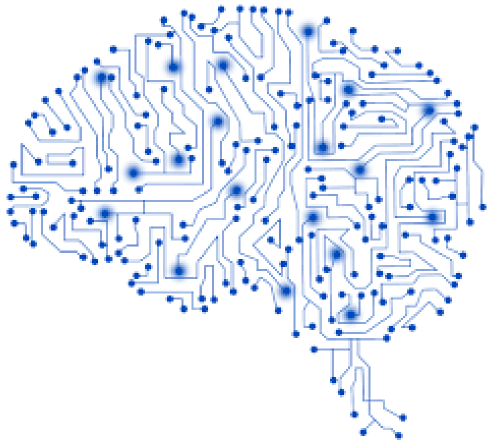
University of Minho
School of Engineering



Aprendizagem Profunda

Deep Neural Network – CNN Multiclass

APP @ MEI/4º ano – 2º Semestre
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Part III

Hands On

CNN for multiclass image classification

MNIST (Modified National Institute of Standards and Technology) Dataset

It is considered the "hello world" dataset of *computer vision*.

- Dataset of manually written digit images
- Inputs: 28x28 pixels images
- Output: class representing the digit (10 classes, digits 0-9)
- 70k images of which 60k are for training and 10k for testing
- 2 attributes: the image id and its label

We will use a convolutional neural network to classify the digit in each 28x28 image.

0. Prepare the setup

Install pytorch (if needed)

Imports

Constants

Device management (optional)

0. Prepare the setup

```
device = torch.device("cuda" if
torch.cuda.is_available() else "cpu")


def get_default_device():
    if torch.cuda.is_available():
        return torch.device('cuda')
    else:
        return torch.device('cpu')

def to_device(data, device):
    if isinstance(data, (list,tuple)):
        return [to_device(x, device) for x in data]
    return data.to(device, non_blocking=True)
```

```
class DeviceDataLoader():
    def __init__(self, dl, device):
        self.dl = dl
        self.device = device

    def __iter__(self):
        for b in self.dl:
            yield to_device(b, self.device)

    def __len__(self):
        return len(self.dl)

device = get_default_device()
print(device)
```

1. Prepare the data

```
train_transform = Compose(
        [ToTensor(),
         Normalize(mean=(0.1307,), std=(0.3081,))
        ])
test_transform = Compose(
        [ToTensor(),
         Normalize(mean=(0.1307,), std=(0.3081,))
        ])
```

1. Prepare the data

```
class CSVDataset(Dataset):

    def __init__(self, path, transform=None):
        self.transform = transform
        df_set = pd.read_csv(path, header=0)
        self.x = df_set.values[:, 1:]
        self.y = df_set.values[:, 0]
        self.x = self.x.astype('float32')
        self.y = self.y.astype('long')

    def __len__(self):
        return len(self.x)
```

```
def __getitem__(self, idx):
    label = self.y[idx]
    image = self.x[idx]
    if self.transform is not None:
        image = self.transform(image)
    return image, label

def get_TensorDataset(self):
    x = self.x.reshape(len(self.x), 1, 28, 28)
    xmax, xmin = x.max(), x.min()
    x = (x - xmin)/(xmax - xmin)
    x  = torch.from_numpy(np.array(x)).float()
    y  = torch.from_numpy(np.array(self.y)).type(
            torch.LongTensor)
    cases = torch.utils.data.TensorDataset(x,y)
    return cases
```

1. Prepare the data

```
def prepare_data_loaders(path_train, path_test):
    dataset_train = CSVDataset(path_train,transform=train_transform)
    dataset_test = CSVDataset(path_test,transform=test_transform)
    train = dataset_train.get_TensorDataset()
    train_size = int(0.8 * len(train))
    val_size = len(train) - train_size
    train, validation = random_split(train, [train_size, val_size], generator=torch.Generator().manual_seed(42))
    test = dataset_test.get_TensorDataset()
    train_dl = DataLoader(train, batch_size=BATCH_SIZE, shuffle=True)
    val_dl = DataLoader(validation, batch_size=BATCH_SIZE, shuffle=True)
    test_dl = DataLoader(test, batch_size=BATCH_SIZE, shuffle=True)
    train_dl_all = DataLoader(train, batch_size=len(train), shuffle=False)
    val_dl_all = DataLoader(validation, batch_size=len(validation), shuffle=True)
    test_dl_all = DataLoader(test, batch_size=len(test), shuffle=False)
    return train_dl, val_dl, test_dl, train_dl_all, val_dl_all, test_dl_all

train_dl, val_dl, test_dl, train_dl_all, val_dl_all, test_dl_all = prepare_data_loaders(PATH_TRAIN, PATH_TEST)
```

1.1 Visualize the data

```
def output_label(label,mapping='label'):
    if mapping == 'ext':
        output_mapping = { 0:"zero", 1:"um", 2:"dois", 3:"tres", 4:"quatro", 5:"cinco", 6:"seis", 
7:"sete",
                           8:"oito", 9:"nove" }
    elif mapping == 'ext2':
        output_mapping = { "0":"zero", "1":"um", "2":"dois", "3":"tres", "4":"quatro", "5":"cinco",
                           "6":"seis", "7":"sete", "8":"oito", "9":"nove" }
    else:
        output_mapping = { 0: "0", 1: "1", 2: "2", 3: "3", 4: "4", 5: "5", 6: "6", 7: "7", 8: "8", 9: "9"}
    input = (label.item() if type(label) == torch.Tensor else label)
    return output_mapping[input]
```

1.1 Visualize the data

```
from IPython.display import display
def visualize_data(path):
    df = pd.read_csv(path, header=0)
    display(df)
```

```
def visualize_dataset(train_dl, test_dl):
    print(f"Quantidade de casos de Treino:{len(train_dl.dataset)}")
    print(f"Quantidade de casos de Validação:{len(val_dl.dataset)}")
    print(f"Quantidade de casos de Teste:{len(test_dl.dataset)}")
    x, y = next(iter(train_dl))
    print(f"Shape tensor batch casos treino, input: {x.shape}, output: {y.shape}")
    x, y = next(iter(val_dl))
    print(f"Shape tensor batch casos validação, input: {x.shape}, output: 
{y.shape}")
    x, y = next(iter(test_dl))
    print(f"Shape tensor batch casos test, input: {x.shape}, output: {y.shape}")
    print(f'Valor máximo:{torch.max(x)} Valor mínimo:{torch.min(x)}')
    x=x.detach().numpy()
    print(f'Valor máximo:{np.max(x)} Valor mínimo:{np.min(x)}')
    print(y)

visualize_data(PATH_TRAIN)
```

