

Heimatkunde: Dataset for Multi-modal Historical Document Analysis

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Abstract: This paper introduces a novel Heimatkunde dataset comprising printed documents in German, specifically designed for evaluating layout analysis methods with a focus on multi-modality. The dataset is openly accessible for research purposes. The study further presents baseline results for instance segmentation and multi-modal element classification. Three advanced models, Mask R-CNN, YOLOv8, and LayoutLMv3, are employed for instance segmentation, while a fusion-based model integrating BERT and various vision Transformers are proposed for multi-modal classification. Experimental findings reveal that optimal bounding box segmentation is achieved with YOLOv8 using an input image size of 1280 pixels, and the best segmentation mask is produced by LayoutLMv3 with PubLayNet weights. Moreover, the research demonstrates superior multi-modal classification results using BERT for textual and Vision Transformer for image modalities. The study concludes by suggesting the integration of the proposed models into the historical Porta fontium portal to enhance the information retrieval from historical data.

1 INTRODUCTION

Multi-modal document processing, which involves the analysis of complex documents comprising multiple modalities such as text, images, audio, or video, has become a rapidly growing area of research. This is because the use of multiple modalities can compensate for errors that may arise when only one modality is employed. Such documents can range from books and scientific papers to social media posts or medical data. This field closely follows advances in several research fields such as natural language processing (NLP), computer vision (CV) or automatic speech recognition.

This work focuses on the utilization of modern multi-modal techniques in order to perform document layout analysis (DLA) on historical documents containing visual and textual modalities. This task is usually composed of two steps: instance segmentation to identify individual image components and the subsequent classification of these elements.

The main contribution of this paper is creating

a large document layout analysis dataset that can be used for both image-only/multi-modal document analysis. This dataset is freely available for research purposes at <https://corpora.kiv.zcu.cz/heimatkunde/>. We further propose and implement a model for multi-modal layout analysis and evaluate it on this dataset, representing another contribution of this paper.

The outcomes of this work will be integrated into historical Porta fontium portal¹ to improve information retrieval from historical documents.

2 RELATED WORK

The following text introduces key concepts used in multi-modal document processing as well as the state-of-the-art models applicable to the task. We primarily cover models that process images and text, as these are the types of data processed in this paper, but many of the techniques can be adapted to other modalities such as audio or video.

The most common approach is to use state-of-the-art networks for each modality and merge their out-

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puts. This technique is commonly referred to as a *fusion*. For image-text documents, this typically involves the use of deep convolutional networks such as InceptionV3 (Szegedy et al., 2015), VGG16 (Simonyan and Zisserman, 2014), or vision-based Transformers to process the visual part, and a Transformer encoder model such as BERT (Devlin et al., 2018) to process the textual modality.

A relatively simple, but in many cases effective, approach is to use a linear combination of the output probabilities from each network. For instance, Ferrando et al. (Ferrando et al., 2020) use EfficientNet (for visual information) and BERT (for textual information) on the Small-Tobacco and Big-Tobacco image datasets with different weights for the modalities. Gallo et al. (Gallo et al., 2020) concatenate the outputs of individual networks into a single vector, which is then fed into another classifier model. The authors use BERT and InceptionV3 to perform classification on the Food101 (Bossard et al., 2014) dataset. They use two variants of building the fused vector. Late fusion uses class probabilities for each modality as input to the classifier, while early fusion uses features from the last hidden layer of each network.

The use of early and late fusion differs in each paper using such a technique. The previously mentioned paper (Gallo et al., 2020) reports better results with early fusion. In contrast, other papers such as (Dauphinee et al., 2019) only use late fusion.

With the rise of self-attention and Transformers (Vaswani et al., 2017) in general, various fusion blocks emerged. For example, audio and visual modalities are fused in (Huang et al., 2020) using the multi-head attention. The visual features are encoded as query and audio features as key and value. Self-attention is used also in (Prakash et al., 2021) to fuse image and LiDAR inputs. Mid-fusion and fusion bottlenecks are presented in (Nagrani et al., 2021). In short, it uses the Transformer and a multi-modal input that consists of individual modality tokens and optionally bottleneck tokens. Depending on the context, the token can attend to bottleneck tokens or other tokens including different modalities.

