OCR

January 1, 2023

[1]:
```
!pip install --quiet -r requirements.txt
```

[2]:
```
!nvidia-smi
```

```
Sun Jan  1 14:04:19 2023
+-----------------------------------------------------------------------------+
| NVIDIA-SMI 525.60.11    Driver Version: 525.60.11    CUDA Version: 12.0     |
|-------------------------------+----------------------+----------------------+
| GPU  Name        Persistence-M| Bus-Id        Disp.A | Volatile Uncorr. ECC |
| Fan  Temp  Perf  Pwr:Usage/Cap|         Memory-Usage | GPU-Util  Compute M. |
|                               |                      |               MIG M. |
|===============================+======================+======================|
|   0  NVIDIA GeForce …  Off  | 00000000:1F:00.0  On |                  N/A |
| 83%   62C    P5    29W / 170W |    958MiB / 12288MiB |     16%      Default |
|                               |                      |                  N/A |
+-------------------------------+----------------------+----------------------+

+-----------------------------------------------------------------------------+
| Processes:                                                                  |
|  GPU   GI   CI        PID   Type   Process name                  GPU Memory |
|        ID   ID                                                   Usage      |
|=============================================================================|
|    0   N/A  N/A       590      G   /usr/lib/Xorg                     403MiB |
|    0   N/A  N/A       627      G   /usr/bin/kwalletd5                  2MiB |
|    0   N/A  N/A       706      G   /usr/bin/ksmserver                  2MiB |
|    0   N/A  N/A       708      G   /usr/bin/kded5                      2MiB |
|    0   N/A  N/A       709      G   /usr/bin/kwin_x11                  83MiB |
|    0   N/A  N/A       755      G   /usr/bin/plasmashell               48MiB |
|    0   N/A  N/A       772      G   …de-authentication-agent-1        2MiB |
|    0   N/A  N/A       774      G   …ib/xdg-desktop-portal-kde       30MiB |
|    0   N/A  N/A       854      G   /usr/bin/msm_kde_notifier           2MiB |
|    0   N/A  N/A       855      G   /usr/lib/kdeconnectd                2MiB |
|    0   N/A  N/A       867      G   /usr/bin/kaccess                    2MiB |
|    0   N/A  N/A       870      G   /usr/bin/pamac-tray-plasma          2MiB |
|    0   N/A  N/A      1056      G   …720691463375437107,131072      320MiB |
|    0   N/A  N/A      1261      G   …-browser-integration-host        2MiB |
|    0   N/A  N/A      1270      G   …AAAAAAAAA= --shared-files       33MiB |
|    0   N/A  N/A      2101      G   /usr/bin/konsole                    2MiB |
|    0   N/A  N/A      3911      G   /usr/bin/dolphin                            2MiB |
|    0   N/A  N/A      6775      G   /usr/lib/kf5/kioslave5                      2MiB |
+-----------------------------------------------------------------------------+
```

[3]:

```
import os

filenames = []
for root, dirs, files in os.walk("CCPD2019-dl1"):
    for f in files:
        if f.endswith(".jpg") or f.endswith(".JPG"):
            filenames.append(os.path.join(root, f))
filenames[:5]
```

[3]:

```
['CCPD2019-dl1/test/0319- ASW872.jpg',
 'CCPD2019-dl1/test/0401- AWW227.jpg',
 'CCPD2019-dl1/test/0199- AX0L55.jpg',
 'CCPD2019-dl1/test/0245- A9U395.jpg',
 'CCPD2019-dl1/test/0389- AT219T.jpg']
```

[4]:

```
len(filenames)
```

[4]:

```
209979
```

[5]:

```
def get_label(filename: str) -> str:
    return filename.split(".")[0].split("-")[-1]

filenames[0], get_label(filenames[0])
```

[5]:

```
('CCPD2019-dl1/test/0319- ASW872.jpg', ' ASW872')
```

[6]:

```
import cv2
import matplotlib.pyplot as plt
from ipywidgets import interact, IntSlider

def plot(index: int):
    plt.imshow(cv2.cvtColor(cv2.imread(filenames[index]), cv2.COLOR_BGR2RGB));
    plt.axis("off")
    plt.show()

interact(plot, index=IntSlider(min=0, max=len(filenames) - 1, value=0));
```

```
interactive(children=(IntSlider(value=0, description='index', max=209978), Output()), _dom_clas
```

[7]:

```
labels = list(map(get_label, filenames))
all_w, all_h, ratio = [], [], []

for filename in filenames[:20000]:
    h, w, _ = cv2.imread(filename).shape
    all_w.append(w)
    all_h.append(h)
    ratio.append(w / h)
```

[8]:

```
import numpy as np

lens = list(map(len, labels))
np.mean(all_w), np.mean(all_h), np.mean(ratio), np.mean(lens)
```