1.1 Visualize the data

	label	1x1	1x2	1x3	1x4	1x5	1x6	1x7	1x8	1x9	...	28x19	28x20	28x21	28x22	28x23	28x24	28x25	28x26	28x27	28x28
0	5	0	0	0	0	0	0	0	0	0	...	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	...	0	0	0	0	0	0	0	0	0	0
2	4	0	0	0	0	0	0	0	0	0	...	0	0	0	0	0	0	0	0	0	0
3	1	0	0	0	0	0	0	0	0	0	...	0	0	0	0	0	0	0	0	0	0
4	9	0	0	0	0	0	0	0	0	0	...	0	0	0	0	0	0	0	0	0	0
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
59995	8	0	0	0	0	0	0	0	0	0	...	0	0	0	0	0	0	0	0	0	0
59996	3	0	0	0	0	0	0	0	0	0	...	0	0	0	0	0	0	0	0	0	0
59997	5	0	0	0	0	0	0	0	0	0	...	0	0	0	0	0	0	0	0	0	0
59998	6	0	0	0	0	0	0	0	0	0	...	0	0	0	0	0	0	0	0	0	0
59999	8	0	0	0	0	0	0	0	0	0	...	0	0	0	0	0	0	0	0	0	0

60000 rows × 785 columns

```
Quantidade de casos de Treino:48000
Quantidade de casos de Validação:12000
Quantidade de casos de Teste:10000
Shape tensor batch casos treino, input: torch.Size([32, 1, 28, 28]), output: torch.Size([32])
Shape tensor batch casos validação, input: torch.Size([32, 1, 28, 28]), output: torch.Size([32])
Shape tensor batch casos test, input: torch.Size([32, 1, 28, 28]), output: torch.Size([32])
Valor máximo:1.0 Valor mínimo:0.0
Valor máximo:1.0 Valor mínimo:0.0
tensor([7, 1, 7, 4, 3, 4, 2, 8, 7, 4, 2, 5, 8, 3, 2, 5, 1, 1, 5, 4, 3, 2, 1, 2,
        3, 9, 5, 6, 7, 7, 3, 9])
```

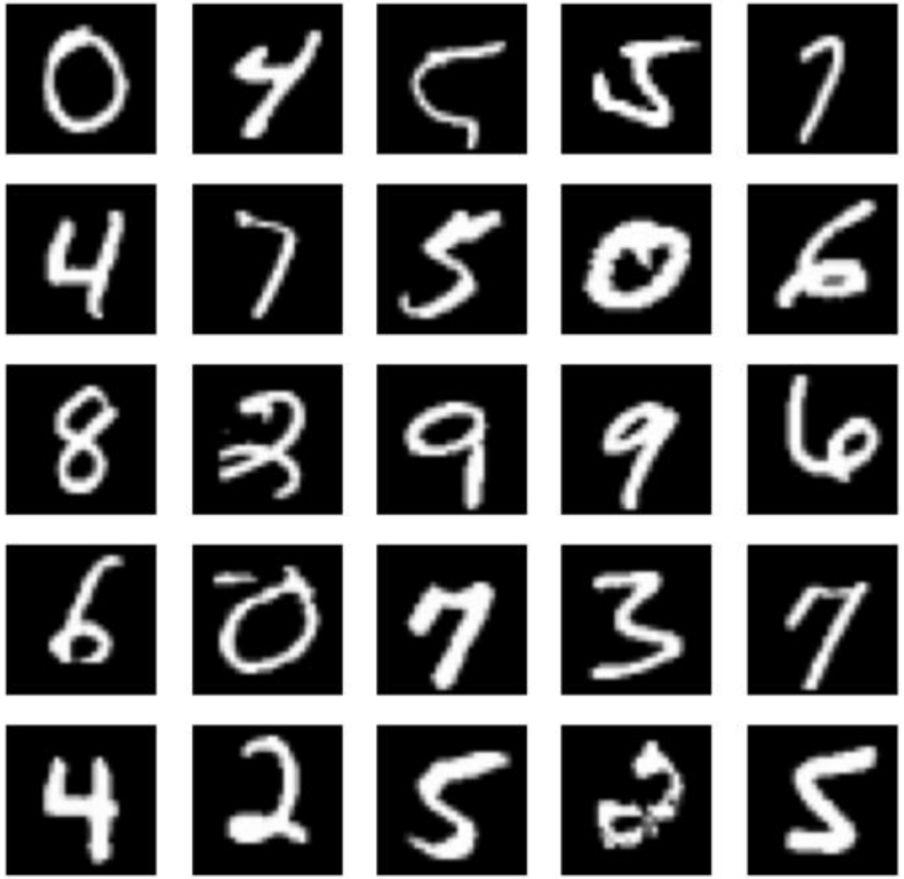
1.1 Visualize the data

```
def visualize_mnist_images(dl):
    i, (inputs, targets) = next(enumerate(dl))
    print(inputs.shape)
    plt.figure(figsize=(8,8))
    for i in range(25):
        plt.subplot(5, 5, i+1)
        plt.axis('off')
        plt.grid(b=None)
        plt.imshow(inputs[i][0], cmap='gray')
    plt.show()

visualize_mnist_images(train_dl)
```

1.1 Visualize the data

```
def visualize_mnist_images(dl):
    i, (inputs, targets) = next(enumerate(dl))
    print(inputs.shape)
    plt.figure(figsize=(8,8))
    for i in range(25):
        plt.subplot(5, 5, i+1)
        plt.axis('off')
        plt.grid(b=None)
        plt.imshow(inputs[i][0], cmap='gray')
    plt.show()

visualize_mnist_images(train_dl)
```

```
torch.Size([32, 1, 28, 28])
```



1.2 Verify dataset balancing

2. Define the model (1)

Sequential Layer 1(Conv, ReLU, MaxPool)
Sequential Layer 2(Conv, ReLU, MaxPool)
Linear
ReLU
Linear
Softmax

```
class CNNModel_1(Module):
    def __init__(self):
        super(CNNModel_1, self).__init__()
        self.layer1 = Sequential(Conv2d(in_channels=1, out_channels=32, kernel_size=(3,3)),
                                 ReLU(),
                                 MaxPool2d(kernel_size=(2,2), stride=(2,2))
                                )
        self.layer2 = Sequential(Conv2d(in_channels=32, out_channels=32, kernel_size=(3,3)),
                                 ReLU(),
                                 MaxPool2d(kernel_size=(2,2), stride=(2,2))
                                )
        self.fc1 = Linear(in_features=5*5*32, out_features=100)
        kaiming_uniform_(self.fc1.weight, nonlinearity='relu')
        self.act1 = ReLU()
        self.fc2 = Linear(in_features=100, out_features=10)
        xavier_uniform_(self.fc2.weight)
        self.act2 = Softmax(dim=1)
```