3 HEIMATKUNDE DATASET

We use images from two historical books describing political districts in the Czech Republic - *Heimatkunde des Ascher Bezirkes* (Local History of the Aš District) by J. Tittmann and *Heimatkunde des politischen Bezirkes Plan* (Local History of the Planá District) by Georg Weidl. Due to the name of the books, we name the resulting dataset the

Heimatkunde dataset. The documents contain information about the geography, agriculture, population, administration, education, and local history of the districts at the end of the 19th century. The text in both books is printed in Fraktur font and written in German.

The scanned images contain two pages. Most of the pages have a conventional one-column layout in a portrait format. The scans are grayscale with a very high resolution (300 DPI and most of the images are around 3400×2500 pixels in height and width). An unprocessed example from the dataset can be seen in Figure 1.

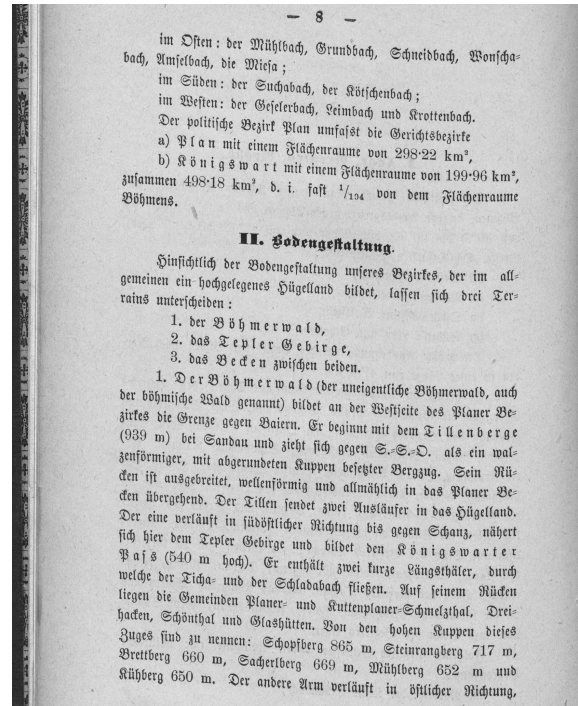


Figure 1: Example of an unprocessed page from the dataset.

In total, both books contain 468 images (930 pages). For our dataset, we use only a subset - 329 images, which we have manually annotated for the document layout analysis task.

3.1 Classes

There are 7 types of objects that we identify in the dataset. Although some of the original documents contain images, we decided not to include them as there are only 10 images in both books and such a sample size is not enough to perform training or validation. Consequently, all of the 7 classes contain some form of text, which should however be advantageous for multi-modal processing since the model

can always utilize both sources of information. The classes of the document entities are as follows:

- **Paragraph** - larger block of text, often with an indented first line.
- **Heading** - bold text in a different font style that is one or few lines long.
- **Footnote** - contains miscellaneous information, located at the bottom of the page, separated from paragraphs by a line.
- **Page number** - always at the top of the page.
- **Table** - collection of rows and columns, often with different formatting. May or may not have borders.
- **List / Listing** - list of items, e.g. animal species, list of inhabitants, etc.
- **Centered text** - typically a small portion of text containing quotations, smaller font size than a paragraph.

Each of the selected categories should be either semantically or visually distinct. Additionally, some classes such as page numbers or footnotes only appear in certain parts of the layout, which is another source of information that could, in theory, be exploited by the model.

Arguably the two most difficult elements to recognize/classify should be tables and centered text. While centered text appears consistently throughout the data, there are not many samples (see Table 1 in the following section), and tables, on the other hand, can have several formats. One solution would be to create a separate class for each type of table but this is likely not feasible here as the number of tables in the text is low as well.

3.2 Annotation Process

To create the annotations we use a widely used Computer Vision Annotation Tool – CVAT² (CVAT.ai Corporation, 2022). Arguably one of the main benefits of this application is that it is open-sourced and can be deployed locally in Docker.

