



Building an efficient OCR system for historical documents with little training data

Jiří Martínek¹ · Ladislav Lenc² · Pavel Král^{1,2}

Received: 25 December 2019 / Accepted: 6 April 2020
© The Author(s) 2020, corrected publication 2020

Abstract

As the number of digitized historical documents has increased rapidly during the last a few decades, it is necessary to provide efficient methods of information retrieval and knowledge extraction to make the data accessible. Such methods are dependent on optical character recognition (OCR) which converts the document images into textual representations. Nowadays, OCR methods are often not adapted to the historical domain; moreover, they usually need a significant amount of annotated documents. Therefore, this paper introduces a set of methods that allows performing an OCR on historical document images using only a small amount of real, manually annotated training data. The presented complete OCR system includes two main tasks: page layout analysis including text block and line segmentation and OCR. Our segmentation methods are based on fully convolutional networks, and the OCR approach utilizes recurrent neural networks. Both approaches are state of the art in the relevant fields. We have created a novel real dataset for OCR from Porta fontium portal. This corpus is freely available for research, and all proposed methods are evaluated on these data. We show that both the segmentation and OCR tasks are feasible with only a few annotated real data samples. The experiments aim at determining the best way how to achieve good performance with the given small set of data. We also demonstrate that obtained scores are comparable or even better than the scores of several state-of-the-art systems. To sum up, this paper shows a way how to create an efficient OCR system for historical documents with a need for only a little annotated training data.

Keywords CNN · FCN · Historical documents · LSTM · Neural network · OCR · Porta fontium · Synthetic data

1 Introduction

Digitization of historical documents is an important task for preserving our cultural heritage. During the last a few decades, the amount of digitized archival material has

increased rapidly, and therefore, an efficient method to convert these document images into a text form has become essential to allow information retrieval and knowledge extraction on such data. Nowadays, state-of-the-art methods are usually not adapted to the historical domain; moreover, they usually need a significant amount of annotated documents which is very expensive and time-consuming to acquire.

Therefore, this paper introduces a set of methods to convert historical scans into their textual representation for efficient information retrieval based on a minimal number of manually annotated documents. This problem includes two main tasks: page layout analysis (including text block and line segmentation) and optical character recognition (OCR). We address all these issues, and we propose several approaches to solve these tasks.

This research is realized in the frame of the *Modern Access to Historical Sources* project, presented through the

✉ Pavel Král
pkral@kiv.zcu.cz

Jiří Martínek
jimar@kiv.zcu.cz

Ladislav Lenc
llenc@kiv.zcu.cz

¹ Department of Computer Science and Engineering, Faculty of Applied Sciences, University of West Bohemia, Plzeň, Czech Republic

² NTIS - New Technologies for the Information Society, Faculty of Applied Sciences, University of West Bohemia, Plzeň, Czech Republic

Porta fontium portal¹. One goal of this project is to enable an intelligent full-text access to the printed historical documents from the Czech–Bavarian border region. Accordingly, our original data sources are scanned texts from German historical newspapers printed with Fraktur from the second half of the nineteenth century.

All proposed methods are evaluated and compared on the real data from the Porta fontium portal. We have also built a novel annotated corpus for historical OCR based on such data. This dataset is intended for the evaluation of state-of-the-art OCR systems and is freely available for research purposes.² Based on the experiments, the reader can very quickly build his historical OCR system.

Traditional OCR approaches usually detect and segment words and single characters in the documents. The spaces between the isolated characters and words are sometimes not evident due to their particular form or by the noise in the images. This fact brings often OCR errors. With the development of deep learning (especially recurrent neural networks), the methods based on processing of whole text lines became dominant. Such methods benefit from the context that is available when processing the text line as a sequence of frames and are thus not affected by character segmentation errors. High computational power and solutions to the vanishing and exploding gradient issues [1] allowed the learning of deep architectures that are capable of accommodating such input data. A great benefit is also the connectionist temporal classification (CTC) loss [2] which can map the labels into specific image frames.

Traditional text segmentation methods used to be solved by simple computer vision algorithms. Nowadays, approaches based on deep neural networks outperform the traditional methods. The best results in the text segmentation field are obtained by fully convolutional networks (FCN) [3]. Therefore, our proposed segmentation is also based on this network type. The current trend in the OCR field is to utilize neural networks which process whole text lines using recurrent neural networks (RNN) [4] including convolutional neural networks (CNNs) for feature extraction [5]. A great benefit of these approaches is that the segmentation to characters is not necessary. Hence, our OCR method is also based on the combination of convolutional and recurrent neural networks. A natural ability of RNNs is to learn an implicit language model (LM) [6–8]. To be able to learn the LM, we must provide the network with a sufficient amount of meaningful text in the domain we work in. A frequently used way how to obtain the texts is generating synthetic data. Synthetic data should be created with respect to the LM. We will show the influence of

different types of synthetic data in the experimental section.

The main contribution of this paper is thus as follows:

1. Proposing text region and text line segmentation approaches based on fully convolutional networks using transfer learning for efficient training with only few real training examples;
2. Proposing an OCR method based on recurrent neural networks with a learning algorithm using synthetic data and a relatively small amount of real annotated data samples;
3. Building a novel dataset from the real historical data available on the Porta fontium portal dedicated to evaluation of OCR systems;
4. Evaluation of all methods on real data from Porta fontium portal;
5. Giving an overview of how to create an efficient OCR system with minimal costs (i.e., minimal human effort during annotation process as well as the minimal time required to train models).

The paper structure is as follows. The following section gives an overview of related work. Section 3 describes our segmentation approaches used for page segmentation into individual blocks and lines, respectively. It also illustrates the pipeline of the whole process. Section 4 describes the OCR engine which is based on the combination of convolutional and recurrent neural networks. In Sect. 5, we present datasets used for our experiments. Then, we present experimental evaluation of the proposed methods on these data. This section also includes experimental setup and hyperparameter settings. The last section concludes the paper and proposes some further research directions.

2 Related work

This section is focused on four related research areas: image processing in general, segmentation, optical character recognition and, finally, tools and systems for OCR and associated tasks (e.g., ground-truth labeling).

2.1 Image processing in general

With the development of deep neural networks in the field of image processing, there are efforts to use an input image without any preprocessing (binarization or thresholding) and use an image-to-image architecture. Isola et al. [9] defined (as an analogy to automatic language translation) automatic image-to-image translation as the task of translating one possible representation of a scene into another, given sufficient training data. Such a translating operation, the goal of which is to predict pixels from pixels, has many

¹ <http://www.portafontium.eu/>.

² <http://ocr-corpus.kiv.zcu.cz/>.

applications that have an impact on the OCR task, i.e., binarization [10] or image segmentation [11]. Another example of image-to-image translating is the problem of detecting edges and object boundaries in natural images [12]. Huang et al. [13] go even further and present an unsupervised image-to-image translation, the goal of which is to learn (based on a given image in the source domain) the conditional distribution of corresponding images in the target domain without seeing any examples of corresponding image pairs.

2.2 Segmentation

Before performing any document image processing task, layout analysis and page segmentation need to be implemented. Traditional approaches [14] usually use geometric algorithms or heuristics fine-tuned on a target domain. However, in the following text we focus on the use of neural networks which achieve state-of-the-art results in many research areas including segmentation and OCR.

Page segmentation is very similar to the semantic segmentation. Shelhamer et al. [15] show that a FCN trained end to end (pixels to pixels) can reach interesting results. The most important elements of a document are baselines of individual text lines and blocks of texts. Annotations in the dataset are segments of interest (baselines or text blocks) plotted in the image (e.g., image mask). An example of the FCN architecture—U-Net [11]—was developed originally for medical image segmentation. With appropriate dataset, it can be simply trained on the text document images to perform a page segmentation. Another technique usable for semantic segmentation, object detection or page segmentation is a mask R-CNN [16]. For the feature extraction, the Mask R-CNN uses an FCN and it produces a class label and an appropriate bounding box offset.

Breuel [17] describes the use of deep neural networks, in particular a combination of convolutional and multidimensional long short-term memory (LSTM) [18]. It is demonstrated that the relatively simple networks are capable of fast, reliable text line segmentation and document layout analysis even on complex and noisy inputs, without manual parameter tuning or heuristics. Furthermore, the method is easily adaptable to new datasets by retraining.

2.3 Optical character recognition

In recent years, the popular LSTM networks have been used for OCR tasks [4] because their training in the case of OCR is considerably simpler than previous training methods, since all training is carried out in terms of text line images and transcriptions. A combination of deep convolutional and recurrent neural networks (CRNN) is also used

for line-based OCR [19] with even better performance. Convolutional neural networks [20] play a significant role in the feature extraction task. It is also a computationally efficient technique, which allows to process large images.

Graves et al. [2] introduced the connectionist temporal classification (CTC) alignment. According to them, the crucial step is to transform the network outputs into a conditional probability distribution over label sequences. The network can then be used as a classifier by selecting the most probable labeling for a given input sequence. More precisely, a CTC network has a softmax output layer with one extra unit. The activations are interpreted as the probabilities of observing the corresponding labels at particular times. The activation of the extra unit is the probability of observing no label (so-called *blank symbol*). This algorithm (architecture and the corresponding loss function) allows us to train a classifier in a very efficient way, because we only need a ground-truth (GT) text sequence for the CTC loss function.

Furthermore, classical RNN requires pre-segmented training data to provide the correct target at each time step, regardless of its ability to model long-range dependencies. The CTC is a way to extend the RNN for this type of non-segmented data [21].

He et al. [22] used the deep-text recurrent network classifier with the CTC alignment for scene text reading, which is more difficult task than OCR. In their system, the CTC layer is directly connected to the outputs of LSTM layers and works as the output layer of the whole RNN. Elagouni et al. [21] used the CTC for text recognition in videos.

Graves also introduced the sequence transduction as an alternative to CTC, which extends the CTC from discrete to continuous output sequences [23]. A combination of CTC with the attention mechanism [24] was utilized by Bluche et al. [25] in the handwritten text recognition task.

A line-based classifier which uses the CTC algorithm needs a huge number of training examples, which leads us to the synthetic data and data augmentation.

Jaderberg et al. presented a framework for recognition and synthetic data generation [26]. Margner et al. [27] presented synthetic data for Arabic OCR, and another synthetic data generation was proposed by Gaur et al. [28]. Put simply, data augmentation is a way to increase the size of a dataset by perturbing existing data to create more examples. In the case of image processing, performing such operations as light rotations or skewing is a simple way to create new samples with low cost. If we consider the OCR task, we can perform a data augmentation operation on blocks of text, on text lines, on individual characters or even on a whole page. If we go to the extreme, we can even replace some characters with other similar looking ones ($O \rightarrow O$ or $i \rightarrow l$ and so on). Perez et al. [29] tried

to learn the best augmentations for a concrete dataset and classification task by a neural network—neural augmentation.