2. Define the model (1)

Sequential Layer 1(Conv, ReLU, MaxPool)
Sequential Layer 2(Conv, ReLU, MaxPool)
Linear
ReLU
Linear
Softmax

```
    def forward(self, x):
        out = self.layer1(x)
        out = self.layer2(out)
        out = out.view(-1, 4*4*50)
        out = self.fc1(out)
        out = self.act1(out)
        out = self.fc2(out)
        out = self.act2(out)
        return out

model = CNNModel_1()
print(summary(model, input_size=(BATCH_SIZE, 1,28,28), verbose=0))
model.to(device)
```

2. Define the model (1)

Sequential Layer 1(Conv, ReLU, MaxPool)
Sequential Layer 2(Conv, ReLU, MaxPool)
Linear
ReLU
Linear
Softmax

```
==========================================================================================
Layer (type:depth-idx)                   Output Shape              Param #
==========================================================================================
├─Sequential: 1-1                        [32, 32, 13, 13]          --
│    └─Conv2d: 2-1                       [32, 32, 26, 26]          320
│    └─ReLU: 2-2                         [32, 32, 26, 26]          --
│    └─MaxPool2d: 2-3                    [32, 32, 13, 13]          --
├─Sequential: 1-2                        [32, 32, 5, 5]            --
│    └─Conv2d: 2-4                       [32, 32, 11, 11]          9,248
│    └─ReLU: 2-5                         [32, 32, 11, 11]          --
│    └─MaxPool2d: 2-6                    [32, 32, 5, 5]            --
├─Linear: 1-3                            [32, 100]                 80,100
├─ReLU: 1-4                              [32, 100]                 --
├─Linear: 1-5                            [32, 10]                  1,010
├─Softmax: 1-6                           [32, 10]                  --
==========================================================================================
Total params: 90,678
Trainable params: 90,678
Non-trainable params: 0
Total mult-adds (M): 54.24
==========================================================================================
Input size (MB): 0.10
Forward/backward pass size (MB): 6.56
Params size (MB): 0.36
Estimated Total Size (MB): 7.02
==========================================================================================
```

3. Train the model


```
def train_model(h5_file, train_dl, val_dl, model, criterion, optimizer):
    liveloss = PlotLosses()
    for epoch in range(EPOCHS):
        logs = {}
        model.train()
        running_loss  = 0.0
        running_corrects  = 0.0
        for inputs, labels in train_dl:
            inputs = inputs.to(device)
            labels = labels.to(device)
            outputs = model(inputs)
            loss = criterion(outputs, labels)
            optimizer.zero_grad()
            loss.backward()
            optimizer.step()
            running_loss += loss.detach() * inputs.size(0)
            _, preds = torch.max(outputs, 1)
            running_corrects += torch.sum(preds == labels.data)
        (...)
```

```
        (...)
        epoch_loss = running_loss / len(train_dl.dataset)
        epoch_acc = running_corrects.float()/len(train_dl.dataset)
        logs['loss'] = epoch_loss.item()
        logs['accuracy'] = epoch_acc.item()

        model.eval()
        running_loss  = 0.0
        running_corrects  = 0.0
        for inputs, labels in val_dl:
            inputs = inputs.to(device)
            labels = labels.to(device)
            outputs = model(inputs)
            loss = criterion(outputs, labels)
            running_loss += loss.detach() * inputs.size(0)
            _, preds = torch.max(outputs, 1)
            running_corrects += torch.sum(preds == labels.data)
        epoch_loss = running_loss / len(val_dl.dataset)
        epoch_acc = running_corrects.float() / len(val_dl.dataset)
        logs['val_loss'] = epoch_loss.item()
        logs['val_accuracy'] = epoch_acc.item()
        liveloss.update(logs)
        liveloss.send()
    torch.save(model,h5_file)
```

Sequential Layer 1(Conv, ReLU, MaxPool)
Sequential Layer 2(Conv, ReLU, MaxPool)
Linear
ReLU
Linear
Softmax

3. Train the model (1)

For model 1:

```
model = CNNModel_1()
print(summary(model, input_size=(BATCH_SIZE, 1,28,28), verbose=0))
model.to(device)

EPOCHS = 15
LEARNING_RATE = 0.001
criterion = CrossEntropyLoss()
optimizer = SGD(model.parameters(), lr=LEARNING_RATE)
starttime = time.perf_counter()
train_model('CNNModel_1.pth', train_dl, val_dl, model, criterion, optimizer)
endtime = time.perf_counter()
print(f"Tempo gasto: {endtime - starttime} segundos")
```

Sequential Layer 1(Conv, ReLU, MaxPool)
Sequential Layer 2(Conv, ReLU, MaxPool)
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Linear
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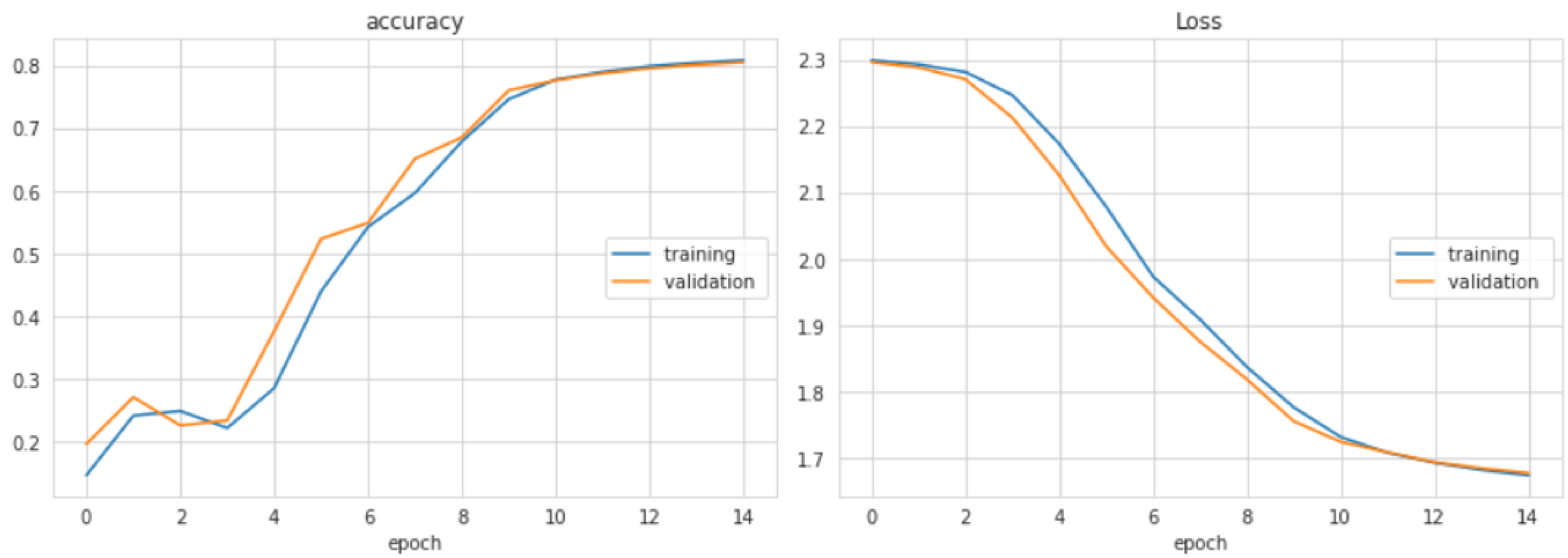
3. Train the model (1)


```
==========================================================================================
Layer (type:depth-idx)                   Output Shape              Param #
==========================================================================================
├─Sequential: 1-1                        [32, 32, 13, 13]          --
│    └─Conv2d: 2-1                       [32, 32, 26, 26]          320
│    └─ReLU: 2-2                         [32, 32, 26, 26]          --
│    └─MaxPool2d: 2-3                    [32, 32, 13, 13]          --
├─Sequential: 1-2                        [32, 32, 5, 5]            --
│    └─Conv2d: 2-4                       [32, 32, 11, 11]          9,248
│    └─ReLU: 2-5                         [32, 32, 11, 11]          --
│    └─MaxPool2d: 2-6                    [32, 32, 5, 5]            --
├─Linear: 1-3                            [32, 100]                 80,100
├─ReLU: 1-4                              [32, 100]                 --
├─Linear: 1-5                            [32, 10]                  1,010
├─Softmax: 1-6                           [32, 10]                  --
==========================================================================================
Total params: 90,678
Trainable params: 90,678
Non-trainable params: 0
Total mult-adds (M): 54.24
==========================================================================================
Input size (MB): 0.10
Forward/backward pass size (MB): 6.56
Params size (MB): 0.36
Estimated Total Size (MB): 7.02
==========================================================================================
```

