Post-OCR Paragraph Recognition by Graph Convolutional Networks

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Abstract

We propose a new approach for paragraph recognition in document images by spatial graph convolutional networks (GCN) applied on OCR text boxes. Two steps, namely line splitting and line clustering, are performed to extract paragraphs from the lines in OCR results. Each step uses a β-skeleton graph constructed from bounding boxes, where the graph edges provide efficient support for graph convolution operations. With pure layout input features, the GCN model size is 3~4 orders of magnitude smaller compared to R-CNN based models, while achieving comparable or better accuracies on PubLayNet and other datasets. Furthermore, the GCN models show good generalization from synthetic training data to real-world images, and good adaptivity for variable document styles.

1. Introduction

Document image understanding is a task to recognize, structure, and understand the contents of document images, and is a key technology to digitally process and consume such images, which are ubiquitous and can be found in numerous applications. Document image understanding enables the conversion of such documents into a digital format with rich structure and semantic information and makes them available for subsequent information tasks.

A document can be represented by its semantic structure and physical structure [14]. The task to recover the semantic structure is called logical layout analysis [5] or semantic structure extraction [36] while the task to recover the physical structure is called geometric (physical, or structural) layout analysis [5]. These tasks are critical subproblems of document image understanding.

A paragraph is a semantic unit of writing consisting of one or more sentences that usually develops one main idea. Paragraphs are basic constituents of semantic structure and thus paragraph boundary estimation is an important building block of logical layout analysis. Moreover, paragraphs are often appropriate as processing units for various downstream tasks such as translation and information extraction because they are self-contained and have rich semantic information. Therefore, developing a generic paragraph estimation algorithm is of great interest by itself.

Paragraphs are usually rendered in a geometric layout structure according to broadly accepted typographical rules. In this work, we exclude semantic paragraphs that can span over multiple text columns or pages, and only consider physical/geometrical paragraphs. There are usually clear visual cues to identify such paragraphs, but the task of estimating paragraphs is non-trivial as shown in Fig. 1.

Previous studies have attempted to develop a paragraph estimation method by defining handcrafted rules based on careful observations [24, 30, 4, 29] or by learning an object detection model to identify the regions of paragraphs from an image [36, 39]. For the former approaches, it is usually challenging to define a robust set of heuristics even for a limited domain, and hence machine-learning-based solutions are generally preferable. The latter approaches tend to have difficulty dealing with diverse aspect ratios and text shapes, and the wide range of degradations observed in real-world applications such as image skews and perspective distortions.

In this paper, we propose to apply graph convolutional networks (GCNs) in a post-processing step of an optical
character recognition (OCR) system for paragraph recognition. Recent advancements in graph neural (convolutional) networks \cite{27,35} have enabled deep learning on non-Euclidian data. GCNs can learn spatial relationships among entities combining information from multiple sources and provide a natural way to learn the non-linear mapping from OCR results to paragraphs.

More specifically, we design two classifiers based on GCNs — one for line splitting and one for line clustering. A word graph is constructed for the first stage and a line graph for the second stage. Both are constructed based on the $\beta$-skeleton algorithm \cite{16} that produces a graph with good connectivity and sparsity.

To fully utilize the models’ capability, it is desirable to have a diverse set of document styles in the training data. We create synthetic data sets from web pages where the page styles are randomly modified in the web scraping engine. By leveraging open web sites like Wikipedia \cite{1} for source material to render in randomized styles, we have access to practically unlimited document data.

We evaluate the 2-step models on both the PubLayNet \cite{39} and our own datasets. We show that GCN based models can be small and efficient by taking OCR produced bounding boxes as input, and are also capable of generating highly accurate results. Moreover, with synthesized training data from a browser-based rendering engine, these models can be a step towards a reverse rendering engine that recovers comprehensive layout structure from document images.

2. Related Work

2.1. Page Segmentation

A lot of previous work have studied the page segmentation task, including CRF based approaches \cite{23,31,19}, CNN based approaches \cite{36,18} and mixed algorithms \cite{22}.