[8]:

```
(254.9241, 86.28205, 2.9521506126516366, 7.0)
```

[9]:

```
from collections import Counter

print(Counter(all_w).most_common(5), Counter(all_h).most_common(5),␣
 ↪Counter(ratio).most_common(5), Counter(lens).most_common(5), sep="\n")
```

```
[(244, 151), (225, 150), (235, 148), (231, 147), (220, 146)]
[(80, 504), (78, 494), (84, 492), (82, 492), (86, 491)]
[(3.0, 366), (2.75, 59), (2.8, 53), (2.6666666666666665, 53),
(2.857142857142857, 51)]
[(7, 209979)]
```

1 Augmentations

[10]:

```
import albumentations as A

img_w, img_h = 256, 96

transforms = A.Compose([
    A.Resize(img_h, img_w, interpolation=cv2.INTER_CUBIC),
    A.Rotate(limit=10, p=0.25),
    A.RandomBrightnessContrast(brightness_limit=0.15, contrast_limit=0.15, p=0.
 ↪5)
])

val_transforms = A.Compose([
    A.Resize(img_h, img_w, interpolation=cv2.INTER_CUBIC),
])
```

[11]:

```
img = cv2.cvtColor(cv2.imread(filenames[0]), cv2.COLOR_BGR2RGB)
plt.imshow(img)
plt.axis("off");
```

[12]:
```
nrows, ncols = 3, 3
_, axs = plt.subplots(nrows, ncols, figsize=(12, 12))

for i in range(nrows):
    for j in range(ncols):
        transformed = transforms(image=img)["image"]
        axs[i][j].imshow(transformed)
        axs[i][j].axis("off")
```

2 Tokenizer

[13]:
```
import numpy as np

alphabet = np.array(sorted(list(set("".join(labels)))))
alphabet
```

[13]:
```
array(['0', '1', '2', '3', '4', '5', '6', '7', '8', '9', 'A', 'B', 'C',
       'D', 'E', 'F', 'G', 'H', 'J', 'K', 'L', 'M', 'N', 'O', 'P', 'Q',
       'R', 'S', 'T', 'U', 'V', 'W', 'X', 'Y', 'Z', ' ', ' ', ' ', ' ',
       ' ', ' ', ' ', ' ', ' ', ' ', ' ', ' ', ' ', ' ', ' ', ' ', ' ',
       ' ', ' ', ' ', ' ', ' ', ' ', ' ', ' ', ' ', ' ', ' ', ' ', ' ',
       ' '], dtype='<U1')
```

[14]:
```
alphabet.shape
```

[14]:
```
(66,)
```

[15]:
```
!python --version
```

```
Python 3.10.8
```

[16]:
```
#from __future__ import annotations

class Tokenizer:
    def __init__(self, alphabet: list[str]):
        self.word2token = {alphabet[i]: i for i in range(len(alphabet))}
        self.token2word = {v: k for k, v in self.word2token.items()}

    def encode(self, x: str) -> list[int]:
        return [self.word2token[i] for i in x]

    def __call__(self, x: str) -> list[int]:
        return self.encode(x)

    def decode(self, tokens: list[int]) -> str:
        return "".join([self.token2word[i] for i in tokens])

    def __len__(self) -> int:
        return len(self.word2token)

tokenizer = Tokenizer(alphabet)
len(tokenizer)
```

[16]:
```
66
```

[17]:
```
tokenized = tokenizer(labels[0])
labels[0], tokenized, tokenizer.decode(tokenized)
```

[17]:
```
(' ASW872', [51, 10, 27, 31, 8, 7, 2], ' ASW872')
```

3 Dataset

[18]:
```
x_train = list(filter(lambda x: "train" in x, filenames))
x_test = list(filter(lambda x: "test" in x, filenames))
x_train[0], x_test[0]
```

[18]:
```
('CCPD2019-dl1/train/0244025383142- APX882.jpg',
 'CCPD2019-dl1/test/0319- ASW872.jpg')
```

[19]:
```
len(x_train), len(x_test)
```

[19]:
```
(199980, 9999)
```

[20]:

```
y_train = list(map(get_label, x_train))
y_test = list(map(get_label, x_test))
y_train[0], y_test[0]
```

[20]:

```
(' APX882', ' ASW872')
```

[21]:

```
len(y_train), len(y_test)
```

[21]:

```
(199980, 9999)
```

[22]:

```
import torch

device = torch.device("cuda:0" if torch.cuda.is_available() else "cpu")
torch.manual_seed(3407)
torch.cuda.manual_seed_all(3407)
device
```