2.4 Existing tools and OCR systems

There are a number of tools (i.e., tool for Arabic OCR [27] or Aletheia [30]) which deal with the synthetic data generation and annotation. Aletheia is a full-document image analysis system, which allows to annotate documents for layout evaluation (page element localization) and OCR in the form of XML file—e.g., PAGE XML [31]. There is also a web version of Aletheia³.

OCRopus [32] is an efficient document analysis and OCR system. This system has a modular architecture and it is possible to use it freely for any purpose. The main components are dedicated to analysis of document layout, use of statistical language models and OCR. Last, but not least within the OCRopus, there is a tool ocropus-linegen that allows rendering text line images, usable for training an OCR engine.

Tesseract⁴ is one of the best OCR engines in terms of integrated language support and recognition scores. It is available for Linux, Windows and Mac OS X; however, due to limited resources it is sufficiently tested only under Windows and Ubuntu [33]. The current version 4.0⁵ uses a powerful LSTM based OCR engine and integrates models for 116 additional languages.

Transkribus [34, 35] is another complex platform for analysis of historical documents which covers many research areas such as layout analysis and handwritten text recognition. It includes also OCR using ABBYY FineReader Engine 11⁶. To the best of our knowledge, Tesseract and Transcribus are the best performing OCR systems. Therefore, they will be used for comparison with our approach.

3 Page layout analysis and segmentation

3.1 Whole process description

The OCR results depend on the layout analysis. Based on the layout analysis, we can perform image segmentation into smaller logical units as individual text blocks and lines which are the input of our OCR engine. The whole process is decomposed into three main tasks: block segmentation,

line segmentation and optical character recognition itself as depicted in Fig. 1.

The goal of the block segmentation is extracting text regions with respect to the reading order. (An ordered set of image regions containing text is the output.) The next task is segmenting the regions into individual text lines. Although there are some algorithms which can solve the text line segmentation from the whole page in one step, we prefer using the two-step approach, which allows to determine logical text units and simplifies determining the reading order. The subsequent segmentation into lines becomes then significantly easier.

Documents that we process have mostly a two-column layout. In the case of well separated columns, one-step approach would be sufficient. However, there are also more complicated pages with irregularities where the determination of reading order from coordinates of single lines is complicated. The one-step approach can also merge lines across column separators, which can jeopardize the reading order too. In most cases, the presented two-step approach is more appropriate because it takes into account the reading order and it is also able to filter out some types of noise, such as pictographic illustrations or various decorative elements. The last task is the OCR which converts the detected text lines into their textual representation.

Our segmentation method is as follows. The input page is first preprocessed which includes binarization and page rotation. The next step is the block segmentation. The page is first processed by an FCN which predicts a mask indicating the text region positions. Based on the predicted mask, we extract individual regions. The list of extracted text regions is the input to the line segmentation process. In this step, we apply a line segmentation method in order to obtain images of individual text lines. After a necessary post-processing which removes noise and parts of surrounding text lines, we can feed the resulting text line images directly to the OCR engine. The above-described layout analysis and segmentation processes are illustrated in Fig. 2.

3.2 Text block segmentation

Recent methods for image segmentation are often based on fully convolutional networks. A well-known example of such an architecture is U-Net [11] which was initially developed for semantic segmentation of medical images. The architecture of this network is depicted in Fig. 3.

It consists of a contracting path (left side) and an expansive path (right side). The contracting path follows the typical architecture of a convolutional network. It consists of the repeated application of two 3×3 convolutions (unpadded convolutions), each followed by a rectified linear unit (ReLU) and a 2×2 max pooling operation

³ <https://github.com/PRImA-Research-Lab/prima-aletheia-web>.

⁴ <https://github.com/tesseract-ocr/>.

⁵ <https://github.com/tesseract-ocr/tesseract/wiki/4.0-with-LSTM>.

⁶ <https://www.abbyy.com/>.

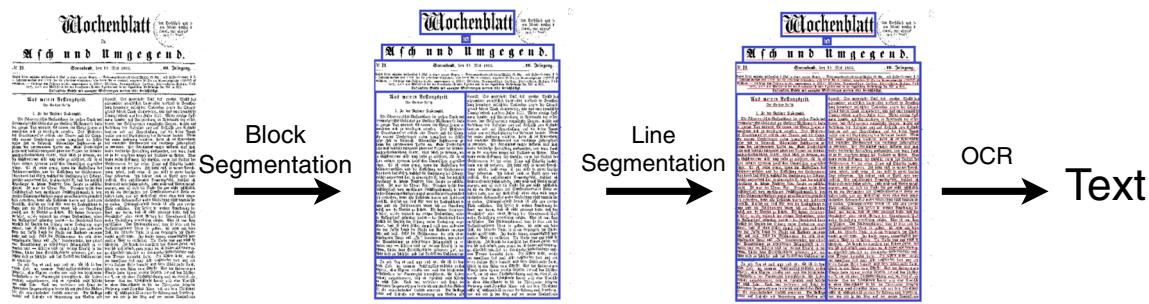


Fig. 1 Whole process pipeline: source image (left), text region segmentation (blue color; middle) and individual line segmentation (red color; right) (color figure online)

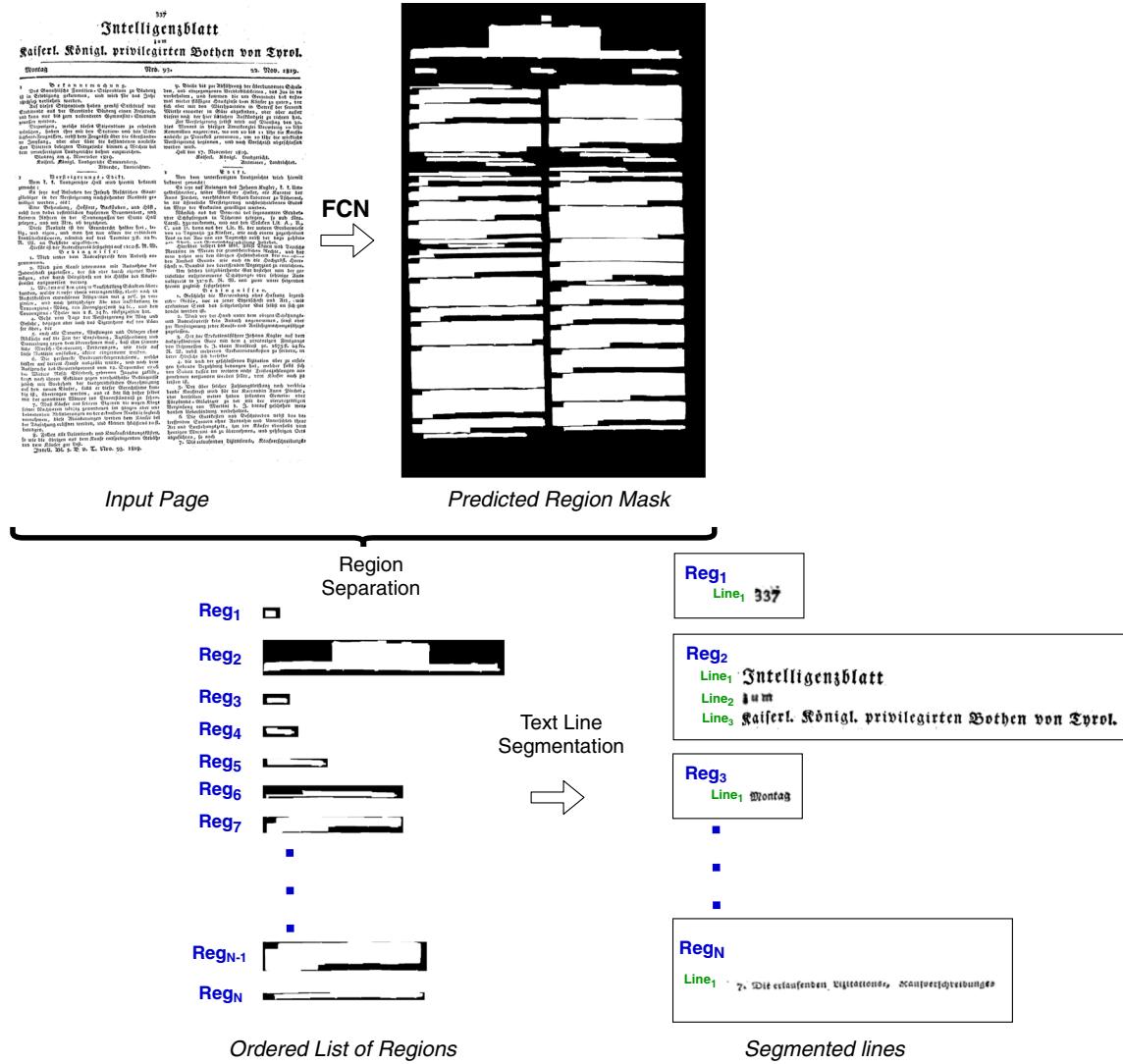


Fig. 2 Region and line segmentation task scheme

with the stride 2 for downsampling. At each downsampling step we double the number of feature channels. Every step in the expansive path consists of an upsampling of the feature map followed by the 2×2 convolution (“upconvolution”) that halves the number of feature channels,

a concatenation with the correspondingly cropped feature map from the contracting path, and two 3×3 convolutions, each followed by a ReLU. The cropping is necessary due to the loss of border pixels in every convolution. At the final layer, the 1×1 convolution is used to map each