All the images are annotated for the instance segmentation task, where we mark the area of each object by a bounding polygon. An example of the annotation from the editor can be seen in Figure 2. Additionally, we also save bounding boxes of each object (simply by using the minimum and maximum of x and y coordinates), as they are used to extract additional data such as text that is needed for the experiments.

²<https://github.com/opencv/cvat>

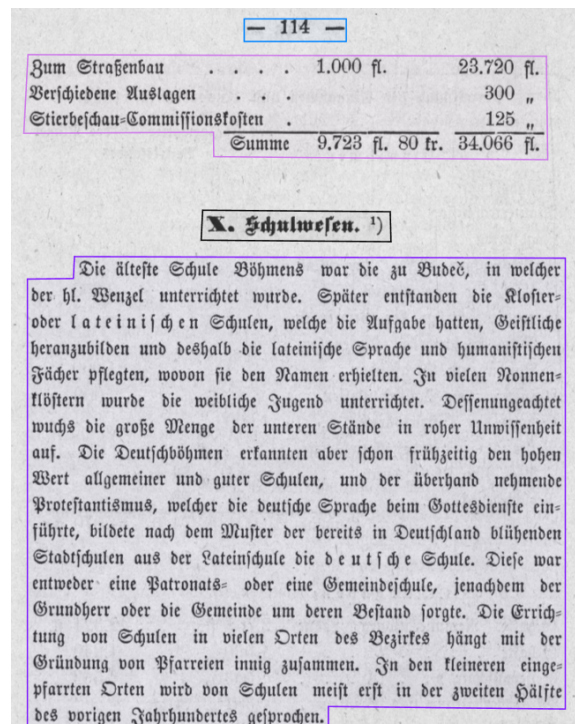


Figure 2: An example of the annotation in the CVAT application. There are four classes in the image - page number (blue), table (pink), heading (black), and paragraph (purple).

The annotations are converted to the COCO format, which makes the most sense for our use case as this format is directly supported by many image segmentation frameworks. Additionally, it is very straightforward to work with and can be easily transformed into other formats such as YOLO.

3.3 Resulting Dataset

As a result of the annotation process, we obtained a dataset that can be used for layout analysis in historical documents. In total, there are 4.640 annotations across 329 images. The created dataset has a relatively large imbalance between the classes, which is to be expected since some elements such as paragraphs occur much more frequently than elements such as tables or footnotes.

The counts of the individual classes can be seen in Table 1. The two most common types of entities are paragraphs and listings. On the other hand, centered text and tables appear infrequently and should be harder for the model to detect.

Finally, we split the dataset for training and evaluation. Approximately 70% of the dataset is used for training while the remaining 30% is kept as evaluation data. The counts for each split can be seen in Table 2.

Class name	Count	[%]
Paragraph	2079	44.8
Listing	1306	28.1
Page number	640	13.8
Heading	378	8.1
Footnote	107	2.3
Table	91	2.0
Centered text	39	0.8
Total	4640	100

Table 1: Number of occurrences for each class in the dataset, sorted according to class frequencies

Class name	Train		Test	
	Count	[%]	Count	[%]
Paragraph	1483	45.4	596	43.5
Listing	921	28.2	385	28.1
Page number	447	13.7	193	14.1
Heading	264	8.1	114	8.3
Footnote	74	2.3	33	2.4
Table	59	1.8	32	2.3
Centered text	22	0.7	17	1.2
Total	3270	100	1370	100

Table 2: Number of occurrences for each class in the train-test split, sorted according to class frequencies

3.3.1 OCR Subset

In addition to the document layout analysis variant of our dataset described above, we also annotate a subset of its images with a text layer used for training and evaluation of OCR models.

Each example comprises an image that contains a text line as well as a corresponding ground truth label. Such examples are shown below in Figures 3 and 4.

des Volkes, das er über alles in der Welt liebt. Der Jüngling ge-

Figure 3: Example of a test sample with reference text: "des Volkes, das er über alles in der Welt liebt. Der Jüngling ge-".

For training, we use two variants of the dataset. The first variant contains only the annotated examples from our dataset, which is around 14 pages, or 782 lines. The other variant is larger and includes our annotations as well as annotations from the Historical German OCR Corpus (Martínek et al., 2019). This OCR dataset contains very similar data and has 1386 lines. In total, the second variant results in 2168 lines of text.