[22]:

```
device(type='cuda', index=0)
```

[23]:

```
from torch.utils.data import Dataset, DataLoader
from torchvision.transforms import ToTensor

class OCRDataset(Dataset):
    def __init__(self, filenames: list[str], labels: list[str],␣
 ↪transforms=None):
        self.filenames, self.labels, self.transforms = filenames, labels,␣
 ↪transforms

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

    def __getitem__(self, index: int):
        img = cv2.cvtColor(cv2.imread(self.filenames[index]), cv2.COLOR_BGR2RGB)
        if self.transforms:
            img = transforms(image=img)["image"]
        img = ToTensor()(img)
        return img, torch.LongTensor(tokenizer(self.labels[index]))

train_ds = OCRDataset(x_train, y_train, transforms)
val_ds = OCRDataset(x_test, y_test, val_transforms)

batch_size = 128
train_dl = DataLoader(train_ds, batch_size=batch_size, shuffle=True,␣
 ↪num_workers=4)
val_dl = DataLoader(val_ds, batch_size=batch_size, shuffle=False)

train_ds[0]
```

```
[23]: (tensor([[[0.0549, 0.0549, 0.0549,  …, 0.6196, 0.0549, 0.0745],
                 [0.0549, 0.0549, 0.0549,  …, 0.6706, 0.0549, 0.0667],
                 [0.0588, 0.0549, 0.0549,  …, 0.6706, 0.0549, 0.0627],
                 …,
                 [0.1608, 0.1608, 0.1608,  …, 0.0549, 0.0549, 0.0549],
                 [0.1765, 0.1804, 0.1765,  …, 0.0549, 0.0549, 0.0549],
                 [0.1804, 0.1961, 0.2000,  …, 0.0549, 0.0549, 0.0549]],

                [[0.0627, 0.0588, 0.0588,  …, 0.6039, 0.0549, 0.0588],
                 [0.0549, 0.0588, 0.0627,  …, 0.6667, 0.0549, 0.0549],
                 [0.0549, 0.0549, 0.0549,  …, 0.6706, 0.0549, 0.0549],
                 …,
                 [0.1686, 0.1647, 0.1608,  …, 0.0549, 0.0549, 0.0549],
                 [0.1765, 0.1804, 0.1765,  …, 0.0549, 0.0549, 0.0549],
                 [0.1804, 0.1961, 0.2000,  …, 0.0549, 0.0549, 0.0549]],

                [[0.0549, 0.0549, 0.0627,  …, 0.6000, 0.0549, 0.0549],
                 [0.0549, 0.0549, 0.0588,  …, 0.6588, 0.0549, 0.0549],
                 [0.0549, 0.0549, 0.0549,  …, 0.6706, 0.0549, 0.0588],
                 …,
                 [0.1647, 0.1608, 0.1608,  …, 0.0549, 0.0549, 0.0549],
                 [0.1686, 0.1725, 0.1765,  …, 0.0549, 0.0549, 0.0549],
                 [0.1725, 0.1882, 0.2000,  …, 0.0549, 0.0549, 0.0549]]]),
        tensor([51, 10, 24, 32,  8,  8,  2]))
```

```
[24]: train_ds[0][0].size(), train_ds[0][1].size()
```

```
[24]: (torch.Size([3, 96, 256]), torch.Size([7]))
```

4 CRNN

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

      class ConvBlock(nn.Module):
          def __init__(self, in_channels: int, out_channels: int, kernel_size=(3, 3),␣
       ↪stride=1, padding=1):
              super().__init__()

              self.conv = nn.Conv2d(in_channels, out_channels, kernel_size, stride,␣
       ↪padding)
              self.activate_fn = nn.ReLU(inplace=True)
              self.bn = nn.BatchNorm2d(out_channels)

          def forward(self, x):
```

```
        x = self.conv(x)
        x = self.activate_fn(x)
        x = self.bn(x)
        return x

class RNNBlock(nn.Module):
    def __init__(self, input_size: int, hidden_size: int, num_layers=2,␣
↪dropout=0.1, bidirectional=True):
        super().__init__()

        self.rnn = nn.GRU(input_size, hidden_size, num_layers,␣
↪batch_first=True, dropout=dropout, bidirectional=bidirectional)

    def forward(self, x):
        out, _ = self.rnn(x)
        return out
```

[26]:

```
class CRNN(nn.Module):
    def __init__(self, num_classes: int):
        super().__init__()

        self.cnn = nn.Sequential(
            ConvBlock(3, 64),
            ConvBlock(64, 64),
            nn.MaxPool2d(kernel_size=2),

            ConvBlock(64, 128),
            ConvBlock(128, 128),
            nn.MaxPool2d(kernel_size=2),

            ConvBlock(128, 256),
            ConvBlock(256, 256),
            nn.MaxPool2d(kernel_size=2)
        )

        self.avg_pool = nn.AdaptiveAvgPool2d((7, 256))

        self.rnn = RNNBlock(256, 128)

        self.classifier = nn.Sequential(
            nn.Linear(128 * 2, 256),
            nn.ReLU(inplace=True),
            nn.Dropout(0.1),
            nn.Linear(256, num_classes)
        )

    def forward(self, x):
        x = self.cnn(x)
        bs, ch, h, w = x.size()
        x = x.reshape(bs, -1, 256)
        x = self.avg_pool(x)
        x = self.rnn(x)
        x = self.classifier(x)
        x = x.transpose(2, 1)
        return x

model = CRNN(len(tokenizer))
model = model.to(device)
model
```

[26]:

```
CRNN(
  (cnn): Sequential(
    (0): ConvBlock(
      (conv): Conv2d(3, 64, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
      (activate_fn): ReLU(inplace=True)
      (bn): BatchNorm2d(64, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    )
    (1): ConvBlock(
      (conv): Conv2d(64, 64, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
      (activate_fn): ReLU(inplace=True)
      (bn): BatchNorm2d(64, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    )
    (2): MaxPool2d(kernel_size=2, stride=2, padding=0, dilation=1,
ceil_mode=False)
    (3): ConvBlock(
      (conv): Conv2d(64, 128, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
      (activate_fn): ReLU(inplace=True)
      (bn): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    )
    (4): ConvBlock(
      (conv): Conv2d(128, 128, kernel_size=(3, 3), stride=(1, 1), padding=(1,
1))
      (activate_fn): ReLU(inplace=True)
      (bn): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    )
    (5): MaxPool2d(kernel_size=2, stride=2, padding=0, dilation=1,
ceil_mode=False)
    (6): ConvBlock(
      (conv): Conv2d(128, 256, kernel_size=(3, 3), stride=(1, 1), padding=(1,
1))
```

```
      (activate_fn): ReLU(inplace=True)
      (bn): BatchNorm2d(256, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    )
    (7): ConvBlock(
      (conv): Conv2d(256, 256, kernel_size=(3, 3), stride=(1, 1), padding=(1,
1))
      (activate_fn): ReLU(inplace=True)
      (bn): BatchNorm2d(256, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    )
    (8): MaxPool2d(kernel_size=2, stride=2, padding=0, dilation=1,
ceil_mode=False)
  )
  (avg_pool): AdaptiveAvgPool2d(output_size=(7, 256))
  (rnn): RNNBlock(
    (rnn): GRU(256, 128, num_layers=2, batch_first=True, dropout=0.1,
bidirectional=True)
  )
  (classifier): Sequential(
    (0): Linear(in_features=256, out_features=256, bias=True)
    (1): ReLU(inplace=True)
    (2): Dropout(p=0.1, inplace=False)
    (3): Linear(in_features=256, out_features=66, bias=True)
  )
)
```

[27]:

```
from torchsummary import summary

summary(model, (3, 96, 256));
```

```
================================================================================
==========
Layer (type:depth-idx)                   Output Shape              Param #
================================================================================
==========
 Sequential: 1-1                        [-1, 256, 12, 32]         --
|     ConvBlock: 2-1                    [-1, 64, 96, 256]         --
|    |     Conv2d: 3-1                  [-1, 64, 96, 256]         1,792
|    |     ReLU: 3-2                    [-1, 64, 96, 256]         --
|    |     BatchNorm2d: 3-3             [-1, 64, 96, 256]         128
|     ConvBlock: 2-2                    [-1, 64, 96, 256]         --
|    |     Conv2d: 3-4                  [-1, 64, 96, 256]         36,928
|    |     ReLU: 3-5                    [-1, 64, 96, 256]         --
|    |     BatchNorm2d: 3-6             [-1, 64, 96, 256]         128
|     MaxPool2d: 2-3                    [-1, 64, 48, 128]         --
|     ConvBlock: 2-4                    [-1, 128, 48, 128]        --
|    |     Conv2d: 3-7                  [-1, 128, 48, 128]        73,856
|    |     ReLU: 3-8                    [-1, 128, 48, 128]        --
|    |     BatchNorm2d: 3-9             [-1, 128, 48, 128]        256
|     ConvBlock: 2-5                    [-1, 128, 48, 128]        --
|    |     Conv2d: 3-10                 [-1, 128, 48, 128]        147,584
|    |     ReLU: 3-11                   [-1, 128, 48, 128]        --
|    |     BatchNorm2d: 3-12            [-1, 128, 48, 128]        256
|     MaxPool2d: 2-6                    [-1, 128, 24, 64]         --
|     ConvBlock: 2-7                    [-1, 256, 24, 64]         --
|    |     Conv2d: 3-13                 [-1, 256, 24, 64]         295,168
|    |     ReLU: 3-14                   [-1, 256, 24, 64]         --
|    |     BatchNorm2d: 3-15            [-1, 256, 24, 64]         512
|     ConvBlock: 2-8                    [-1, 256, 24, 64]         --
|    |     Conv2d: 3-16                 [-1, 256, 24, 64]         590,080
|    |     ReLU: 3-17                   [-1, 256, 24, 64]         --
|    |     BatchNorm2d: 3-18            [-1, 256, 24, 64]         512
|     MaxPool2d: 2-9                    [-1, 256, 12, 32]         --
 AdaptiveAvgPool2d: 1-2                 [-1, 7, 256]              --
 RNNBlock: 1-3                          [-1, 7, 256]              --
|     GRU: 2-10                         [-1, 7, 256]              592,896
 Sequential: 1-4                        [-1, 7, 66]               --
|     Linear: 2-11                      [-1, 7, 256]              65,792
|     ReLU: 2-12                        [-1, 7, 256]              --
|     Dropout: 2-13                     [-1, 7, 256]              --
|     Linear: 2-14                      [-1, 7, 66]               16,962
================================================================================
==========
Total params: 1,822,850
Trainable params: 1,822,850
Non-trainable params: 0
Total mult-adds (G): 3.67
================================================================================
==========
Input size (MB): 0.28
Forward/backward pass size (MB): 84.03
Params size (MB): 6.95
Estimated Total Size (MB): 91.27
================================================================================
==========
```

5 Utils

[28]:

```python
from Levenshtein import distance

def CER(pred: list[str], true: list[str]) -> float:
    return np.mean([distance(p, t) / max(len(p), len(t)) for p, t in zip(pred,␣
↪true)])

def accuracy(pred: list[str], true: list[str]) -> float:
    return np.mean([p == t for p, t in zip(pred, true)])

CER([" APX882"], [" APX8782"]), CER([" APX882"], [" APX8772"]),␣
↪accuracy([" APX882", " APX883", " APX884", " APX885"], [" APX882", " APX882",␣
↪" APX884", " APX882"])
```

[28]:

```
(0.125, 0.25, 0.5)
```

[29]:

```
def prob2word(p: list[list[float]]) -> str:
    return tokenizer.decode([np.argmax(i) for i in p])

prob2word([[0.1, 0.6, 0.3, 0], [0.5, 0.4, 0.1, 0], [0, 0, 0, 1]]),␣
↪list(tokenizer.token2word.items())[:5]
```

[29]:

```
('103', [(0, '0'), (1, '1'), (2, '2'), (3, '3'), (4, '4')])
```

[30]:

```
class AverageMeter(object):
    def __init__(self):
        self.reset()

    def reset(self):
        self.val = 0
        self.avg = 0
        self.sum = 0
        self.count = 0

    def update(self, val, n=1):
        self.val = val
        self.sum += val * n
        self.count += n
        self.avg = self.sum / self.count
```

6 Training

[31]:

```
from tqdm.notebook import tqdm

def training(model, dl, criterion, optimizer, scheduler=None):
    model.train()
    loss_meter, acc_meter, cer_meter = AverageMeter(), AverageMeter(),␣
↪AverageMeter()
    for x, y in tqdm(dl):
        x, y = x.to(device), y.to(device)

        optimizer.zero_grad()

        out = model(x)

        loss = criterion(out, y)

        pred = list(map(prob2word, out.transpose(2, 1).cpu().detach().numpy()))
        true = list(map(tokenizer.decode, y.cpu().detach().numpy()))

        loss_meter.update(loss.item())
        acc_meter.update(accuracy(pred, true))
        cer_meter.update(CER(pred, true))

        loss.backward()
        optimizer.step()

        if scheduler:
            scheduler.step()

        del x
        del y
        del out
        del loss
        del pred
        del true
        torch.cuda.empty_cache()
    return loss_meter.avg, acc_meter.avg, cer_meter.avg

def validation(model, dl, criterion):
    model.eval()
    loss_meter, acc_meter, cer_meter = AverageMeter(), AverageMeter(),␣
 ↪AverageMeter()
    for x, y in dl:
        x, y = x.to(device), y.to(device)

        with torch.no_grad():
            out = model(x)

        loss = criterion(out, y)

        pred = list(map(prob2word, out.transpose(2, 1).cpu().detach().numpy()))
        true = list(map(tokenizer.decode, y.cpu().detach().numpy()))

        loss_meter.update(loss.item())
        acc_meter.update(accuracy(pred, true))
        cer_meter.update(CER(pred, true))

        del x
        del y
        del out
        del loss
        del pred
        del true
        torch.cuda.empty_cache()
    return loss_meter.avg, acc_meter.avg, cer_meter.avg
```

[32]:

```
import shutil
import gc

try:
    shutil.rmtree("checkpoints")
except FileNotFoundError:
    pass
finally:
    os.makedirs("checkpoints", exist_ok=True)

epochs = 20
criterion = nn.CrossEntropyLoss()
optimizer = torch.optim.AdamW(model.parameters(), lr=3e-4)

best_val_loss = float("inf")

all_train_loss, all_train_acc, all_train_cer = [], [], []
all_val_loss, all_val_acc, all_val_cer = [], [], []

for e in range(1, epochs + 1):
    print(f"========== Epoch {e} / {epochs} ==========")

    train_loss, train_acc, train_cer = training(model, train_dl, criterion,␣
 ↪optimizer)
    print(f"Train loss {train_loss} accuracy {train_acc} CER {train_cer}")
    all_train_loss.append(train_loss)
    all_train_acc.append(train_acc)
    all_train_cer.append(train_cer)

    val_loss, val_acc, val_cer = validation(model, val_dl, criterion)
    print(f"Validation loss {val_loss} accuracy {val_acc} CER {val_cer}\n")
    all_val_loss.append(val_loss)
    all_val_acc.append(val_acc)
    all_val_cer.append(val_cer)

    if val_loss < best_val_loss:
```

```python
        best_val_loss = val_loss
        torch.save(model.state_dict(), f"checkpoints/epoch={e};loss={val_loss}")

    gc.collect()
```

```
========== Epoch 1 / 20 ==========

  0%|          | 0/1563 [00:00<?, ?it/s]


Train loss 0.45709893480896646 accuracy 0.6876967552201478 CER
0.12333663617252884
Validation loss 0.08500499303063637 accuracy 0.8981408227848101 CER
0.02013166817359855

========== Epoch 2 / 20 ==========

  0%|          | 0/1563 [00:00<?, ?it/s]