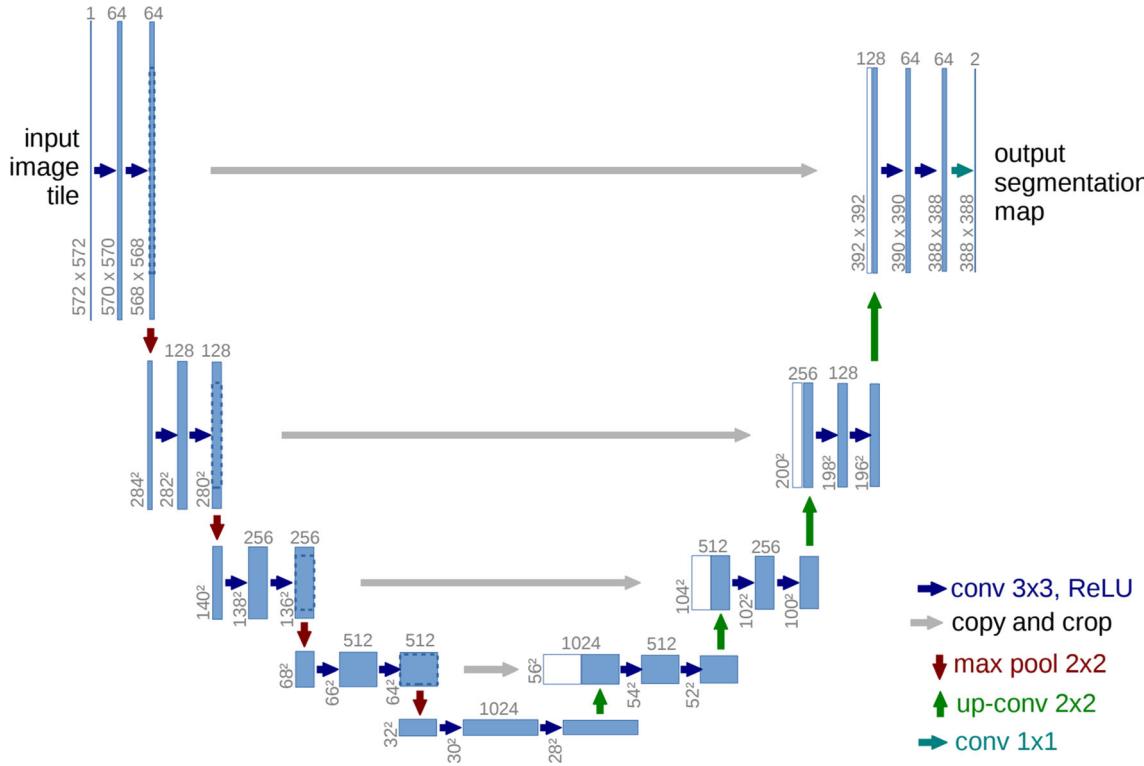


Fig. 3 U-Net architecture [11]

64-component feature vector to the desired number of classes.

A modification of the U-Net model used for segmentation of historical document images was proposed by Wick and Puppe [36]. The main difference from U-Net is that it does not use skip connections. The whole architecture of this network is much simpler (see Fig. 4), and the number of parameters is also much lower. The encoder part has five convolutional and two pooling layers. The size of convolution kernels is set to 5, and padding is used to keep the dimension. The decoder consists of four deconvolution layers. We will refer this modification as *U-Net (Wick)*.

We classify the image pixels into two classes: text region (regardless of whether the pixel is part of the text or background—white) and non-text region (black). The output of the FCNs is a prediction map with the same dimension as the input image. Each position in the map indicates the probability that a pixel belongs to the region. To obtain a binary image, we threshold the output. We use the widely used Otsu's [37] method for this task. The resulting binary image mask contains ones within the text regions and zeros elsewhere.

Based on the predicted segmentation mask, we divide the image into text regions and we also determine the reading order. We solve this task by recursive searching for horizontal and vertical separators in the segmentation map. Firstly, we search for horizontal separators and divide the

image into several regions according to it. In the sequel, we attempt to divide the resulting regions. Again, we first search for horizontal separators, and if none is found, we search for the vertical ones. The recursion is applied, till we reach the desired level (granularity) of segmentation. We apply three levels of block segmentation on the data from Porta fontium. This approach respects the logical reading order of the processed documents. The outcome of this step is an ordered list of image regions containing text.

An example of the recursive search of region separators is shown in Fig. 5. The red lines represent the horizontal separators (first level), while the green ones are the vertical separators (second level). The blue lines then mark the horizontal separators in the third level.

3.3 Text line segmentation

In our previous work [38], we utilized a simple projection profile based text line segmenter. The approach works very well for simple regions with regularly positioned lines. However, it might not be sufficient for more complex regions, and hence, in this paper, we present two more sophisticated methods for text line segmentation. We will refer to the original profile based method as *Profile*.

Fig. 4 Modified U-Net architecture proposed by Wick and Puppe [36]

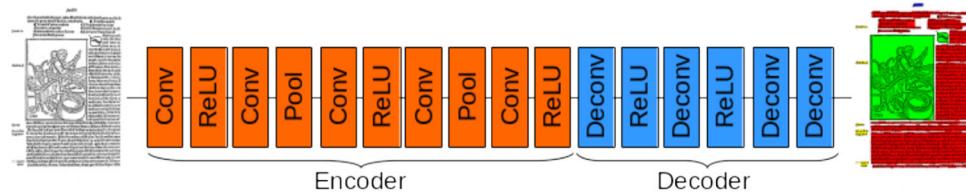
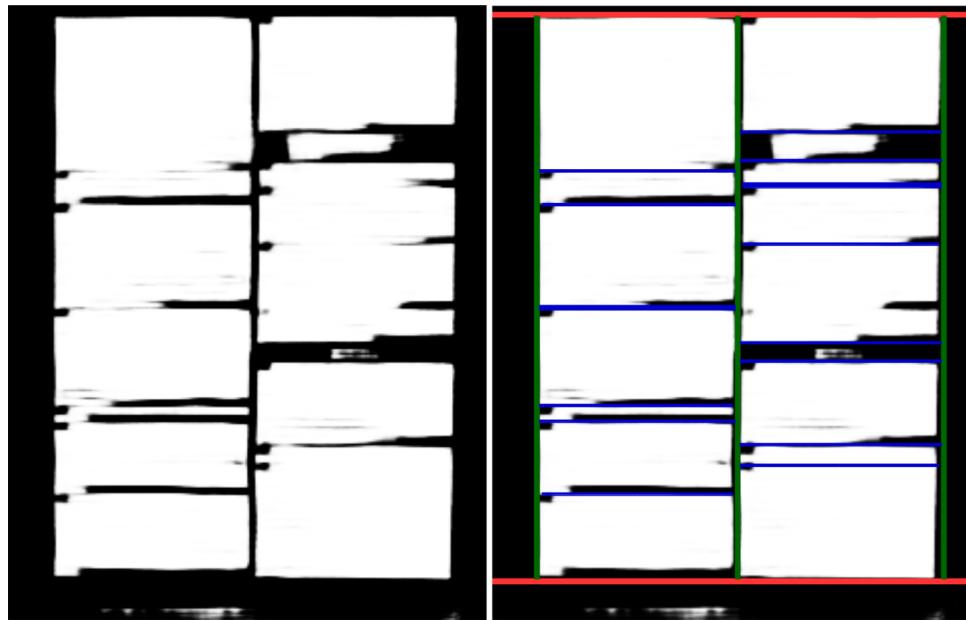


Fig. 5 Block segmentation example (recursive search of horizontal and vertical separators) (color figure online)



3.3.1 ARU-Net

Gruning et al. [3] proposed a novel deep neural network, called ARU-Net, which is able to detect text lines in handwritten historical documents. This network extends U-Net by two more key concepts—spatial attention (A) and depth (R, residual structure). The attention mechanism allows the ARU-Net to focus on image content at different positions and scales [3]. As a consequence, it should lead to a better detection of texts with variable font sizes. Due to the deep structures of the architecture, residual blocks are used to address vanishing gradient issues [39].

Our method builds on the prediction result of the ARU-Net trained to recognize baselines. The output mask is first binarized, and then, we extract the positions of baselines. Next, we perform analysis of connected components on the binarized region image and we search the components that intersect with or are very close to the detected baseline. Based on the relevant component statistics, we can induce the boundaries of the text line. We are then able to extract the line image according to the boundary. The process is depicted in Fig. 6.

3.3.2 Kraken

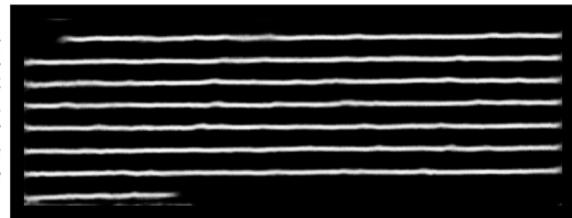
Kraken⁷ is an open-source OCR software forked from OCROpus. Although this tool offers a lot of features (e.g., script detection), we use only segmentation, more precisely text line bounding box prediction. When deploying on the extracted text block, it produces bounding box coordinates in a json file. The bounding boxes, based on json file, are depicted in Fig. 7. Since Kraken provides only bounding boxes with a rectangular shape, it is beneficial to reduce segmentation errors by performing image preprocessing, especially deskewing and dewarping. Another option would be to use Kraken to locate word bounding boxes. In such a case, bounding boxes with rectangular shape would be sufficient.

Because the line bounding boxes sometimes overlap each other, it is necessary to remove the remainder of the text of the previous or next line (see Fig. 8). We address this issue by removing connected components which are close to the bottom or top edge of the image.

⁷ <https://github.com/mittagessen/kraken>.

„Schweig, Schlingel!“ gebietet Falkner und kehrt dem Zimmer den Rücken. Er eilt ins Schloß und stattet dem Herzog so schonend wie möglich den traurigen Rapport ab. Die Nachricht jedoch wirkt so alterirend auf den Kranken, daß ihn sofort ein Wundfieber befällt und der Leibarzt den Kammerherrn ins Nebenzimmer zieht, wo er ihm die heftigsten Vorwürfe macht, nicht zurückhaltender gewesen zu sein.

„Schweig, Schlingel!“ gebietet Falkner und kehrt dem Zimmer den Rücken. Er eilt ins Schloß und stattet dem Herzog so schonend wie möglich den traurigen Rapport ab. Die Nachricht jedoch wirkt so alterirend auf den Kranken, daß ihn sofort ein Wundfieber befällt und der Leibarzt den Kammerherrn ins Nebenzimmer zieht, wo er ihm die heftigsten Vorwürfe macht, nicht zurückhaltender gewesen zu sein.



„Schweig, Schlingel!“ gebietet Falkner und kehrt dem Zimmer den Rücken. Er eilt ins Schloß und stattet dem Herzog so schonend wie möglich den traurigen Rapport ab. Die Nachricht jedoch wirkt so alterirend auf den Kranken, daß ihn sofort ein Wundfieber befällt und der Leibarzt den Kammerherrn ins Nebenzimmer zieht, wo er ihm die heftigsten Vorwürfe macht, nicht zurückhaltender gewesen zu sein.

Fig. 6 ARU-Net text line segmentation example

„Schweig, Schlingel!“ gebietet Falkner und kehrt dem Zimmer den Rücken. Er eilt ins Schloß und stattet dem Herzog so schonend wie möglich den traurigen Rapport ab. Die Nachricht jedoch wirkt so alterirend auf den Kranken, daß ihn sofort ein Wundfieber befällt und der Leibarzt den Kammerherrn ins Nebenzimmer zieht, wo er ihm die heftigsten Vorwürfe macht, nicht zurückhaltender gewesen zu sein.