3. Train the model (1)

Sequential Layer 1(Conv, ReLU, MaxPool)
Sequential Layer 2(Conv, ReLU, MaxPool)
Linear
ReLU
Linear
Softmax




```
accuracy
        training                 (min:    0.147, max:    0.808, cur:    0.808)
        validation               (min:    0.197, max:    0.804, cur:    0.804)
Loss
        training                 (min:    1.674, max:    2.299, cur:    1.674)
        validation               (min:    1.678, max:    2.296, cur:    1.678)
Tempo gasto: 2236.4488256331533 segundos
```

4. Evaluate the model


```
def evaluate_model(test_dl, model):
    predictions = list()
    actual_values = list()
    for inputs, labels in test_dl:
        inputs = inputs.to(device)
        labels = labels.to(device)
        yprev = model(inputs)
        yprev = yprev.detach().cpu().numpy()
        actual = labels.cpu().numpy()
        yprev = np.argmax(yprev, axis=1)
        actual = actual.reshape((len(actual), 1))
        yprev = yprev.reshape((len(yprev), 1))
        predictions.append(yprev)
        actual_values.append(actual)
        break
    predictions, actual_values = np.vstack(predictions), np.vstack(actual_values)
    return actual_values, predictions
```

4. Evaluate the model


```
def display_predictions(actual_values, predictions):
    acertou=0
    falhou = 0
    primeiros=0
    for r,p in zip(actual_values, predictions):
        if primeiros <20:
            print(f'real:{r} previsão:{p}')
            primeiros +=1
        if r==p: acertou+=1
        else: falhou+=1
    corrects = np.sum(predictions == actual_values)
    acc = corrects/len(test_dl.dataset)
    (...)
```

```
    (...)
    acc = accuracy_score(actual_values, 
predictions)
    print(f'Accuracy: {acc:0.3f}\n')
    print(f'acertou:{acertou} falhou:{falhou}')
    acc = accuracy_score(actual_values, 
predictions)
    print(f'Accuracy: {acc:0.3f}\n')
    print(f'acertou:{acertou} falhou:{falhou}')
```

4. Evaluate the model


```
def display_confusion_matrix(cm,list_classes):
    plt.figure(figsize = (16,8))
    sns.heatmap(cm,annot=True,xticklabels=list_classes,yticklabels=list_classes, annot_kws={"size": 12},
                      fmt='g', linewidths=.5)
    plt.ylabel('True label')
    plt.xlabel('Predicted label')
    plt.show()

model= torch.load('CNNModel_1.pth')
actual_values, predictions = evaluate_model(test_dl_all, model)
display_predictions(actual_values, predictions )
print(classification_report(actual_values, predictions))
cr =classification_report(actual_values, predictions, output_dict=True)
list_classes=[output_label(n,'ext2') for n in list(cr.keys())[0:10] ]
cm = confusion_matrix(actual_values, predictions)
print (cm)
display_confusion_matrix(cm,list_classes)
```

4. Evaluate the model


```
real:[7] previsão:[7]
real:[2] previsão:[2]
real:[1] previsão:[1]
real:[0] previsão:[0]
real:[4] previsão:[4]
real:[1] previsão:[1]
real:[4] previsão:[4]
real:[9] previsão:[9]
real:[5] previsão:[5]
real:[9] previsão:[9]
real:[0] previsão:[0]
real:[6] previsão:[6]
real:[9] previsão:[9]
real:[0] previsão:[0]
real:[1] previsão:[1]
real:[5] previsão:[5]
real:[9] previsão:[9]
real:[7] previsão:[7]
real:[3] previsão:[3]
real:[4] previsão:[4]
Accuracy: 0.975

acertou:9752 falhou:248
Accuracy: 0.975

acertou:9752 falhou:248
```

```
              precision    recall  f1-score   support

           0       0.97      0.99      0.98       980
           1       0.98      0.99      0.99      1135
           2       0.97      0.96      0.97      1032
           3       0.98      0.98      0.98      1010
           4       0.98      0.98      0.98       982
           5       0.98      0.98      0.98       892
           6       0.99      0.97      0.98       958
           7       0.97      0.96      0.96      1028
           8       0.97      0.97      0.97       974
           9       0.97      0.96      0.97      1009

    accuracy                           0.98     10000
   macro avg       0.98      0.98      0.98     10000
weighted avg       0.98      0.98      0.98     10000

[[ 969    0    2    0    0    0    3    2    4    0]
 [    0 1128    1    2    1    1    1    0    1    0]
 [    6    5  993    3    5    0    2    9    8    1]
 [    0    0    2  993    0    5    0    6    2    2]
 [    1    0    1    0  965    0    4    1    3    7]
 [    3    1    0    4    0  876    3    1    4    0]
 [    8    3    1    1    3    7  933    0    2    0]
 [    1    5   16    7    0    0    0  982    2   15]
 [    6    0    2    5    4    1    1    7  944    4]
 [    8    5    1    1    8    4    0    9    4  969]]
```

Sequential Layer 1(Conv, ReLU, MaxPool)
Sequential Layer 2(Conv, ReLU, MaxPool)
Linear
ReLU
Linear
Softmax