Train loss 0.026273303878983998 accuracy 0.9581293077124411 CER
0.006739661490141335
Validation loss 0.058788502706757076 accuracy 0.924940664556962 CER
0.014508928571428567

========== Epoch 3 / 20 ==========

  0%|          | 0/1563 [00:00<?, ?it/s]


Train loss 0.016522144474746373 accuracy 0.971769033909149 CER
0.004424298510191025
Validation loss 0.0422614835190905 accuracy 0.9452136075949367 CER
0.01028481012658228

========== Epoch 4 / 20 ==========

  0%|          | 0/1563 [00:00<?, ?it/s]


Train loss 0.011459875265659225 accuracy 0.9794670250974233 CER
0.0031774247825111703
Validation loss 0.04620456840560029 accuracy 0.9395239978902954 CER
0.011267141350210974

========== Epoch 5 / 20 ==========

  0%|          | 0/1563 [00:00<?, ?it/s]


Train loss 0.009397910206523705 accuracy 0.9829559086546851 CER
0.0026633685013003764
```

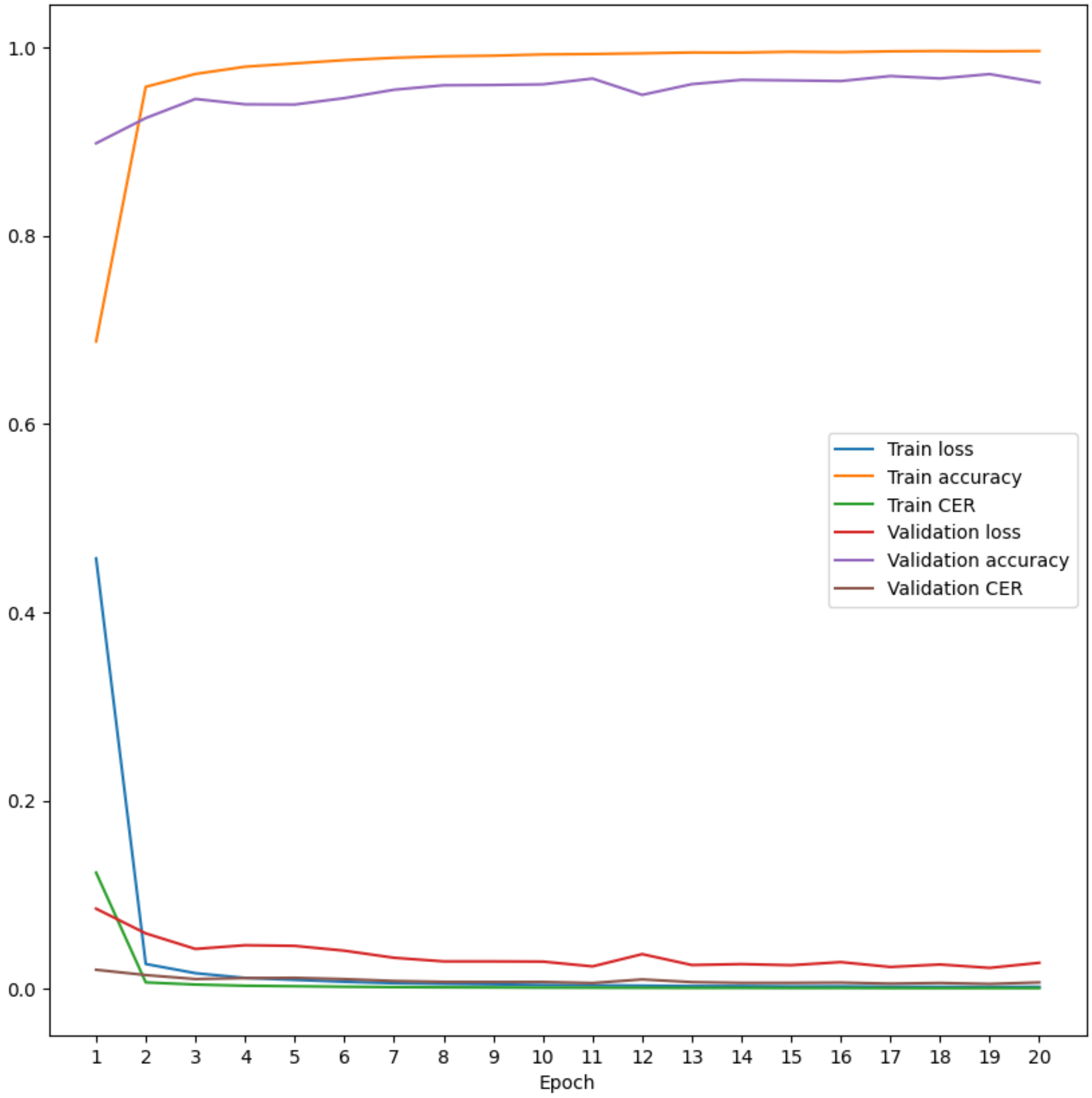
```
Validation loss 0.045520578704102414 accuracy 0.9392800632911392 CER
0.011556283905967453

========== Epoch 6 / 20 ==========

  0%|          | 0/1563 [00:00<?, ?it/s]