„Schweig, Schlingel!“ gebietet Falkner und kehrt dem Zimmer den Rücken. Er eilt ins Schloß und stattet dem Herzog so schonend wie möglich den traurigen Rapport ab. Die Nachricht jedoch wirkt so alterirend auf den Kranken, daß ihn sofort ein Wundfieber befällt und der Leibarzt den Kammerherrn ins Nebenzimmer zieht, wo er ihm die heftigsten Vorwürfe macht, nicht zurückhaltender gewesen zu sein.

Fig. 7 Kraken text line segmentation example

bich!“ Rollenden Auges klammert sie sich an seinen

Fig. 8 Overlapping text line example extracted by Kraken segmenter

4 OCR engine

The classifier utilizes a combination of a convolutional neural network [20] and the LSTM neural network [18].

The inputs of our network are binarized line images with a dimension of 1250×40 pixels. Based on our preliminary experiments, the images are padded from the left by 50 pixels, so the input layer shape increases to 1300×40 . On the input layer, we apply two convolutional layers with 40 kernels with a shape of 3×3 and *MaxPooling* layers. After this first phase, we obtain 40 feature maps and we also reduce dimensionality by scaling down the input to 325×10 .

Through a reshaping mechanism, we create a dense layer which is fed into two Bidirectional LSTM layers. Each Bi-LSTM layer comprises two LSTM layers which process the input from opposite sides. One LSTM layer contains 256 units. The outputs of the LSTMs from the first Bi-LSTM layer are merged by addition operation, while the outputs of the second pair of LSTMs are concatenated.

The concatenated output is given to a dense layer with softmax activation. It is a representation of probability distributions of individual symbols per each time frame. Let \mathcal{A} ($|\mathcal{A}| = 90$) be a set of symbols. It includes out of

vocabulary (*OOV*) and *blank symbol*. The most probable symbol \hat{a}_t of each time frame t is determined as:

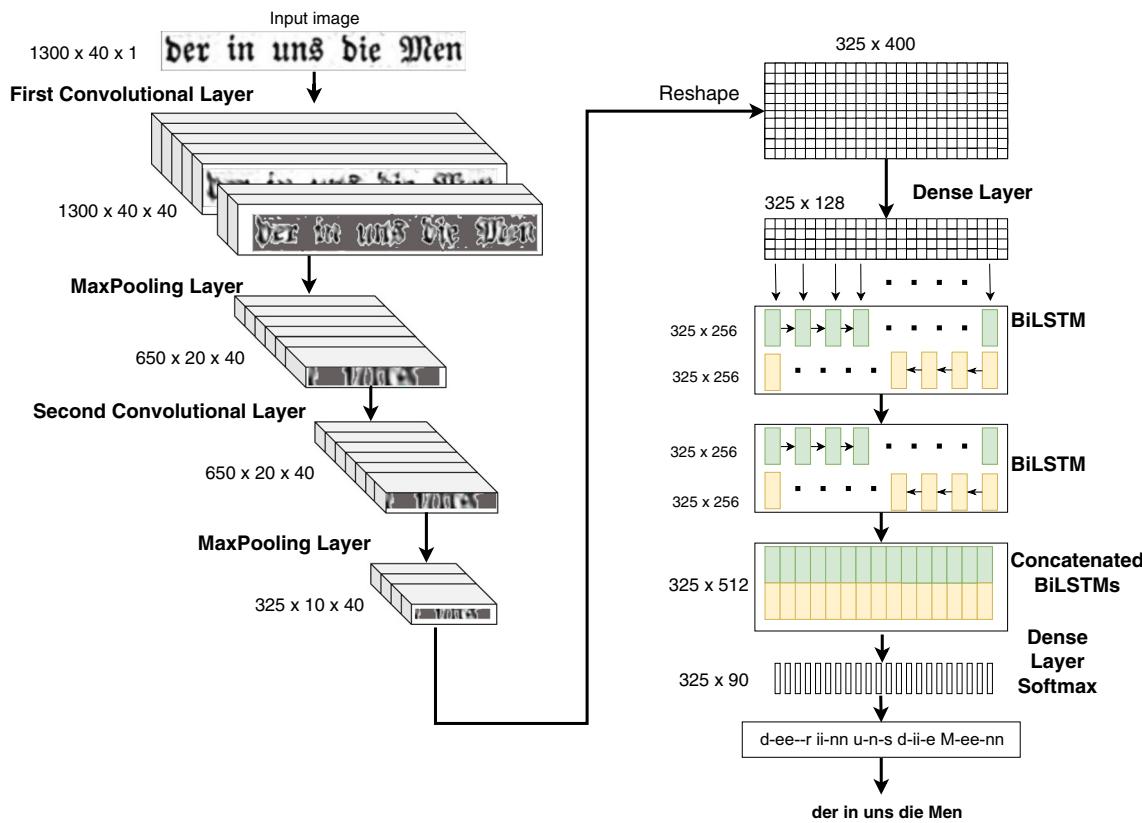
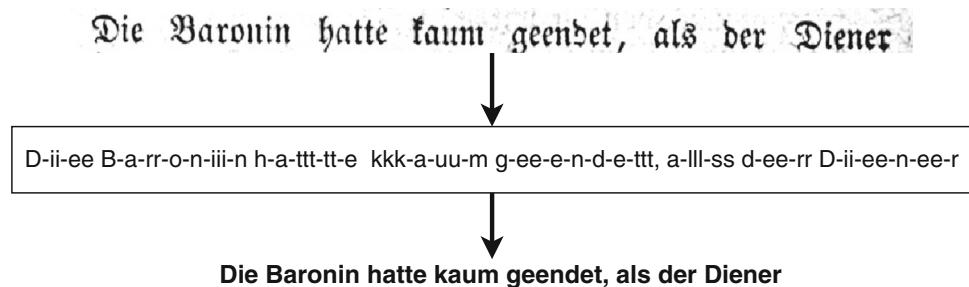
$$\hat{a}_t = \underset{a_i \in \mathcal{A}}{\operatorname{argmax}} p_t^{a_i} \quad (1)$$

where $p_t^{a_i}$ is a probability of observing character a_i at a given time t . At each time t , the sum of the probabilities of all symbols is equal to 1.

$$\sum_{i=1}^{|\mathcal{A}|} p_t^{a_i} = 1 \quad (2)$$

The final part of the classifier is a transcription layer, which decodes the predictions for each frame into an output sequence.

We use connectionist temporal classification (CTC) output layer. CTC is an output layer designed for sequence labeling with RNNs [2], and therefore, it is capable of classifying unsegmented line images and retrieving the character sequences. The architecture of the classifier is depicted in Fig. 9. Figure 10 shows another input image processed by the model and the CTC alignment. Note that this model was already used in our previous work [38].

**Fig. 9** OCR engine architecture**Fig. 10** Another example of CTC alignment

5 Datasets

In this section, we describe the datasets we utilize for our experiments. The first one is the Europeana dataset. It was chosen because of its similarity to the data we are processing (newspaper pages). We use it to pre-train our page segmentation neural networks.

The second dataset is newly created from the Portafontium portal⁸. It contains newspaper pages that we process in the frame of the *Modern Access to Historical Sources* project. It contains full transcriptions of the pages as well as layout information. It is utilized both for page

segmentation and OCR engine training. It allows us to measure the quality of the developed methods on real data.

5.1 Europeana

The Europeana Newspapers Project Dataset [40] was created in the context of the Europeana Newspapers Project (ENP). The goal of the project is aggregating a representative set of historical newspapers. The dataset was created so that it takes into consideration all the challenges and issues related to the processing of historical document images. The dataset contains more than 500 newspaper pages and their ground truths containing full transcribed text, layout information and reading order.

⁸ <http://www.portafontium.cz/>.

Table 1 Statistical information about the Europeana dataset

	Page #	Block #	Line #	Word #	Character #
Training	68	6849	27,098	149,464	832,331
Validation	9	741	2549	15,597	81,839
Testing	18	2469	8010	41,409	234,208

From this set, we have selected a subset of 95 pages mostly written in German and with varying layouts so that it can provide enough flexibility for the text segmentation model. Table 1 illustrates the relevant statistical information, and Fig. 11 shows one page example from the Europeana dataset.

5.2 Porta fontium

Porta fontium is a project which aims at digitizing archival documents from Czech–Bavarian border area. The goal is to join again the Czech and German archival materials that come from the border area which were forcibly separated in the past.

We have created an OCR and page layout analysis dataset from one selected newspaper, namely “Ascher Zeitung,” printed in the second half of the nineteenth century. The main script used in this newspaper is “Fraktur.” However, there are also some parts printed in Latin script and with different fonts. The dataset consists of 10 pages that are completely transcribed. All of them are accompanied with ground truths containing layout information and reading order. The ground truth is stored in the PAGE format [31].

We have selected the pages that are printed completely in Fraktur so that they can be used to train an OCR model for this script. We have divided the 10 pages into training, validation and testing parts (see Table 2 for the details). An example of one page is shown in Fig. 12.

The second part of this dataset contains 15 additional pages with ground truths containing only the layout information. We have selected the pages with more complicated layouts. The intended use of these additional pages is facilitating the training of page segmentation models.

5.3 Synthetic data

Using synthetic data is very important in the proposed OCR training procedure, because we used such data for pre-training of the OCR models. This section analyzes different types of synthetic data creation. It is beneficial

that these data are as similar as possible to the annotated images depicted in Fig. 13. We have created two types of synthetic data. The first type is referred as *Hybrid* according to our previous work [38]. It is basically a composition of images containing single characters. The second one is referred as *Generated* and is produced simply by a generator with specified font.

5.3.1 Impact of the implicit language model

Language models are often used in the OCR field to correct recognition errors [41]. Sabir et al. [6] showed that LSTM-based models are able to learn language model implicitly. This LM is trained during the learning of the whole network.

Therefore, in the following experiments we will study the impact of this implicit language model for the final OCR accuracy. We assume that the best results will be obtained if we use the training data from the target domain which are, in our case, historical German texts from the second half of the nineteenth century. To show the influence of the implicit model, we used three text sources for network training:

1. Completely random text—characters have a uniform probability distribution
2. Historical German text
3. Modern German text from the Reuters dataset [42]

Although the second and the third type of data have similar distribution of characters (see Fig. 14), the quality of the language model will slightly differ (types of expression, vocabulary and so on).

5.3.2 Hybrid data

The first approach to generate text lines for OCR training consists in concatenation of the images of individual characters. It must be done with respect to the target font though. Based on our previous studies [38], we utilize so-called *random space* approach for generating the hybrid data. This method adds a gap of a random size (within some reasonable bounds) between each pair of adjacent characters.

To introduce variances in our generated text lines, we have several different examples of each symbol and we use a randomly selected image for a given symbol. This is a form of data augmentation technique (e.g., Perez et al. [29]) because from one source text line it is possible to create several different corresponding images. Based on our previous experiments [38], we use random gaps between characters in the interval [1; 5] pixels. Figure 15 shows an example of generated data using this approach.