For the evaluation, we annotated around 12 pages, resulting in 439 lines or 4430 words. Such a sample size should provide meaningful enough results to estimate the performance of an OCR model.

erstreckte sich über die Bezirke von Weiden, Thierstein, Asch und El-".

Figure 4: Example of a test sample with reference text: "erstreckte sich über die Bezirke von Weiden, Thierstein, Asch und El-".

4 APPROACH

As mentioned previously, the whole task is decomposed into two steps: instance segmentation and element classification which are subsequently described below.

4.1 Instance Segmentation

An instance segmentation model is used to detect the individual components in the document. We analyse and compare three different models for this task.

YOLO and Mask R-CNN are used since they are commonly employed for instance segmentation, while the LayoutLMv3-based model is used because it achieves state-of-the-art results on various document layout analysis datasets such as PubLayNet (Zhong et al., 2019).

4.1.1 Mask R-CNN

Mask R-CNN is one of the most popular solutions for instance segmentation. We use Mask R-CNN implemented in Detectron2³ (Wu et al., 2019), which is an image segmentation/object detection framework developed by the authors of PyTorch. Specifically, we use the `mask_rcnn_R_50_FPN_3x` configuration, which utilizes ResNet50 as its backbone.

4.1.2 YOLO

As a second model, the latest iteration of YOLO is used - YOLOv8⁴, which is developed by Ultralytics (Jocher et al., 2023). The advantage of this model is its scalability, as it can even be deployed on mobile devices or e.g. Raspberry Pi because the smallest model n has only 3.4M parameters. On the other hand, larger variants l and x should match or exceed the performance of Mask R-CNN.

In the context of our implementation, the main drawback of the model is that it is not directly implemented in Detectron2, which requires additional effort to incorporate it into our multi-modal system. We choose to use the l variant of the model, as it has a similar number of parameters to Mask R-CNN.

³<https://github.com/facebookresearch/detectron2>

⁴<https://github.com/ultralytics/ultralytics>

4.1.3 LayoutLMv3 with Cascade R-CNN

The third model is based on LayoutLMv3. The implementation used is adapted from the official repository⁵ and also utilizes Detectron2 for training and inference.

The main advantage of this model over YOLOv8 and Mask R-CNN should be its multi-modal pre-training. We expect this model to perform the best since all our classes contain textual features. The network is used as a backbone, while the segmentation is performed by Cascade R-CNN.

The detected instance images and their corresponding text are then used as input for the subsequent multi-modal classifier.

4.2 Multi-modal Classification

Using both text and image features in a multi-modal way might improve the number of correct predictions, especially in cases where semantics is important. Alternatively, should the model not yield better results, it can still be useful, e.g. for further validation of the document layout analysis results, where we can be more certain if both classifier and segmentation predictions match.

We employ a fusion model that uses early fusion to generate the prediction for this task.

4.2.1 Fusion-based Model

The architecture of this network is depicted in Fig. 5. To process the textual modality, we use a German pre-trained variant of BERT. The visual stream is handled by a vision Transformer - either ViT or Swin Transformer V2.

The architecture of the model follows early fusion and thus, all of the variants of the Transformers are used without a classification head on top and serve as feature extractors. In our configuration, BERT produces a matrix with the shape of (512, 768), corresponding to 512 768-dimensional word embeddings. Similarly, ViT and Swin output either 197 or 49 of identically long patch embeddings.

The features extracted from each modality should reflect the sequence as a whole, for which a single pass through a fully-connected layer is not optimal. Therefore, we introduce an additional layer on top of each Transformer output, which is an BiLSTM, similarly to (Gallo et al., 2020). Additionally, it can be used to harmonize the dimension vector length for the different modalities.

The outputs from both directions are concatenated, resulting in much more compact 128 or 256-dimensional vectors, depending on the hyperparameter configuration. To reduce the chance of overfitting during training, the LSTM output is passed through a dropout layer with 30% probability of being zeroed. Finally, the vector is modified by the ReLU activation and concatenated.