5. Use the model (1)

```
def make_prediction(model, img):
    img = img.reshape(1, 1, 28, 28)
    print(img.shape)
    print(img.dtype)
    img = img.to(device) #valves
    prediction = model(img).cpu().detach().numpy()[0].argmax()
    print("predict:",prediction)
    img=img.cpu()
    plt.axis('off')
    plt.grid(b=None)
    plt.imshow(img[0,0], cmap=plt.get_cmap('gray'))
    plt.show()

model= torch.load('CNNModel_1.pth')
imagens, label = next(iter(test_dl))
make_prediction(model,imagens[3])
```

Sequential Layer 1(Conv, ReLU, MaxPool)
Sequential Layer 2(Conv, ReLU, MaxPool)
Linear
ReLU
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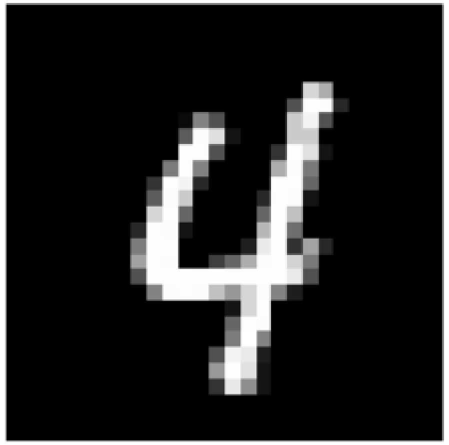
Softmax

5. Use the model (1)

```
def make_prediction(model, img):
    img = img.reshape(1, 1, 28, 28)
    print(img.shape)
    print(img.dtype)
    img = img.to(device) #valves
    prediction = model(img).cpu().detach().numpy()[0].argmax()
    print("predict:",prediction)
    img=img.cpu()
    plt.axis('off')
    plt.grid(b=None)
    plt.imshow(img[0,0], cmap=plt.get_cmap('gray'))
    plt.show()

model= torch.load('CNNModel_1.pth')
imagens, label = next(iter(test_dl))
make_prediction(model,imagens[3])
```

```
torch.Size([1, 1, 28, 28])
torch.float32
predict: 4
```



Exercise 4

- Apply the same process to models 2, 3 and 4, improve and present the best value, detailing the best model

Exercise 4

epochs		
batch size		
lesrning rate		
size splits	test: train:	test: train:
layers + activation functions		
loss function		
optimization function		
accuracy		

Sequential Layer 1(Conv, ReLU, MaxPool)
Sequential Layer 2(Conv, ReLU, MaxPool)
Linear

2. Define the model (2)

```
class CNNModel_2(Module):
    def __init__(self):
        super(CNNModel_2, self).__init__()
        self.layer1 = Sequential(Conv2d(in_channels=1, out_channels=16, kernel_size=3, stride=1, padding=0),
                                 ReLU(),
                                 MaxPool2d(kernel_size=2)
                                )
        self.layer2 = Sequential(Conv2d(in_channels=16, out_channels=32, kernel_size=3, stride=1, padding=0),
                                 ReLU(),
                                 MaxPool2d(kernel_size=2)
                                )
        self.fc1 = Linear(32 * 5 * 5, 10)
```

Sequential Layer 1(Conv, ReLU, MaxPool)
Sequential Layer 2(Conv, ReLU, MaxPool)
Linear

2. Define the model (2)

```
    def forward(self, x):
        out = self.layer1(x)
        out = self.layer2(out)
        out = out.view(out.size(0), -1)
        out = self.fc1(out)
        return out

model = CNNModel_2()
print(summary(model, input_size=(BATCH_SIZE, 1,28,28), verbose=0))
```

2. Define the model (3)

Sequential Layer 1(Conv, BatchNorm, ReLU, MaxPool)
Sequential Layer 2(Conv, BatchNorm, ReLU, MaxPool)
Linear
Dropout
Linear
Linear

```
class CNNModel_3(Module):
    def __init__(self):
        super(CNNModel_3, self).__init__()
        self.layer1 = nn.Sequential(Conv2d(in_channels=1, out_channels=32, kernel_size=3, padding=1),
                                    BatchNorm2d(32),
                                    ReLU(),
                                    MaxPool2d(kernel_size=2, stride=2)
                                    )
        self.layer2 = nn.Sequential(Conv2d(in_channels=32, out_channels=64, kernel_size=3),
                                    BatchNorm2d(64),
                                    ReLU(),
                                    MaxPool2d(2)
                                    )
        self.fc1 = Linear(in_features=64*6*6, out_features=600)
        self.drop = nn.Dropout2d(0.25)
        self.fc2 = Linear(in_features=600, out_features=120)
        self.fc3 = Linear(in_features=120, out_features=10)
```

2. Define the model (3)

Sequential Layer 1(Conv, BatchNorm, ReLU, MaxPool)
Sequential Layer 2(Conv, BatchNorm, ReLU, MaxPool)
Linear
Dropout
Linear
Linear

```
    def forward(self, x):
        out = self.layer1(x)
        out = self.layer2(out)
        out = out.view(out.size(0), -1)
        out = self.fc1(out)
        out = self.drop(out)
        out = self.fc2(out)
        out = self.fc3(out)
        return out

model = CNNModel_3()
print(summary(model, input_size=(BATCH_SIZE, 1,28,28), verbose=0))
```

Sequential Layer (Conv, BatchNorm, ReLU, MaxPool, Dropout)
Linear
Linear

2. Define the model (4)

```
class CNNModel_4(Module):
    def __init__(self):
        super(CNNModel_4, self).__init__()
        self.layer1 = Sequential(nn.Conv2d(in_channels=1, out_channels=32, kernel_size=5, padding=0),
                                 BatchNorm2d(32),
                                 ReLU(),
                                 MaxPool2d(2),
                                 Dropout2d(0.2)
                                 )
        self.fc1 = Linear(in_features=32*12*12, out_features=128)
        self.fc2 = Linear(in_features=128, out_features=10)
```

Sequential Layer (Conv, BatchNorm, ReLU, MaxPool, Dropout)
Linear
Linear

2. Define the model (4)

```
    def forward(self, x):
        out = self.layer1(x)
        out = out.view(out.size(0), -1)
        out = self.fc1(out)
        out = self.fc2(out)
        return out


model = CNNModel_4()
print(summary(model, input_size=(BATCH_SIZE, 1,28,28), verbose=0))
```

Exercise 5

- Apply the same models to fashion-MNIST dataset, improve and present the best value

Exercise 5

epochs		
batch size		
lesrning rate		
size splits	test: train:	test: train:
layers + activation functions		
loss function		
optimization function		
accuracy		

1.1 Visualize the data

```
def output_label(label):
    output_mapping = { 0: "T-shirt/Top", 1: "Trouser", 2: "Pullover",
                       3: "Dress",       4: "Coat",    5: "Sandal",
                       6: "Shirt",       7: "Sneaker", 8: "Bag",
                       9: "Ankle Boot" }
    output_mapping2 = { 0: "0", 1: "1", 2: "2", 3: "3", 4: "4",
                        5: "5", 6: "6", 7: "7", 8: "8", 9: "9"}
    input = (label.item() if type(label) == torch.Tensor else label)
    return output_mapping[input]
```