Fig. 11 Page example from the Europeana Dataset

Berühmte Männer und der Sport.

„Mens sana in corpore sano.“

Nurjere Zeit hat bietes klassische Erziehungssodal in die Tageszeitung. Nam es nicht, daß den Griechen darauf an, Griechen? Aber gleichzeitig durchaus haben, so haben doch jüngste Zeiten auch Erziehungsmethoden gelernt, und nach langen Jahrhunderten, in denen die Erziehung einzigartig auf die Ausbildung der geistigen Fähigkeiten begrenzt war, dämmert nun ein Zeitalter heraus, das den Wert der Leibesbildung in vollem Umfange anzuerkennen bereit ist. Wie für die gesitteten Jugend früher die Kenntnis des Homer einfach ein Standesforderungsmerkmal war, so heute die Ausbildung einzelner Sportarten unbedingt eine Notwendigkeit, die erst zum Vollmeisten, zum modernen Menschen hinspielt. Ein Mensch, der nicht schwimmen kann, — läßt sich darüber nicht leichter über den Bauernbürokrat, der nicht lesen kann?

Es wäre nun ganz verfehlt, anzunehmen, daß es in der einzigartig ausgeführten Erziehung der damaligen Zeit nicht auch Männer gab, die unserem heutigen Geschlecht als erste Kämpfer und Vorläufer einer großen Bewegung gelten könnten. Und gerade jenen, die über die großartige Entwicklung des Sports die Hände ringen und den Untergang ihres Homer für gekommen halten, gerade jenen sollte ein Blick in die Geschichte zeigen, daß viele berühmte Männer so etwas wie Sport treiben, daß sie, aus dem Rahmen der Gewohnheiten ihrer Zeiten gestossen, gleichsam einen Handwerksmarkt haben von dem neuen Geiste, der mit dem Sport über den Menschen kam. Mens sana in corpore sano.

Erinnern wir uns des großen Feldherrn Prinzen Eugen, der ein Turner war, und auf heutigen Turnhallen seine Poste hielten könnte. Erinnern wir uns und allen Kanalchwimmern, daß er gelangt, daß sie einen großen Vorläufer hatten, nämlich François I., der einmal über 100 Kilometer auf der Themse schwamm. Eine beachtliche Leistung für damals! Und vergessen wir den ehrwürdigen Tolstoi nicht, der ein ebenso guter Schwimmer wie Läufer war. Merchierte er doch einmal eine Strecke von 200 Kilometern in drei Tagen, wobei zwei junge Leute, die ihn begleiteten, völlig versagten, und Tolstoi allein aus Ziel gelangte.

Und kennen wir nicht Byron auch als Schwimmer und Reiter, als Boxer von Form? Brahms machte Bergtouren. Wagner soll noch mit sechzig Jahren sich den Kopftanz erlaubt haben, seine Göttin mit einem Kopftanz zu erfreuen. Remond mit zum Schluß den Größten von allen, um die Reise berühmter Männer, die in ihrem Sinn Sportfreunde waren, hier abzufügen, Goethe.

Es ist wenig bekannt, daß Goethe ein ausgewachsener Reiter und ein lebensgefährlicher Eisläufer war und die körperliche Betätigung als Ausgleich der seelischen Einsamkeit ernstlich schätzte. Daher mußte es ihm folglich auftallen, wie salzig und unangenehm man zu seiner Zeit die Jugend ergo, wie weit unterdrückt das Alter-Geistige, wie sehr unterdrückt der körperliche Zustand der Jugend wurde und wie wenig man die gute Wirkung der Leibesübungen auf den arbeitenden Geist erkannt hatte.

„Es geht bei uns alles dahin“, sagt Goethe, „die liebe Jugend fröhligst zähmt zu machen, alle Originalität und alle Weitläufigkeit auszutreiben, so daß am Ende nichts übrig bleibt als der Phister.“

Und als man sich aus politischen Gründen gewogenen glaubte, den eben ausüblichen Turnwesen die Regel vorzuschreiben, war Goethe eigentlich betroffen. Zu Gedenken sagt er darüber: „Ich bin den deutschen Turnübungen durchaus nicht abgeneigt; und so mehr habe ich seitdem, daß ich sehr bald militärisches Leben einschläfst, so daß die Verdronnenheit mich gelehrt, sich für zu beschäftigen oder möglicherweise gar zu verabscheuen. Dann ist mir ein Rinten im Bauch verblieben. Aber ich hoffe, daß meine Jugend am Anfang wieder herstellen, denn unter deutscher Jugend bedarf es, besonders die jugendliche, der bei dem vielen geistigen und gelehrten Treiben ältere Väterliche Gleichgewicht.“

Goethe ist also die Doppelwirkung des Sports von Anbeginn klar gewesen, und daß mag der Grund gewesen sein, warum aller Sport ihm persönlich so wichtig geworden ist.

„Zürchtung und Wahlrecht“ beschreibt er uns, wie er fechten und reiten lernte, und beweist uns zugleich, wie ernsthaft und erdig er und seine Sportfameraden sich dem Fechten hingeben haben: „Wir waren nun herangewachsen.“ sagt er, „und den Schenktionen nach sollten wir auch neben anderen Dingen fechten und reiten lernen, um uns gelegentlich unserer Haut zu wehren und zu Werde kein häulerhaftes Aufsehen zu haben. Was den ersten Punkt betrifft, so war und eine solche Übung sehr angenehm: denn wir hatten uns schon längst Haupträpere von Hofsoldaten, mit Stören von Bedien, sauber geschlossen, um die Hand zu schärfen, zu verschaffen gewußt. Nun durften wir uns wirklich häulerne Klinge zulegen, und das Geräusch, das wir damit machen, war sehr lebhaft. Es befanden sich damals zwei Fechtmäster in Frankfurt, ein älterer Deutlicher, der auf strenge und nüchterne Weise ging, und ein Franzose, der seinen Vor teil durch Anwärteren und Reizieren, durch leichten, flüchtige Stöße, welche stets mit einigen Ausrufen begleitet waren, zu erreichen suchte. Die Meisterschaft, welche Art die beste sei, waren geteilt und es ward fast ebenso sehr mit Werken gefritten, als mit der Klinge gehoben. Und um zugleich der Sache ein Ende zu machen, ward um Wettkampf zwischen beiden Weitern verhandelt. Ein Deutscher, der seiner Waffenseite eine Waffe wußte aus seinem Vor teil und wußte mit Battieren und Zepieren seiner Gegner das eine über das andere Wal zu entfernen. Dieser Deutermann, das ist nicht Nation und führ mit seiner Beweglichkeit fort, den anderen in Stein zu legen. Auch brachte er dem Deutschen wohl einige Stöße bei, die ihn aber leicht, wenn es Ernst gewesen wäre, in die andere Welt geschleift hätten.“

Goethe wird heute oft zitiert, wenn es gilt, dem Sportgebunden eine Freiheit zu schlagen. Und das mit Recht; wenn zu seiner Zeit der Sport noch keineswegs die universelle Bedeutung haben konnte, die er sich heute erklängt hat — so sind die Aussprüche Goethes doch Bekennnisse eines Geistes, der Kommenches abtute. Und das ist uns im Kampf gegen die Sportverächter heute noch eine starke Waffe.

Verantwortlicher Redakteur: cand. phil. H. Becker.
Herausgeber: Wilhelm Becker.

Für Recht und Ordnung!!

Deutsche Krankenkassen-Glieder Windaus!

Stimmt zu den am 13. und 14. Juli bevorstehenden Wahlen der Bevollmächtigten für die deutsche

Liste Nr. 7.

1. Werner v. Lutzau	8. Otto v. Jannau
2. Otto Tiedemann	9. Alexander Schwedersky
3. Harald Gutschmidt	10. Heinrich Paulin
4. Herbert Marks	11. Karl Sawitsky
5. Eduard Karlson	12. Karl Lorenz
6. Karl Schreiber	13. Herbert Friedrich
7. Eduard Boehm	14. Johann Neumann

Achtet darauf, daß Eure Kassenbücher erneuert sind, da Ihr sonst nicht stimmen könnt. Nehmt Kassenbücher und Pässe zum Wahllokal mit! Nehmt keinerlei Streichungen in den Listen vor, da Eure Stimme sonst ungültig ist! Meldet Euch nach der Stimmbgabe im deutschen Wahlbüro!

Das Wahlbüro (Große Str., im Hause des Gewerbe-Berlins) ist ab Mittwoch, den 3. Juli, täglich von 12—1 und von 19—20 Uhr geöffnet. Alle Auskünfte dagegen. An den Wahltagen wird das Büro den ganzen Tag über geöffnet sein.

Für Recht und Ordnung!!

ENGLISCHE ROYAL STAR
Fahräder
sind zu haben in der
Buchhandlung Ferd. Besthorn
Inh. W. Beritz
Goldingen.

Rechtsanwalt
Kurt Sladde
empfängt jetzt
Windau,
Goldinger Straße № 10.

mit nie versagendem
Dosenöffner.
K/S Sidol Company.
Riga, Kisezera iela № 3, Telephon
35317.

Malermeister R. Urban,
Goldingen, Polizei-Str. № 3.
Übernahme verschiedene Maler-
arbeiten zur sofortigen Ausführung.