Train loss 0.007390949275164066 accuracy 0.986434795410923 CER
0.002113544444998388
Validation loss 0.040412505729053215 accuracy 0.9461036392405063 CER
0.01024242766726944

========== Epoch 7 / 20 ==========

  0%|          | 0/1563 [00:00<?, ?it/s]


Train loss 0.005837200362419204 accuracy 0.9889489908683767 CER
0.0016908225731402328
Validation loss 0.03287486243356444 accuracy 0.9550039556962026 CER
0.008236324593128393

========== Epoch 8 / 20 ==========

  0%|          | 0/1563 [00:00<?, ?it/s]


Train loss 0.005147156110961811 accuracy 0.9905130358285349 CER
0.0014752422082076556
Validation loss 0.029045885817819757 accuracy 0.9597507911392406 CER
0.00728978300180832

========== Epoch 9 / 20 ==========

  0%|          | 0/1563 [00:00<?, ?it/s]


Train loss 0.004675342475732351 accuracy 0.9911778230966091 CER
0.0013781304268348335
Validation loss 0.029022535850932007 accuracy 0.9600474683544303 CER
0.00721914556962025

========== Epoch 10 / 20 ==========

  0%|          | 0/1563 [00:00<?, ?it/s]


Train loss 0.003920244600211253 accuracy 0.992522392834293 CER
0.0011653413764738032
Validation loss 0.02880717850164245 accuracy 0.9607397151898734 CER
0.00720501808318264
```

```
========== Epoch 11 / 20 ==========

  0%|          | 0/1563 [00:00<?, ?it/s]


Train loss 0.0036194277222167956 accuracy 0.9929627064793811 CER
0.0010845879967760863
Validation loss 0.023710776082110366 accuracy 0.9668710443037974 CER
0.006060691681735983

========== Epoch 12 / 20 ==========

  0%|          | 0/1563 [00:00<?, ?it/s]


Train loss 0.003245913009259259 accuracy 0.9936870201535508 CER
0.0009725459281601239
Validation loss 0.036751869217127184 accuracy 0.9495648734177216 CER
0.009889240506329116

========== Epoch 13 / 20 ==========

  0%|          | 0/1563 [00:00<?, ?it/s]


Train loss 0.002839836073081437 accuracy 0.9945721914441924 CER
0.0008396663716961179
Validation loss 0.025179882118289795 accuracy 0.9609375 CER 0.007021360759493665

========== Epoch 14 / 20 ==========

  0%|          | 0/1563 [00:00<?, ?it/s]


Train loss 0.002806696706186022 accuracy 0.994476767434421 CER
0.0008468718581482436
Validation loss 0.026161488008359744 accuracy 0.9654865506329114 CER
0.006244349005424954

========== Epoch 15 / 20 ==========

  0%|          | 0/1563 [00:00<?, ?it/s]


Train loss 0.0024493736921194784 accuracy 0.9953664827255279 CER
0.0007090588154647622
Validation loss 0.024989574671283814 accuracy 0.9648931962025317 CER
0.006258476491862565

========== Epoch 16 / 20 ==========

  0%|          | 0/1563 [00:00<?, ?it/s]
```

```
Train loss 0.00251026870657116 accuracy 0.9949625210841622 CER
0.000762483278078284
Validation loss 0.0282824625116714 accuracy 0.9642009493670886 CER
0.0065268987341772135

========== Epoch 17 / 20 ==========

  0%|          | 0/1563 [00:00<?, ?it/s]


Train loss 0.0021631120653590056 accuracy 0.995816338771593 CER
0.000637653093867105
Validation loss 0.02311562292448752 accuracy 0.9695411392405063 CER
0.005467337251356236

========== Epoch 18 / 20 ==========

  0%|          | 0/1563 [00:00<?, ?it/s]


Train loss 0.002014831066763753 accuracy 0.9961462332053743 CER
0.0005840988026688597
Validation loss 0.025750953161829633 accuracy 0.9669699367088608 CER
0.006131329113924047

========== Epoch 19 / 20 ==========

  0%|          | 0/1563 [00:00<?, ?it/s]


Train loss 0.00198260690326702 accuracy 0.9958713211772233 CER
0.000616231377387806
Validation loss 0.02216226708540351 accuracy 0.9716178797468354 CER
0.005142405063291135

========== Epoch 20 / 20 ==========

  0%|          | 0/1563 [00:00<?, ?it/s]


Train loss 0.0019587353731015285 accuracy 0.9961162428023033 CER
0.0005926674892605787
Validation loss 0.027547409252522963 accuracy 0.962618670886076 CER
0.006696428571428572
```

[33]:

```python
n = np.arange(1, epochs + 1)

plt.figure(figsize=(10, 10))
plt.plot(n, all_train_loss, label="Train loss")
plt.plot(n, all_train_acc, label="Train accuracy")
plt.plot(n, all_train_cer, label="Train CER")
plt.plot(n, all_val_loss, label="Validation loss")
plt.plot(n, all_val_acc, label="Validation accuracy")
plt.plot(n, all_val_cer, label="Validation CER")
plt.xlabel("Epoch")
plt.xticks(n)
plt.legend()
plt.show()
```



7 Evaluate

[34]:
```
models = sorted(os.listdir("checkpoints"), reverse=True)
models
```

[34]:
```
['epoch=9;loss=0.029022535850932007',
 'epoch=8;loss=0.029045885817819757',
 'epoch=7;loss=0.03287486243356444',
 'epoch=6;loss=0.040412505729053215',
 'epoch=3;loss=0.0422614835190905',
 'epoch=2;loss=0.058788502706757076',
 'epoch=1;loss=0.08500499303063637',
 'epoch=19;loss=0.02216226708540351',
 'epoch=17;loss=0.02311562292448752',
 'epoch=11;loss=0.023710776082110366',
 'epoch=10;loss=0.02880717850164245']
```

[35]:
```
from dataclasses import dataclass, field
from collections import defaultdict
from ipywidgets import Dropdown
import pandas as pd

@dataclass
class Info:
    filename: str = ""
    pred: str = ""
    true: str = ""
    metrics: list[float] = field(default_factory=list)

def evaluate(model_name):
    model = CRNN(len(tokenizer)).to(device)
    model.load_state_dict(torch.load(os.path.join("checkpoints", model_name)))
    model.eval()

    loss_meter, acc_meter, cer_meter = AverageMeter(), AverageMeter(),␣
 ↪AverageMeter()
    max_cer, max_loss = np.zeros(10), np.zeros(10)
    max_cer_info, max_loss_info = [Info() for _ in range(10)], [Info() for _ in␣
 ↪range(10)]
    for filename in tqdm(x_test):
        img = cv2.cvtColor(cv2.imread(filename), cv2.COLOR_BGR2RGB)
        x = val_transforms(image=img)["image"]
        x = torch.unsqueeze(ToTensor()(x), 0).to(device)
        label = get_label(filename)
        y = torch.unsqueeze(torch.LongTensor(tokenizer(label)), 0).to(device)

        with torch.no_grad():
            out = model(x)

            loss = criterion(out, y)

            pred = list(map(prob2word, out.transpose(2, 1).cpu().detach().
↪numpy()))
            true = list(map(tokenizer.decode, y.cpu().detach().numpy()))

            cur_loss = loss.item()
            cur_acc = accuracy(pred, true)
            cur_cer = CER(pred, true)

            min_cer_index, min_loss_index = np.argmin(max_cer), np.
↪argmin(max_loss)
            if cur_cer > max_cer[min_cer_index]:
                max_cer[min_cer_index] = cur_cer
                max_cer_info[min_cer_index] = Info(filename, pred[0], true[0],␣
↪[cur_loss, cur_acc, cur_cer])
            if cur_loss > max_loss[min_loss_index]:
                max_loss[min_loss_index] = cur_loss
                max_loss_info[min_loss_index] = Info(filename, pred[0],␣
↪true[0], [cur_loss, cur_acc, cur_cer])

            loss_meter.update(cur_loss)
            acc_meter.update(cur_acc)
            cer_meter.update(cur_cer)

        del x
        del y
        del out
        del loss
        del pred
        del true
        torch.cuda.empty_cache()

    max_cer, max_cer_info = zip(*sorted(zip(max_cer, max_cer_info), key=lambda␣
↪x: -x[0]))
    max_loss, max_loss_info = zip(*sorted(zip(max_loss, max_loss_info),␣
↪key=lambda x: -x[0]))

    cer_info = defaultdict(list)
    for d in list(map(lambda x: x.__dict__, max_cer_info)):
        for k, v in d.items():
            cer_info[k].append(v)

    loss_info = defaultdict(list)
    for d in list(map(lambda x: x.__dict__, max_loss_info)):
        for k, v in d.items():
            loss_info[k].append(v)

    pd.set_option("display.expand_frame_repr", False)

    print(f"\n Test loss {loss_meter.avg} accuracy {acc_meter.avg} CER␣
 ↪{cer_meter.avg}")
    print("\n ==== Max CER files ==== \n")
    print(pd.DataFrame(dict(cer_info), columns=["filename", "pred", "true",␣
 ↪"metrics"]))
    print("\n ==== Max Loss files ==== \n")
    print(pd.DataFrame(dict(loss_info), columns=["filename", "pred", "true",␣
 ↪"metrics"]))

    @interact(index=IntSlider(min=0, max=len(x_test) - 1, value=0))
    def check_model(index: int):
        img = cv2.cvtColor(cv2.imread(x_test[index]), cv2.COLOR_BGR2RGB)

        plt.imshow(img)
        plt.axis("off")
        plt.show()

        img = val_transforms(image=img)["image"]
        img = torch.unsqueeze(ToTensor()(img), 0).to(device)
        with torch.no_grad():
            out = model(img)
        out = out.squeeze()
        pred = prob2word(out.transpose(1, 0).cpu().detach().numpy())
        true = get_label(x_test[index])
        print("Predicted", pred)
        print("True", true)
        print("CER", CER([pred], [true]))

interact(evaluate, model_name=Dropdown(options=models));
```

```
interactive(children=(Dropdown(description='model_name', options=('epoch=9;loss=0.029022535850
```