CNN for multiclass image classification

CIFAR-10 (Canadian Institute For Advanced Research) Dataset

- Image dataset
- Contains 60 000 colour images with 32x32 pixels classified in 10 different classes
- The classes are: planes, cars, birds, cats, deer, frogs, horses, ships and trucks
- There are 6 000 images for each class
- 5 000 images are used for training and 1 000 for testing

0. Prepare the setup

Install pytorch (if needed)

Imports

Constants

```
PATH = './cifar/'
PATH_CLASSES = './cifar/labels.txt'
PATH_TRAIN = './cifar/train'
PATH_TEST = './cifar/test'

BATCH_SIZE = 128
```

Device management (optional)

1. Prepare the data

```
def get_classes(path):
    with open("cifar/labels.txt") as fich_labels:
        labels = fich_labels.read().split()
        classes = dict(zip(labels, list(range(len(labels)))))
    return classes
dic_classes=get_classes(PATH_CLASSES)
print(dic_classes)

def preprocessar(imagem):
    imagem = np.array(imagem)
    cifar_mean = np.array([0.4914, 0.4822, 0.4465]).reshape(1,1,-1)
    cifar_std  = np.array([0.2023, 0.1994, 0.2010]).reshape(1,1,-1)
    imagem = (imagem - cifar_mean) / cifar_std
    xmax, xmin = imagem.max(), imagem.min()
    imagem = (imagem - xmin)/(xmax - xmin)
    imagem = imagem.transpose(2,1,0)
    return imagem
```

1. Prepare the data

```
def get_classes(path):
    with open("cifar/labels.txt") as fich_labels:
        labels = fich_labels.read().split()
        classes = dict(zip(labels, list(range(len(labels)))))
    return classes
dic_classes=get_classes(PATH_CLASSES)
print(dic_classes)
```

```
{'airplane': 0, 'automobile': 1, 'bird': 2, 'cat': 3, 'deer': 4, 'dog': 5, 'frog': 6, 'horse': 7, 'ship': 8, 'truck': 9}
```

```
def preprocessar(imagem):
    imagem = np.array(imagem)
    cifar_mean = np.array([0.4914, 0.4822, 0.4465]).reshape(1,1,-1)
    cifar_std  = np.array([0.2023, 0.1994, 0.2010]).reshape(1,1,-1)
    imagem = (imagem - cifar_mean) / cifar_std
    xmax, xmin = imagem.max(), imagem.min()
    imagem = (imagem - xmin)/(xmax - xmin)
    imagem = imagem.transpose(2,1,0)
    return imagem
```

1. Prepare the data

```
class Cifar10Dataset(Dataset):
    def __init__(self, path, mun_imagens = 0, transforms=None):
        files = os.listdir(path)
        files = [os.path.join(path,f) for f in files]
        if mun_imagens == 0:
            mun_imagens = len(files)
        self.mun_imagens = mun_imagens
        self.files = random.sample(files, self.mun_imagens)
        self.transforms = transforms

    def __len__(self):
        return self.mun_imagens
```

```
def __getitem__(self, idx):
    fich_imagem = self.files[idx]
    imagem = Image.open(fich_imagem)
    imagem = preprocessar(imagem)
    label_classe = fich_imagem[:-4].split("_")[-1]
    label = dic_classes[label_classe]
    imagem = imagem.astype(np.float32)
    if self.transforms:
        imagem = self.transforms(imagem)
    return imagem, label
```

1. Prepare the data

```
def prepare_data_loaders(path_train, path_test):
    dataset_train = Cifar10Dataset(path_train,transforms=None)
    dataset_test = Cifar10Dataset(path_test,transforms=None)

    train_size = int(0.8 * len(dataset_train))
    val_size = len(dataset_train) - train_size
    train, validation = random_split(dataset_train, [train_size, val_size],
                                                                generator=torch.Generator().manual_seed(42))
    train_dl = DataLoader(train, batch_size=BATCH_SIZE, shuffle=True)
    val_dl = DataLoader(validation, batch_size=BATCH_SIZE, shuffle=True)
    test_dl = DataLoader(dataset_test, batch_size=BATCH_SIZE, shuffle=True)
    train_dl_all = DataLoader(train, batch_size=len(train), shuffle=True)
    val_dl_all = DataLoader(validation, batch_size=len(validation), shuffle=True)
    test_dl_all = DataLoader(dataset_test, batch_size=len(dataset_test), shuffle=True)
    return train_dl, val_dl, test_dl, train_dl_all, val_dl_all, test_dl_all

train_dl, val_dl, test_dl, train_dl_all, val_dl_all, test_dl_all = prepare_data_loaders(PATH_TRAIN, PATH_TEST)
```

1.1 Visualize the data

```
def output_label(label,mapping='label'):
    if mapping == 'ext':
        output_mapping = { 0:"zero", 1:"um", 2:"dois", 3:"tres", 4:"quatro", 5:"cinco", 6:"seis", 
7:"sete",                          8:"oito", 9:"nove" }
    elif mapping == 'ext2':
        output_mapping = { "0":"zero", "1":"um", "2":"dois", "3":"tres", "4":"quatro", "5":"cinco", 
                          "6":"seis", "7":"sete", "8":"oito", "9":"nove" }
    else:
        output_mapping = { 0: "0", 1: "1", 2: "2", 3: "3", 4: "4", 5: "5", 6: "6", 7: "7", 8: "8", 9: "9"}
    input = (label.item() if type(label) == torch.Tensor else label)
    return output_mapping[input]
```