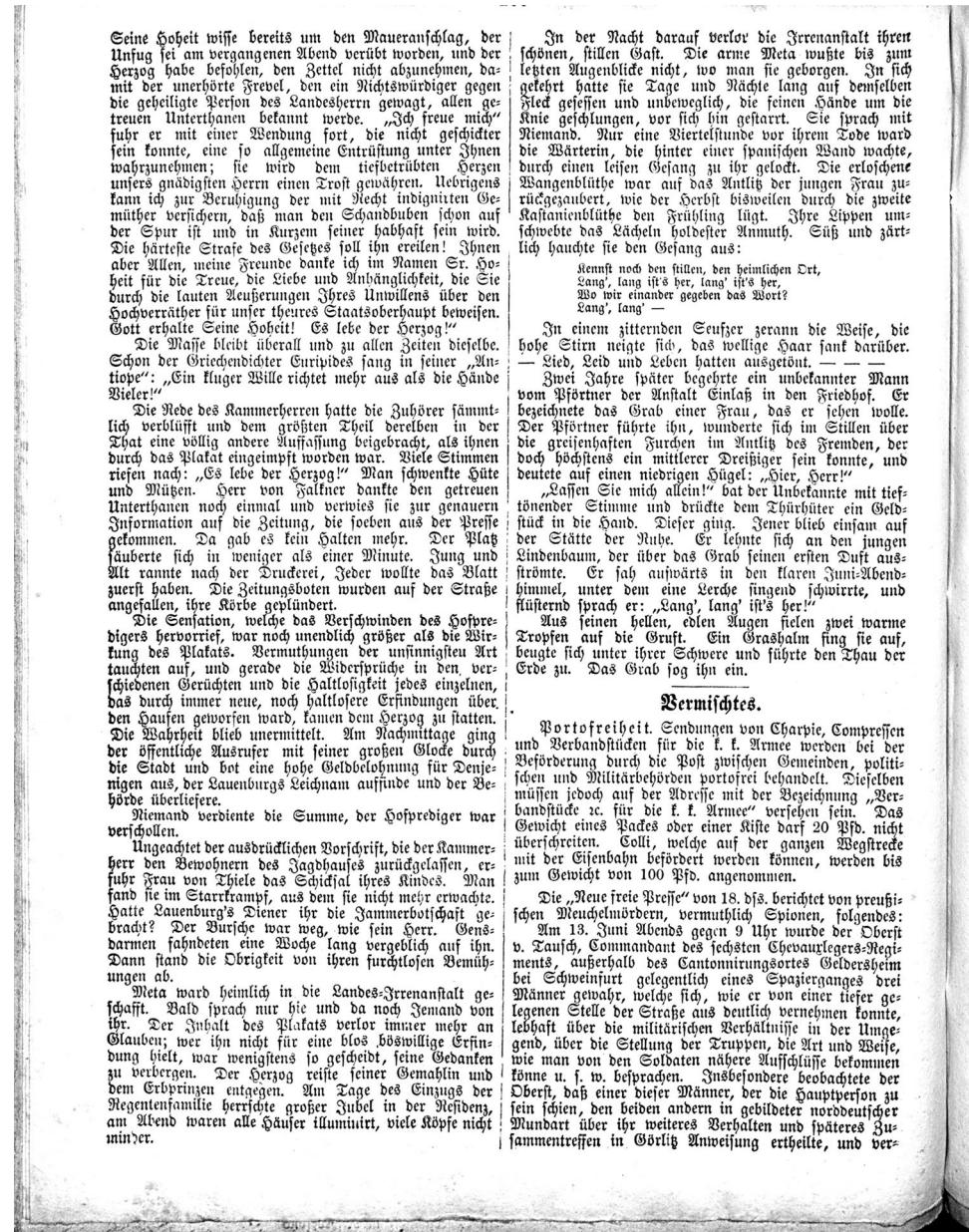
Miet-Quittungs-Bücher
sind vorrätig in der
Buchdruckerei Eugen Petkiewicz, Goldingen.

Foto-Zentrale
H. Kleinberg
(Firma M. Goldingen, Ritterstraße Nr. 16,
empfohlen zu konstanzigen Bildern
Preisen:
Kameras, Stativen, Kaliesten,
Platten, Rollfilme, Filmräder,
Röntgenfilme, Lichtempfindliche
Papiere und Karten, Chemikalien etc. — Landkartenplatten von № 1 — pro Stück.
— Ausarbeitung von Amateuraufnahmen
(Entwickeln von Negativen und
Auffertigung von Kopien).

Budenlokal
mit Wohnung
ist sofort zu vermieten.
zu erfragen: S. Lissmann,
Goldingen, Ritterstr. 27.

Table 2 Statistical information about the Porta fontium dataset

	Page #	Line #	Word #	Character #
Training	7	955	7653	50,426
Validation	1	138	1084	6669
Testing	2	275	2163	13,828

Fig. 12 Page example from the Porta fontium dataset**Fig. 13** Examples of Fraktur script from Porta fontium dataset

das Leben gab, ein Opfer bringen, über das Engel weinen
Charfreitag Abend, als deiner Mutter der Segen, um

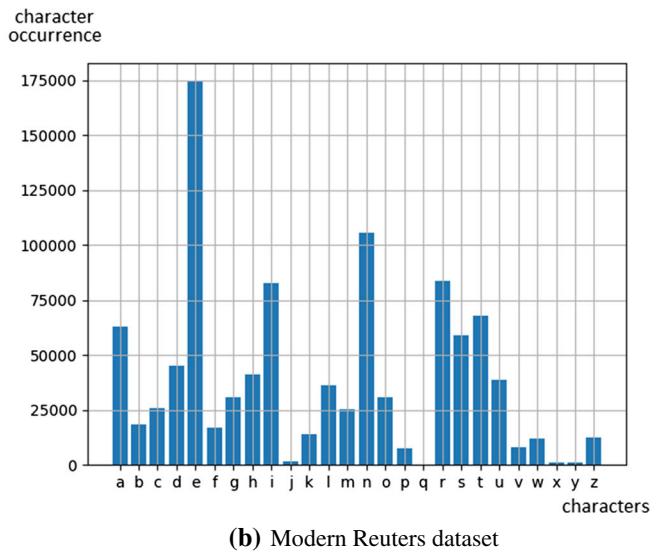
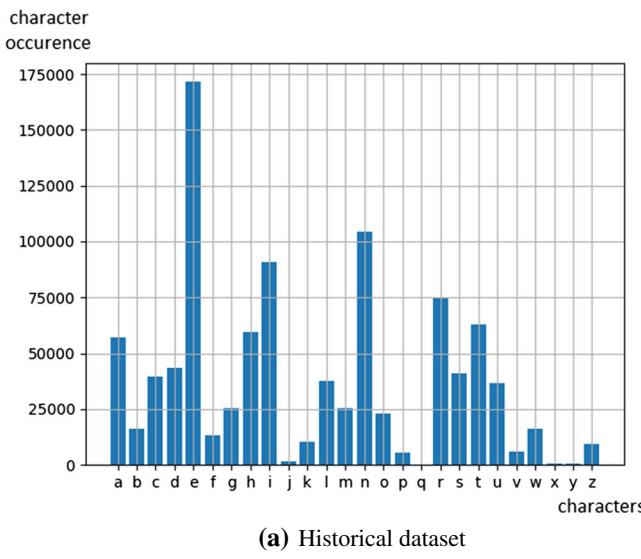


Fig. 14 Histograms of the character frequencies of the historical (left) and modern (right) text data sources



Fig. 15 Examples of hybrid data generated by *random space* method

5.3.3 Generated data

The second approach uses the data generated by the `TextRecognitionDataGenerator`⁹. This tool, written in Python, has many parameters that influence generated images, which includes, for example, background settings (white background or Gaussian noise). Moreover, it allows to choose a font, source texts and several types of image transformations (skewing or warping) to make the desired image of the text line. Figure 16 illustrates two line examples generated by this tool. These examples clearly show that the data are significantly different from the previous ones generated by *random space* method, because the rendered character is always the same.

6 Experiments

All presented experiments are conducted on a PC with Intel Core i7 processor and 64GB RAM. All neural network-based computing is performed on GPU GeForce RTX 2080 Ti with 11 GB RAM.

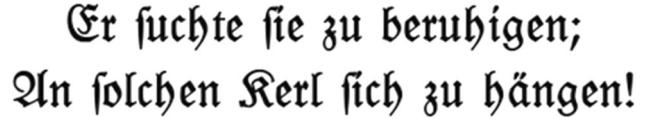


Fig. 16 Two line examples of generated data by `TextRecognitionDataGenerator`

6.1 Layout analysis and segmentation

This experiment is carried out in order to identify the best block segmentation approach which will be then used in all following experiments.

Two text block segmentation approaches described in Sect. 3, namely *U-Net* and *U-Net (Wick)*, are evaluated on both the Porta fontium dataset.

Because the amount of training data in the Porta fontium corpus is limited, we utilize transfer learning [43] in this case. We train the models first on a subset of the Europeana newspaper dataset, and then, the models are fine-tuned on the training set of the Porta fontium dataset.

In both networks, we use ReLU [44] activation function for all layers and Adam [45] optimizer with 0.001 learning rate. We chose the binary cross-entropy as a loss function, since there are only two classes. (A pixel is labeled either as a part of the text region or not.)

Tables 3 and 4 show results of this experiment. The first table shows the ability to predict text blocks. The measures compare directly the segmentation result with the ground-truth map. Table 4 presents the results computed only on foreground pixels within the text blocks.

The segmentation results are evaluated and visualized using DIVA layout evaluator [46] which calculates usual

⁹ <https://github.com/Belval/TextRecognitionDataGenerator>.

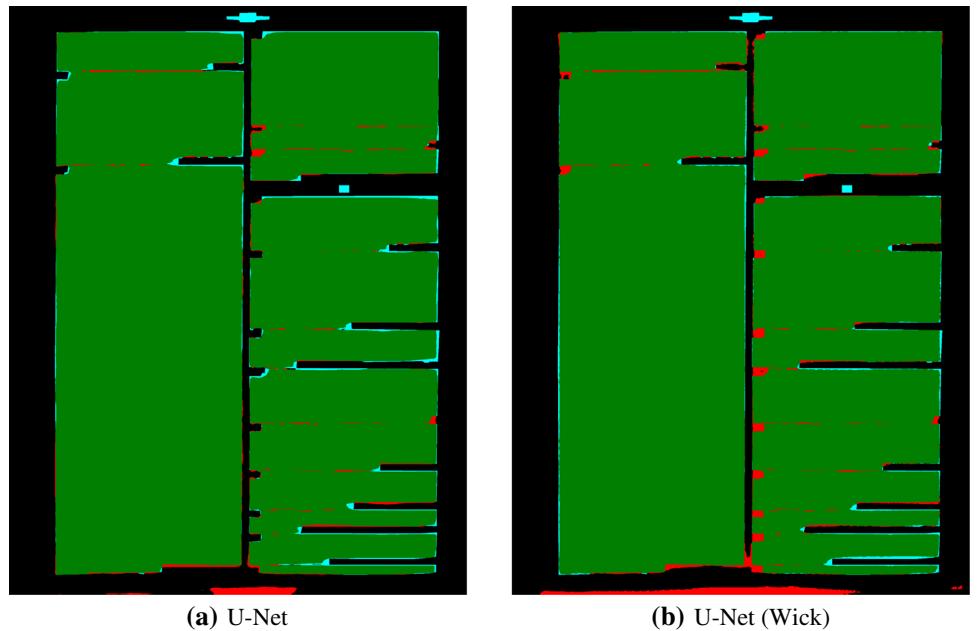
Table 3 Text block segmentation: comparison of the performance of *U-Net* and *U-Net (Wick)* trained on Europeana and Porta fontium datasets, evaluated on Porta fontium dataset

Model	Exact match	F1 score	Jaccard index	Hamming score
U-Net (Europeana)	94.53	94.62	89.96	94.53
U-Net (Porta fontium)	97.67	97.67	95.50	97.67
U-Net (Wick) (Europeana)	95.36	95.42	91.36	95.36
U-Net (Wick) (Porta fontium)	97.60	97.60	95.36	97.60

Table 4 Text block segmentation: comparison of the performance of *U-Net* and *U-Net (Wick)* trained on Europeana and Porta fontium datasets, evaluated on Porta fontium dataset, measured only on foreground (text) pixels

Model	Exact match	F1 score	Jaccard index	Hamming score
U-Net (Europeana)	99.65	99.65	99.30	99.65
U-Net (Porta fontium)	99.91	99.91	99.82	99.91
U-Net (Wick) (Europeana)	99.73	99.73	99.47	99.73
U-Net (Wick) (Porta fontium)	99.92	99.92	99.84	99.92

Fig. 17 Visualization of text block segmentation using *U-Net* and *U-Net (Wick)* on Porta fontium dataset (color figure online)



evaluation metrics for this task: exact match, F1 score, Jaccard index and Hamming score.