Depending on the hyperparameters, the fusion model can also employ information from the bounding box of the annotation. The data is passed via perceptron with a single 64-neuron hidden layer, that outputs a 16-dimensional vector. Subsequently, such a vector is concatenated with text and image features and fed to the fusion MLP. Note that we do not use the additional LSTM layer for the bounding box features because the data is not sequential and already has very low dimensionality.

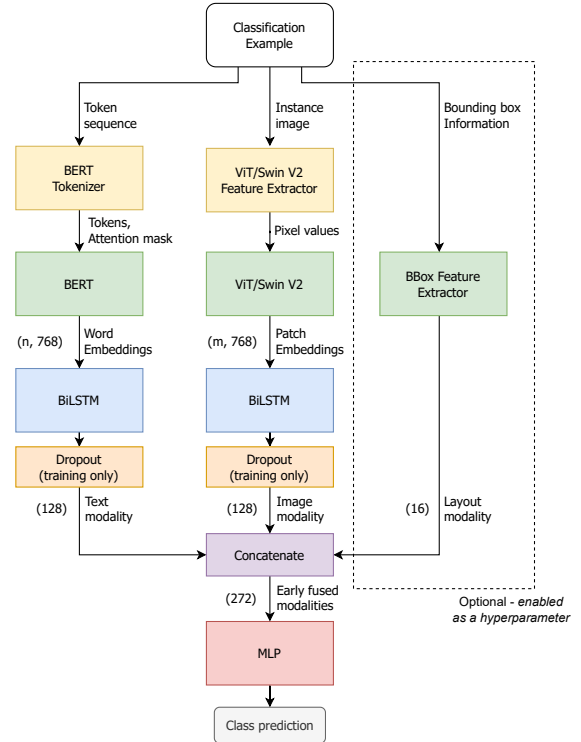


Figure 5: Architecture of the early-fusion model. The shape of the image/text features is either a 128 or 256-dimensional vector.

⁵<https://github.com/microsoft/unilm/tree/master/layoutlmv3>

5 EXPERIMENTS

5.1 Evaluation Metrics

For classification, we use standard accuracy, precision, recall and F1-score metrics (Hossin and Sulaiman, 2015). For document layout analysis we employ COCO evaluation metrics⁶, which are commonly used to evaluate the image segmentation of state-of-the-art models.

5.2 Set-up

The hyper-parameters for all segmentation models are depicted in Table 3. During training, the models are periodically evaluated on the test data, and their best parameters are selected based on the COCO AP@[0.50:0.95] metric.

Model	Input	Init. Weights	LR	Optimizer	Scheduler	Batch
Mask R-CNN	1280	COCO	1×10^{-4}	SGD	None	4
LayoutLMv3	1280	Default	2×10^{-4}	AdamW	CosineLR	3
LayoutLMv3	1280	PubLayNet	2×10^{-4}	AdamW	CosineLR	3
YOLOv8	1280	COCO	1×10^{-2}	SGD	OneCycleLR	2
YOLOv8	640	COCO	1×10^{-2}	SGD	OneCycleLR	4

Table 3: Hyperparameters and variants of the models - model, input size, initial weights, learning rate, optimizer, scheduler, and batch size.

5.3 Instance Segmentation Results

The results regarding bounding boxes are shown in Table 4, while the results for segmentation masks are shown in Table 5. The most important metric is AP@[0.50:0.95] because it is averaged over 10 different Intersection over Union values.

Model	Initial weights	Input size	AP@[0.50:0.95]	AP50	AP75
Mask R-CNN	COCO	1280	73.55	94.75	88.08
LayoutLMv3	PubLayNet	1280	79.45	95.46	91.76
LayoutLMv3	Default	1280	73.59	91.64	82.38
YOLOv8	COCO	1280	83.64	95.68	94.37
YOLOv8	COCO	640	81.34	93.46	91.96

Table 4: Bounding box COCO metrics of each model - Mask R-CNN, LayoutLMv3 with Cascade R-CNN, and YOLOv8. The best values are denoted in bold.