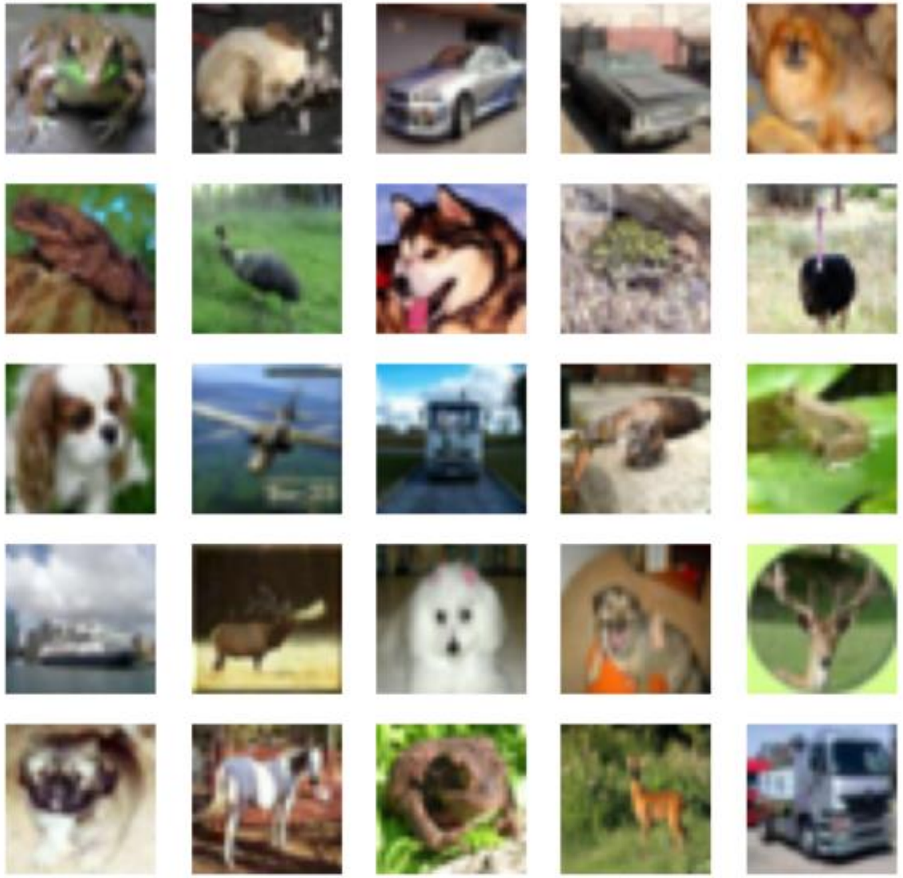
1.1 Visualize the data

```
from IPython.display import display
def visualize_data(path):
    ...

def visualize_dataset(train_dl, test_dl, dataset_train, dataset_test):
    ...

visualize_dataset(train_dl, test_dl, train_dl_all, test_dl_all)

def visualize_images(dl):
    ...

visualize_images(train_dl)
```

1.1 Visualize the data

```
Quantidade de casos de Treino:40000
Quantidade de casos de Validação:10000
Quantidade de casos de Teste:10000
Shape tensor batch casos treino, input: torch.Size([128, 3, 32, 32]), output: torch.Size([128])
Shape tensor batch casos validação, input: torch.Size([128, 3, 32, 32]), output: torch.Size([128])
Shape tensor batch casos test, input: torch.Size([128, 3, 32, 32]), output: torch.Size([128])
Valor maximo:1.0 Valor mínimo:0.0
Valor maximo:1.0 Valor mínimo:0.0
tensor([8, 8, 7, 5, 0, 3, 6, 9, 5, 7, 8, 0, 5, 5, 0, 5, 0, 2, 1, 1, 3, 7, 7, 6,
        9, 5, 3, 0, 2, 6, 5, 1, 5, 1, 8, 1, 7, 8, 9, 4, 8, 3, 6, 0, 7, 8, 1, 1,
        8, 6, 5, 0, 7, 4, 6, 6, 3, 4, 9, 6, 6, 3, 4, 5, 5, 6, 2, 1, 1, 2, 5, 2,
        7, 9, 0, 8, 7, 2, 3, 0, 8, 4, 7, 4, 5, 9, 5, 9, 3, 4, 6, 4, 4, 0, 9, 9,
        6, 0, 8, 8, 1, 0, 4, 8, 6, 7, 7, 1, 9, 2, 5, 5, 3, 7, 7, 9, 6, 0, 4, 2,
        8, 2, 6, 0, 8, 3, 4, 6])
```

```
torch.Size([128, 3, 32, 32])
```



1.2 Verify the dataset balancing

2. Define the model (residual)

Conv Layer 1
Batch Norm 1
Conv Layer 2
Batch Norm 2
Sequential

```
class ResidualBlock(nn.Module):
    def __init__(self, in_channels, out_channels, stride=1):
        super(ResidualBlock, self).__init__()
        self.conv1 = nn.Conv2d(in_channels=in_channels, out_channels=out_channels,kernel_size=(3, 3),
        stride=stride, padding=1, bias=False)
        self.bn1 = nn.BatchNorm2d(out_channels)
        self.conv2 = nn.Conv2d(in_channels=out_channels, out_channels=out_channels,kernel_size=(3, 3),
        stride=1, padding=1, bias=False)
        self.bn2 = nn.BatchNorm2d(out_channels)
        self.shortcut = nn.Sequential()
        if stride != 1 or in_channels != out_channels:
            self.shortcut = nn.Sequential(
                nn.Conv2d(in_channels=in_channels, out_channels=out_channels,kernel_size=(1, 1),
                  stride=stride, bias=False),
                nn.BatchNorm2d(out_channels)
            )
```

2. Define the model (residual)

Conv Layer 1
Batch Norm 1
Conv Layer 2
Batch Norm 2
Sequential

```
    def forward(self, x):
        out = nn.ReLU()(self.bn1(self.conv1(x)))
        out = self.bn2(self.conv2(out))
        out += self.shortcut(x)
        out = nn.ReLU()(out)
        return out

class ResNet(nn.Module):
    def __init__(self, num_classes=10):
        super(ResNet, self).__init__()
        self.conv1 = nn.Conv2d(in_channels=3, out_channels=64, kernel_size=(3, 3),stride=1, padding=1, bias=False)
        self.bn1 = nn.BatchNorm2d(64)
        self.block1 = self._create_block(64, 64, stride=1)
        self.block2 = self._create_block(64, 128, stride=2)
        self.block3 = self._create_block(128, 256, stride=2)
        self.block4 = self._create_block(256, 512, stride=2)
        self.linear = nn.Linear(512, num_classes)
```

2. Define the model (residual)

Conv Layer 1
Batch Norm 1
Conv Layer 2
Batch Norm 2
Sequential

```
def _create_block(self, in_channels, out_channels, stride):
    return nn.Sequential(
        ResidualBlock(in_channels, out_channels, stride),
        ResidualBlock(out_channels, out_channels, 1)
    )

def forward(self, x):
    out = nn.ReLU()(self.bn1(self.conv1(x)))
    out = self.block1(out)
    out = self.block2(out)
    out = self.block3(out)
    out = self.block4(out)
    out = nn.AvgPool2d(4)(out)
    out = out.view(out.size(0), -1)
    out = self.linear(out)
    return out)
```

```
model = ResNet()
print(summary(model, input_size=(BATCH_SIZE, 3,32,32), verbose=0))
```