We further visualize the segmentation results for qualitative analysis (see Fig. 17). The green color represents correctly assigned pixels (each green pixel is predicted as a part of a text region). The red color indicates that the model predicted this pixel to be part of a text region, but it is not. The blue (turquoise)-colored pixels are pixels that should be considered as part of a text region but the model omitted them.

Tables 3 and 4 show that the performance of both models is comparable and both of them are suitable for our task. The advantage of the Wick modification is its lower number of parameters and therefore the faster training. The

results in Table 4 are very similar and comparable, and one cannot make an unbiased decision. The numbers indicate that both networks are able to recognize the text content with the accuracy close to 100%. On the other hand, the results in Table 3 show slightly better performance of U-Net trained on Porta fontium dataset. The results of this table are more important for us as the main goal is to recognize the text regions. Figure 17 shows that *U-Net* model tends to better differentiate text paragraphs and could thus be more suitable for our task (significantly less red and turquoise color).

The time needed for training of the U-Net model was 36 min on the Europeana dataset and 11 min on the Porta fontium dataset, respectively.

6.2 OCR results when training on a small amount of real annotated data

We assume that using only a few real annotated samples for OCR model training will not be sufficient for reaching a good performance.

To support this hypothesis, we performed the following series of experiments to show the OCR results when our engine is trained from scratch using only a little real annotated data. To show the impact of the number of model parameters, we used two different models. The first one [38] has the input width of 650 pixels, while the second, more complex one, uses input width of 1250 pixels. We also evaluate and compare three previously described line segmentation approaches, namely *Profile*, *ARU-Net* and *Kraken*.

Our OCR engine utilizes ReLU activation function for all hidden layers. We use the CTC loss function and stochastic gradient descent (SGD) as an optimizer. For training the model from scratch, we apply 0.002 learning rate, while for fine-tuning, we set a learning rate 0.001. The output layer uses the softmax activation function.

All models are trained with early stopping. We train it until the validation loss begins to stagnate or decrease for some subsequent iterations. We ran all experiments 5 times and present the average values. This experimental settings is used in all following experiments.

For evaluation, we use the standard word error rate (WER) and character error rate (CER) metrics. Additionally, we employ the edit distance, also known as the Levenshtein distance. All metrics are averaged across the text lines. For WER/CER, we first add up all deletions, insertions and substitutions in a text line and divide this value by the number of words/characters in the line. We average the number across all lines in the test corpus. The same procedure is applied to the edit distance metric.

A desirable value of CER, which is mostly reported to evaluate the quality of OCR systems, is below 1% for good quality printed texts. In our case, taking into consideration a lower quality of historical scans and the old language, an acceptable value lies around 2%.

Table 5 shows the OCR results of the smaller model having an input width of 650 pixels while Table 6 illustrates the results of the OCR model with the input width of 1250 pixels. The comparison of the two tables shows that the larger model needs the smaller number of epochs to train. On the other side, the larger model converges worse in the case of the Kraken line segmentation than the smaller one (significantly higher values of the all analyzed metrics).

The bottom line is that the training from scratch with a small amount of annotated data is possible; however, it is difficult to set the network hyperparameters so that the network converges. The obtained character error rates are also higher than desired and it is not possible to use such a model in a production system.

6.3 OCR results when training on synthetic data

As has been proved in many previous studies [26, 47], synthetic data are of great importance when training OCR models. Therefore, in this experiment, we evaluate and compare the performance of our OCR model trained only on different types of synthetic data. Moreover, this experiment evaluates the impact of the implicit language model (LM) on the OCR results. We use the U-Net based block segmentation and Kraken based line segmentation in this experiment, as it achieved the best results in the previous experiments.

Table 7 shows the results of this experiment. We use the model with the input size of 1250×40 pixels.

This table shows insufficient results for the model trained only on synthetic datasets. The best CER we obtained was around 20% for the hybrid training data based on historical German text which is far to be usable in real application. Moreover, the obtained average edit distance value is also very high. (We need almost 10 operations—deletions, insertions or substitutions on average to transform the predicted text in the correct form). We can also conclude that the model based on hybrid data significantly outperforms the model trained on generated data.

Table 5 Comparison of the OCR results using different line segmentation methods: input width of 650 pixels and a training on a little real annotated data from Porta fontium dataset

Line segmentation method	Epoch #	Validation loss	WER	CER	Edit distance
ARU-Net	670	4.557	0.143	0.034	1.370
Kraken	568	4.142	0.142	0.030	1.216
Profile	549	3.538	0.160	0.036	1.615

Table 6 Comparison of the OCR results using different line segmentation methods: input width of 1250 pixels and a training on a little real annotated data from Porta fontium dataset

Line segmentation method	Epoch #	Validation loss	WER	CER	Edit distance
ARU-Net	276	3.790	0.114	0.028	1.073
Kraken	288	12.555	0.234	0.070	2.813
Profile	306	2.909	0.163	0.036	1.584

Table 7 Comparison of the OCR results of models trained only on different synthetic data

Training data	Epoch #	Val. loss	WER	CER	Edit distance
<i>Hybrid data</i>					
Random text	12	108.624	0.833	0.434	20.778
Historical German	10	32.830	0.664	0.205	9.613
Modern German from Reuters	9	83.857	0.805	0.358	16.927
<i>Generated data</i>					
Random text	9	157.321	0.977	0.725	39.166
Historical German	8	145.461	0.966	0.668	32.353
Modern German from Reuters	8	159.603	1.000	0.938	45.688

Best obtained results in bold

Table 8 OCR results of the model pre-trained on synthetic data and fine-tuned using a small annotated dataset

Training data	Epochs	Val. loss	WER	CER	Edit distance	Accuracy
<i>ARU-Net</i>						
Hybrid random	139	3.557	0.111	0.028	1.078	0.513
Hybrid historical	106	3.592	0.106	0.025	1.022	0.531
Hybrid Reuters	115	3.537	0.123	0.029	1.095	0.495
<i>Kraken</i>						
Hybrid random	117	2.843	0.108	0.024	0.926	0.494
Hybrid historical	106	2.877	0.104	0.022	0.838	0.520
Hybrid Reuters	112	2.693	0.112	0.024	0.889	0.495
<i>Profile</i>						
Hybrid random	90	3.291	0.130	0.030	1.308	0.455
Hybrid historical	94	3.265	0.120	0.028	1.265	0.451
Hybrid Reuters	100	3.459	0.140	0.031	1.382	0.428

Best obtained results in bold

Moreover, these results show that the implicit language model has an important impact on the final results. Hence, the historical German language model is the best option.

To sum up, it is crucial to use a text source from the target domain for implicit LM training. The training of the model took 1 h and 20 min.

6.4 OCR results when training on synthetic data with fine-tuning on few real samples

The following experiments confirm the assumption that the models learned on synthetic data with a subsequent fine-tuning using small amount of real annotated samples bring

a significant improvement in the OCR task. We took all three hybrid data models and performed additional training with all three types of extracted text line images (ARU-Net, Kraken and Profile).

The results of this experiment are depicted in Table 8. This table shows that the fine-tuning of the model significantly improves the final OCR performance. This experiment further shows that all results are more or less comparable; however, the model retrained on data provided by Kraken achieved the best results. Therefore, we chose this setting for the final experiment.

It is also worth noting that the accuracy is around 50%, which means that, after retraining and fine-tuning, we are

Table 9 Comparison of the results of our OCR system with Tesseract and Transkribus on Porta fontium dataset

	Our approach	Tesseract (deu_fruk)	Tesseract (Fraktur)	Transkribus
Avg ACC	0.488	0.221	0.217	0.398
Avg ED	1.137	2.518	2.152	1.230
Avg WER	0.118	0.191	0.187	0.120
Avg CER	0.024	0.053	0.045	0.027

Best obtained results in bold

able to perfectly recognize a half of our testing dataset. The training time of the fine-tuning was 15 min.

6.5 Comparison With selected OCR systems

This experiment compares the results of our OCR system on a whole page with Tesseract and Transkribus systems. Based on the previous experiment, we use U-Net-based block segmentation, Kraken-based line segmentation and Hybrid data with fine-tuning for training of our OCR engine.

In the case of Tesseract, we used two models which are available with the system, namely *deu_fruk.traineddata* and *Fraktur.traineddata*. Both are trained on Fraktur script, which is the most common font in our dataset. We report the results of both models. We ran all OCR systems on ten annotated pages with a two-column layout. To improve the significance of this experiment, we carried out a fivefold cross-validation.

The results of this experiment are depicted in Table 9. This table shows that our OCR system outperformed both Tesseract and Transkribus systems; however, the results obtained by Transkribus are almost comparable. Even though we made the cross-validation experiment, we obtained the best average accuracy value and we confirmed our accuracy result obtained previously (see Table 8). This table also shows that Transkribus using ABBYY FineReader Engine 11 outperformed Tesseract significantly.

7 Conclusions and discussion

In this paper, we introduced a complex system for text segmentation and OCR of historical German documents. As a main result, we show that it is possible to use a small amount of real annotated data for training and achieve good results. We guided through the whole process of building an efficient OCR system for historical documents from the preprocessing steps through seeking an optimal strategy for training the OCR system.

We divided the paper into two logical parts. The first part dealt with page layout analysis and segmentation. Within it, we discussed approaches for page segmentation and we provided a comprehensive analysis. The second part is dedicated to the OCR system itself.

A great benefit is certainly the analysis and comparison of several methods for both the segmentation and OCR training. In the case of historical documents, we struggle with a lack of OCR methods that are adapted to such a domain and they usually need a huge training dataset. We also created a set of synthetic data with respect to the language of the given era. We compared several methods for synthetic data preparation and their influence on the final results. We also evaluated and compared a set of line segmentation approaches, namely ARU-Net, Kraken and simple projection profile-based algorithm.

