a8554> in train_model(model, criterion,␣
↪optimizer, scheduler, num_epochs)
       31                 # track history if only in train
       32                 with torch.set_grad_enabled(phase == 'train'):
   ---> 33                     outputs = model(inputs)
       34                     _, preds = torch.max(outputs, 1)
       35                     loss = criterion(outputs, labels)


      /usr/local/lib/python3.7/dist-packages/torch/nn/modules/module.py in␣
↪_call_impl(self, *input, **kwargs)
     1100         if not (self._backward_hooks or self._forward_hooks or self.
↪_forward_pre_hooks or _global_backward_hooks
     1101                 or _global_forward_hooks or␣
↪_global_forward_pre_hooks):
   -> 1102             return forward_call(*input, **kwargs)
     1103         # Do not call functions when jit is used
     1104         full_backward_hooks, non_full_backward_hooks = [], []


      <ipython-input-14-8e2b8e2ee3f0> in forward(self, X)
       34     out = self.conv4(out)
       35     out = self.res2(out) + out
   ---> 36     out = self.classifier(out)
       37
       38     return out


      /usr/local/lib/python3.7/dist-packages/torch/nn/modules/module.py in␣
↪_call_impl(self, *input, **kwargs)
     1100         if not (self._backward_hooks or self._forward_hooks or self.
↪_forward_pre_hooks or _global_backward_hooks
     1101                 or _global_forward_hooks or␣
↪_global_forward_pre_hooks):
```

```
   -> 1102             return forward_call(*input, **kwargs)
      1103         # Do not call functions when jit is used
      1104         full_backward_hooks, non_full_backward_hooks = [], []


      /usr/local/lib/python3.7/dist-packages/torch/nn/modules/linear.py in␣
↪forward(self, input)
       101
       102     def forward(self, input: Tensor) -> Tensor:
   --> 103         return F.linear(input, self.weight, self.bias)
       104
       105     def extra_repr(self) -> str:


      /usr/local/lib/python3.7/dist-packages/torch/nn/functional.py in␣
↪linear(input, weight, bias)
      1846     if has_torch_function_variadic(input, weight, bias):
      1847         return handle_torch_function(linear, (input, weight, bias),␣
↪input, weight, bias=bias)
   -> 1848     return torch._C._nn.linear(input, weight, bias)
      1849
      1850


      RuntimeError: Expected all tensors to be on the same device, but found␣
↪at least two devices, cuda:0 and cpu! (when checking argument for argument␣
↪mat2 in method wrapper_mm)
```