Conv Layer 1
Batch Norm 1
Conv Layer 2
Batch Norm 2
Sequential

2. Define the model (residual)

```
==========================================================================================
Layer (type:depth-idx)                   Output Shape              Param #
==========================================================================================
├─Conv2d: 1-1                            [128, 64, 32, 32]         1,728
├─BatchNorm2d: 1-2                       [128, 64, 32, 32]         128
├─Sequential: 1-3                        [128, 64, 32, 32]         --
│    └─ResidualBlock: 2-1                [128, 64, 32, 32]         --
│    │    └─Conv2d: 3-1                  [128, 64, 32, 32]         36,864
│    │    └─BatchNorm2d: 3-2             [128, 64, 32, 32]         128
│    │    └─Conv2d: 3-3                  [128, 64, 32, 32]         36,864
│    │    └─BatchNorm2d: 3-4             [128, 64, 32, 32]         128
│    │    └─Sequential: 3-5              [128, 64, 32, 32]         --
│    └─ResidualBlock: 2-2                [128, 64, 32, 32]         --
│    │    └─Conv2d: 3-6                  [128, 64, 32, 32]         36,864
│    │    └─BatchNorm2d: 3-7             [128, 64, 32, 32]         128
│    │    └─Conv2d: 3-8                  [128, 64, 32, 32]         36,864
│    │    └─BatchNorm2d: 3-9             [128, 64, 32, 32]         128
│    │    └─Sequential: 3-10             [128, 64, 32, 32]         --
├─Sequential: 1-4                        [128, 128, 16, 16]        --
│    └─ResidualBlock: 2-3                [128, 128, 16, 16]        --
│    │    └─Conv2d: 3-11                 [128, 128, 16, 16]        73,728
│    │    └─BatchNorm2d: 3-12            [128, 128, 16, 16]        256
│    │    └─Conv2d: 3-13                 [128, 128, 16, 16]        147,456
│    │    └─BatchNorm2d: 3-14            [128, 128, 16, 16]        256
│    │    └─Sequential: 3-15             [128, 128, 16, 16]        8,448
│    └─ResidualBlock: 2-4                [128, 128, 16, 16]        --
│    │    └─Conv2d: 3-16                 [128, 128, 16, 16]        147,456
│    │    └─BatchNorm2d: 3-17            [128, 128, 16, 16]        256
│    │    └─Conv2d: 3-18                 [128, 128, 16, 16]        147,456
│    │    └─BatchNorm2d: 3-19            [128, 128, 16, 16]        256
│    │    └─Sequential: 3-20             [128, 128, 16, 16]        --
```

```
├─Sequential: 1-5                        [128, 256, 8, 8]          --
│    └─ResidualBlock: 2-5                [128, 256, 8, 8]          --
│    │    └─Conv2d: 3-21                 [128, 256, 8, 8]          294,912
│    │    └─BatchNorm2d: 3-22            [128, 256, 8, 8]          512
│    │    └─Conv2d: 3-23                 [128, 256, 8, 8]          589,824
│    │    └─BatchNorm2d: 3-24            [128, 256, 8, 8]          512
│    │    └─Sequential: 3-25             [128, 256, 8, 8]          33,280
│    └─ResidualBlock: 2-6                [128, 256, 8, 8]          --
│    │    └─Conv2d: 3-26                 [128, 256, 8, 8]          589,824
│    │    └─BatchNorm2d: 3-27            [128, 256, 8, 8]          512
│    │    └─Conv2d: 3-28                 [128, 256, 8, 8]          589,824
│    │    └─BatchNorm2d: 3-29            [128, 256, 8, 8]          512
│    │    └─Sequential: 3-30             [128, 256, 8, 8]          --
├─Sequential: 1-6                        [128, 512, 4, 4]          --
│    └─ResidualBlock: 2-7                [128, 512, 4, 4]          --
│    │    └─Conv2d: 3-31                 [128, 512, 4, 4]          1,179,648
│    │    └─BatchNorm2d: 3-32            [128, 512, 4, 4]          1,024
│    │    └─Conv2d: 3-33                 [128, 512, 4, 4]          2,359,296
│    │    └─BatchNorm2d: 3-34            [128, 512, 4, 4]          1,024
│    │    └─Sequential: 3-35             [128, 512, 4, 4]          132,096
│    └─ResidualBlock: 2-8                [128, 512, 4, 4]          --
│    │    └─Conv2d: 3-36                 [128, 512, 4, 4]          2,359,296
│    │    └─BatchNorm2d: 3-37            [128, 512, 4, 4]          1,024
│    │    └─Conv2d: 3-38                 [128, 512, 4, 4]          2,359,296
│    │    └─BatchNorm2d: 3-39            [128, 512, 4, 4]          1,024
│    │    └─Sequential: 3-40             [128, 512, 4, 4]          --
├─Linear: 1-7                            [128, 10]                 5,130
```

```
---------------------------------------------
Total params: 11,173,962
Trainable params: 11,173,962
Non-trainable params: 0
Total mult-adds (T): 1.34
=============================================
Input size (MB): 1.57
Forward/backward pass size (MB): 1258.30
Params size (MB): 44.70
Estimated Total Size (MB): 1304.57
=============================================
```

3. Train the model (residual)


```
def train_model(h5_file, train_dl, val_dl, model, criterion, optimizer):
    ...
```

For ResNet model:

```
model = ResNet()
print(summary(model, input_size=(BATCH_SIZE, 3,32,32), verbose=0))
EPOCHS = 30
LEARNING_RATE = 0.001
criterion = CrossEntropyLoss()
optimizer = SGD(model.parameters(), lr=LEARNING_RATE)
starttime = time.perf_counter()
train_model('CNNModel_cifar_Resnet.pth', train_dl, val_dl, model, criterion, optimizer)
endtime = time.perf_counter()
print(f"Tempo gasto: {endtime - starttime} segundos")
```

Conv Layer 1
Batch Norm 1
Conv Layer 2
Batch Norm 2
Sequential

4. Evaluate the model (residual)


```
def evaluate_model(test_dl, model):
    ...
def display_predictions(actual_values, predictions):
    ...
def display_confusion_matrix(cm,list_classes):
    ...
actual_values, predictions = evaluate_model(test_dl_all, model)

model= torch.load('CNNModel_cifar_Resnet.pth')
actual_values, predictions = evaluate_model(test_dl_all, model)
display_predictions(actual_values, predictions )
print(classification_report(actual_values, predictions))
cr =classification_report(actual_values, predictions, output_dict=True)
list_classes=[output_label(n,'ext2') for n in list(cr.keys())[0:10] ]
cm = confusion_matrix(actual_values, predictions)
print (cm)
display_confusion_matrix(cm,list_classes)
```

Conv Layer 1
Batch Norm 1
Conv Layer 2
Batch Norm 2
Sequential

5. Use the model (residual)

```
def make_prediction(model, img):
    ...

model= torch.load('CNNModel_cifar_Resnet.pth')
imagens, label = next(iter(test_dl))
make_prediction(model,imagens[3])
```

Exercise 6

- Apply the same process to models 1, 2, 3 and 4, improve and present the best value, detailing the best model

Exercise 6

epochs		
batch size		
lesrning rate		
size splits	test: train:	test: train:
layers + activation functions		
loss function		
optimization function		
accuracy		