We can conclude that we have developed an efficient domain-dependent OCR system that focuses on historical German documents by picking the best tools and approaches available. We also provided a comparison with several state-of-the-art systems and showed that our system outperforms all of them on our task. Furthermore, we have created a novel Porta fontium historical dataset that can be used for segmentation experiments as well as for the OCR evaluation. Novelty of this paper also lies in the focus on minimal costs needed for the system training. We analyzed mainly the costs related to the preparation of annotated data which is a cornerstone when preparing such a system. We also presented and evaluated several scenarios how to train the best possible models with the limited annotated dataset.

Although this paper has presented several contributions, we would like to highlight the most important one, that is, the possibility to create an efficient OCR system even with a small amount of real annotated training data.

For future work, we plan to enrich our Porta fontium dataset with more annotated pages and we want to finish a transcription of the rest of 25 pages. Last but not least, we would like to state that this paper can be also considered as an overview of the state-of-the-art methods in areas relevant to historical document processing.

Acknowledgements This work has been partly supported from ERDF “Research and Development of Intelligent Components of Advanced Technologies for the Pilsen Metropolitan Area (InteCom)” (no.: CZ.02.1.01/0.0/0.0/17_048/0007267) and by Cross-border Cooperation Program Czech Republic - Free State of Bavaria ETS Objective 2014–2020 (Project No. 211). We also thank Stephen Eugene Taylor for his valuable comments and advice.

Compliance with ethical standards

Conflict of interest The authors whose names are listed in this paper certify that they have NO affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership or other equity interest; and expert testimony or patent-licensing arrangements) or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by/4.0/>.

References

- Pascanu R, Mikolov T, Bengio Y (2013) On the difficulty of training recurrent neural networks. In: International conference on machine learning, pp 1310–1318
- Graves A, Fernández S, Gomez F, Schmidhuber J (2006) Connectionist temporal classification: labelling unsegmented sequence data with recurrent neural networks. In: Proceedings of the 23rd international conference on machine learning (ACM), pp 369–376
- Grüning T, Leifert G, Strauß T, Michael J, Labahn R (2019) A two-stage method for text line detection in historical documents. *Int J Doc Anal Recognit (IJDAR)* 22(3):285
- Breuel TM, Ul-Hasan A, Azawi MIAA, Shafait F (2013) High-performance OCR for printed English and Fraktur using LSTM networks. In: 2013 12th international conference on document analysis and recognition, pp 683–687
- Shi B, Bai X, Yao C (2017) An end-to-end trainable neural network for image-based sequence recognition and its application to scene text recognition. *IEEE Trans Pattern Anal Mach Intell* 39(11):2298
- Sabir E, Rawls S, Natarajan P (2017) Implicit Language Model in LSTM for OCR. In: 2017 14th IAPR international conference on document analysis and recognition (ICDAR), vol 7. IEEE, pp 27–31
- Karpathy A, Johnson J, Fei-Fei L (2015) Visualizing and understanding recurrent networks. arXiv preprint [arXiv:1506.02078](https://arxiv.org/abs/1506.02078)
- Ul-Hasan A, Breuel TM (2013) Can we build language-independent OCR using LSTM networks?. In: Proceedings of the 4th international workshop on multilingual OCR , pp 1–5
- Isola P, Zhu JY, Zhou T, Efros AA (2017) Image-to-image translation with conditional adversarial networks. In: Proceedings of the IEEE conference on computer vision and pattern recognition, pp 1125–1134
- Afzal MZ, Pastor-Pellicer J, Shafait F, Breuel TM, Dengel A, Liwicki M (2015) Document image binarization using lstm: A sequence learning approach. In: Proceedings of the 3rd international workshop on historical document imaging and processing (ACM), pp 79–84
- Ronneberger O, Fischer P, Brox T (2015) U-net: Convolutional networks for biomedical image segmentation. In: International conference on medical image computing and computer-assisted intervention. Springer, pp 234–241
- Xie S, Tu Z (2015) Holistically-nested edge detection. In: Proceedings of the IEEE international conference on computer vision, pp 1395–1403
- Huang X, Liu MY, Belongie S, Kautz J (2018) Multimodal Unsupervised Image-to-image Translation. In: The European conference on computer vision (ECCV)
- Bukhari SS, Shafait F, Breuel TM (2011) Improved document image segmentation algorithm using multiresolution morphology. Document recognition and retrieval XVIII, vol 7874. International Society for Optics and Photonics, p 78740D
- Shelhamer E, Long J, Darrell T (2017) Fully convolutional networks for semantic segmentation. *IEEE Trans Pattern Anal Mach Intell* 39(4):640. <https://doi.org/10.1109/TPAMI.2016.2572683>
- He K, Gkioxari G, Dollár P, Girshick R (2017) Mask r-cnn. In: Proceedings of the IEEE international conference on computer vision, pp 2961–2969
- Breuel TM (2017) Robust, simple page segmentation using hybrid convolutional md_lstm networks. In: 2017 14th IAPR international conference on document analysis and recognition (ICDAR), vol 1. IEEE, pp 733–740
- Hochreiter S, Schmidhuber J (1997) Long short-term memory. *Neural Comput* 9(8):1735
- Breuel TM (2017) High performance text recognition using a hybrid convolutional-lstm implementation. In: 2017 14th IAPR international conference on document analysis and recognition (ICDAR), vol 1. IEEE, pp 11–16
- LeCun Y, Bengio Y et al (1995) Convolutional networks for images, speech, and time series. *Handb Brain Theory Neural Netw* 3361(10):1995
- Elagouni K, Garcia C, Mamalet F, Sébillot P (2012) Text recognition in videos using a recurrent connectionist approach. In: International conference on artificial neural networks. Springer, pp 172–179
- He P, Huang W, Qiao Y, Loy CC, Tang X (2016) Reading scene text in deep convolutional sequences. In: Thirtieth AAAI conference on artificial intelligence
- Graves A (2012) Sequence transduction with recurrent neural networks. arXiv preprint [arXiv:1211.3711](https://arxiv.org/abs/1211.3711)
- Bahdanau D, Cho K, Bengio Y (2014) Neural machine translation by jointly learning to align and translate. arXiv preprint [arXiv:1409.0473](https://arxiv.org/abs/1409.0473)
- Bluche T, Louradour J, Messina R (2017) Scan, attend and read: End-to-end handwritten paragraph recognition with md_lstm attention. In: 2017 14th IAPR international conference on document analysis and recognition (ICDAR), vol 1. IEEE, pp 1050–1055
- Jaderberg M, Simonyan K, Vedaldi A, Zisserman A (2014) Synthetic data and artificial neural networks for natural scene text recognition. arXiv preprint [arXiv:1406.2227](https://arxiv.org/abs/1406.2227)
- Margner V, Pechwitz M (2001) Synthetic data for Arabic OCR system development. In: Sixth international conference on Document analysis and recognition, 2001. Proceedings. IEEE, pp 1159–1163
- Gaur S, Sonkar S, Roy PP (2015) Generation of synthetic training data for handwritten Indic script recognition. In: 2015 13th international conference on document analysis and recognition (ICDAR). IEEE, pp 491–495
- Perez L, Wang J (2017) The effectiveness of data augmentation in image classification using deep learning. arXiv preprint [arXiv:1712.04621](https://arxiv.org/abs/1712.04621)

30. Clausner C, Pletschacher S, Antonacopoulos A (2014) Efficient OCR training data generation with aletheia. In: Proceedings of the international association for pattern recognition (IAPR), Tours, France pp 7–10
31. Pletschacher S, Antonacopoulos A (2010) The page (page analysis and ground-truth elements) format framework. In: 2010 20th international conference on pattern recognition (IEEE), pp 257–260
32. Breuel TM (2008) The OCropus open source OCR system. Document recognition and retrieval XV, vol 6815. International Society for Optics and Photonics, p 68150F
33. Vincent L, Lead UT (2006) Announcing tesseract OCR, Google Code. <http://googlecode.blogspot.com.au/2006/08/announcing-tesseract-ocr.html>. Accessed 1 Nov 2015
34. Leifert G, Strauss T, Grüning T, Labahn R (2016) Citlab argus for historical handwritten documents
35. Strauss T, Weidemann M, Michael J, Leifert G, Grüning T, Labahn R (2018) System description of citlab's recognition & retrieval engine for ICDAR 2017 competition on information extraction in historical handwritten records
36. Wick C, Puppe F (2018) Fully convolutional neural networks for page segmentation of historical document images. In: 2018 13th IAPR international workshop on document analysis systems (DAS). IEEE, pp 287–292
37. Otsu N (1979) A threshold selection method from gray-level histograms. *IEEE Trans Syst Man Cybern* 9(1):62
38. Martínek J, Lenc L, Král P, Nicolaou A, Christlein V (2019) Hybrid Training Data for Historical Text OCR. In: 15th international conference on document analysis and recognition (ICDAR 2019), Sydney, Australia, pp 565–570. <https://doi.org/10.1109/ICDAR.2019.00096>
39. Glorot X, Bengio Y (2010) Understanding the difficulty of training deep feedforward neural networks. In: Proceedings of the thirteenth international conference on artificial intelligence and statistics, pp 249–256
40. Clausner C, Papadopoulos C, Pletschacher S, Antonacopoulos A (2015) The ENP image and ground truth dataset of historical newspapers. In: 2015 13th international conference on document analysis and recognition (ICDAR). IEEE, pp 931–935
41. Tong X, Evans DA (1996) A statistical approach to automatic OCR error correction in context. In: Fourth workshop on very large corpora
42. Lewis DD, Yang Y, Rose TG, Li F (2004) RCV1: a new benchmark collection for text categorization research. *J Mach Learn Res* 5:361
43. Oquab M, Bottou L, Laptev I, Sivic J (2014) Learning and transferring mid-level image representations using convolutional neural networks. In: The IEEE conference on computer vision and pattern recognition (CVPR)
44. Shang W, Sohn K, Almeida D, Lee H (2016) Understanding and improving convolutional neural networks via concatenated rectified linear units. In: International conference on machine learning, pp 2217–2225
45. Kingma DP, Ba J (2014) Adam: a method for stochastic optimization. arXiv preprint [arXiv:1412.6980](https://arxiv.org/abs/1412.6980)
46. Alberti M, Bouillon M, Ingold R, Liwicki M (2017) Open evaluation tool for layout analysis of document images. In: 2017 14th IAPR international conference on document analysis and recognition (ICDAR), Kyoto, Japan, pp 43–47. <https://doi.org/10.1109/ICDAR.2017.311>
47. Jaderberg M, Simonyan K, Vedaldi A, Zisserman A (2016) Reading text in the wild with convolutional neural networks. *Int J Comput Vis* 116(1):1

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.