In terms of bounding box average precision, the two best models are variants of YOLOv8 that process either 640p or 1280p input. The 1280p variant achieves an AP@[0.50:0.95] of **83.64**, while the 640p one attains an AP@[0.50:0.95] of 81.34. These results are surprising because both variants outperform the much larger LayoutLMv3-based model, which is

Model	Initial weights	Input size	AP@[0.50:0.95]	AP50	AP75
Mask R-CNN	COCO	1280	75.12	93.84	89.07
LayoutLMv3	PubLayNet	1280	79.77	95.60	90.99
LayoutLMv3	Default	1280	75.22	91.80	85.77
YOLOv8	COCO	1280	76.34	95.81	86.54
YOLOv8	COCO	640	55.20	86.34	54.89

Table 5: Segmentation COCO metrics of each model - Mask R-CNN, LayoutLMv3 with Cascade R-CNN, and YOLOv8. The best values are denoted in bold.

only competitive when trained with the PubLayNet weights and achieves an AP@[0.50:0.95] of 79.45.

On the other hand, for the segmentation step, the best variant is the LayoutLMv3-based model with the PubLayNet weights, achieving an AP@[0.50:0.95] of **79.77**. The second best model is the 1280p variant of YOLOv8, closely followed by the LayoutLMv3-based model with the default pre-training weights. These models score an AP@[0.50:0.95] of 76.34 and 75.22 respectively. The least competitive model is the 640p variant of YOLOv8 with 55.20 AP@[0.50:0.95].

5.4 Multi-modal Classification Results

We evaluate several configurations of two fusion-based models: BERT + ViT and BERT + Swin V2. In total, we run 48 different configurations for BERT + ViT and BERT + Swin V2.

We select the best model based on its macro-averaged F1. From all configurations, we collect the three best ones for each model, which are depicted in Table 6. The hyperparameters used for these models are shown in Table 7.

The best F1 score of **97.38** is achieved by the fusion model comprising BERT and ViT. The fusion model using BERT and Swin Transformer V2 with the same hyperparameters and an F1 of 97.24 is very close to the best variant.

Model	Configuration	F1	Prec.	Recall	Acc.
BERT + ViT	Fusion-34	97.38	98.16	96.72	96.28
BERT + ViT	Fusion-2	97.21	98.02	96.46	96.20
BERT + ViT	Fusion-1	96.95	97.34	96.59	95.69
BERT + Swin V2	Fusion-34	97.24	97.92	96.62	96.13
BERT + Swin V2	Fusion-7	96.85	97.80	95.98	95.69
BERT + Swin V2	Fusion-26	96.54	96.99	96.14	95.18

Table 6: F1, precision, recall and accuracy [%] of the top 3 variants of each model. The best values are denoted in bold. F1, precision, and recall are macro averaged.

6 CONCLUSIONS

In this paper, we present a novel Heimatkunde dataset composed of printed documents in German. This

⁶<https://cocodataset.org/#detection-eval>

Configuration	Learning rate	Scheduler steps	BBox features	Text vector size	Image vector size
Fusion-1	1×10^{-5}	None	True	128	128
Fusion-2	1×10^{-5}	None	True	128	256
Fusion-7	1×10^{-5}	1000	True	256	128
Fusion-26	1×10^{-5}	None	False	128	256
Fusion-34	1×10^{-5}	1500	False	128	256

Table 7: Hyperparameter configurations used in the top two best models. Learning rate, number of steps in the learning rate scheduler, whether to use bounding box features, size of the extracted text vector from BERT, and size of the extracted image vector from ViT/Swin Transformer V2.

dataset is dedicated to the evaluation of methods for layout analysis, with a focus on multi-modality. The dataset is freely available for research purposes.

Next, we present baseline results for instance segmentation and multi-modal element classification. For instance segmentation, we employed three state-of-the-art models, namely Mask R-CNN, YOLOv8, and LayoutLMv3. For multi-modal classification, we proposed a fusion-based model that combines BERT with various vision Transformers.

We experimentally showed that the best segmentation of bounding boxes was obtained using YOLOv8 with an input image size of 1280 pixels, while the best segmentation mask was produced by LayoutLMv3 with the PubLayNet weights.

We further demonstrated that the best multi-modal classification results has been obtained with BERT for textual and ViT for image modalities.

Based on these experimental results, we can conclude that the proposed models will be integrated into Porta fontium portal to facilitate the information extraction from historical data.

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