While the pixel masks from a segmentation can tell us where the paragraphs are, they do not produce individual paragraphs. For example, when text is dense and paragraphs are only hinted by subtle indentations, the adjacency graph in \cite{22} produces many false positive edges that form multiparagraph text components.

As a result, the problem we are trying to solve is different. Our work takes OCR result (text lines and words) rather than the image as input, and the goal is to recognize the paragraphs among the lines so as to improve the overall structure of the OCR engine output.

2.2. Geometric and Rule-based Approaches

Early studies have proposed geometric methods \cite{4,3} and rule-based methods \cite{24,30,29}. Both categories have algorithms to find column gaps by searching for white space \cite{3} or text alignment \cite{29}.

Limitations of these approaches include susceptibility to input noise and false positive column boundaries from monospace font families. Especially when handling scene text with perspective distortions from camera angles, rule based algorithms can be fragile and inconsistent.

2.3. Image Based Detection

The PubLayNet paper \cite{39} provides a large dataset for multiple types of document entities, as well as two object detection models F-RCNN \cite{25} and M-RCNN \cite{12} trained to detect these entities. Both show good metrics in evaluations, but with some inherent limitations.

- Cost: Object detection models are typically large in size and expensive in computation. When used together with an OCR engine to retrieve text paragraphs, it seems wasteful to bypass the OCR results and attempt to detect paragraphs independently.

- Quality: Paragraph bounding boxes may have high aspect ratios and are sometimes tightly packed. In Fig. \ref{fig:example} several short paragraphs are printed with dense text and rotated by 45 degrees. The region proposals required to detect all the paragraphs are highly overlapped, so some detections will be dropped by non-maximum suppression (NMS). Rotational R-CNN models \cite{15} can mitigate this issue by inclined NMS, but further increase the computational cost while still facing a more difficult task with rotated or warped inputs.

2.4. Graph Neural Networks

Graph neural/convolutional networks have been used to extract document entities like tables \cite{26} and curved lines \cite{28,21}. These work show that graph neural networks are flexible for handling various types of entities with complex shapes. One possible limitation from these approaches is on graph construction – the axis-aligned visibility graph in \cite{26} can usually handle scanned documents but not scene text with image rotations and distortions, and
the KNN graph in [38] [21] can form isolated components that restrict graph operations.

3. Proposed Method

A typical general purpose OCR engine produces a set of text lines with recognized transcriptions [34]. To find paragraphs, we can consider a bottom-up approach to cluster text lines into paragraphs.

As shown in Fig. 3, the detected lines from stage 1 provide rudimentary layout information, but may not match the true text lines. The image in this example contains 2 text columns, each column containing a sentence which also forms a paragraph. The text line detector (stage 1) tries to find the longest curved fitted baselines, thus not able to split the lines by the 2-column layout. It is after stage 2 when the word boxes are available that we can perform a post-OCR layout analysis. We propose a 2-step process, namely line splitting and line clustering, to cluster the words and lines into paragraphs.

Both the line splitting and line clustering are non-trivial tasks for general-purpose paragraph estimation – the input images can be skewed or warped, and the layout styles can vary among different types of documents, e.g. newspapers, books, signs, web pages, handwritten letters, etc. Even though the concept of paragraph is mostly consistent across all document categories, the appearance of a paragraph can differ by many factors such as word spacing, line spacing, indentation, text flowing around figures, etc. Such variations make it difficult, if not impossible, to have a straightforward algorithm that identifies all the paragraphs.

We design the two steps based on graph convolutional neural networks (GCN) [35] [8] that takes input features from the coordinate values of OCR output boxes, together with a \( \beta \)-skeleton graph [16] constructed from these boxes. Neither the original image nor text transcriptions are included in the input, so the models are small, fast, and entirely focused on the layout structure.

- Step 1: Line splitting. Raw text lines from OCR line detectors may cross multiple columns, and thus need to be split into shorter lines. A GCN node classifier takes word boxes to predict splitting points in lines.
- Step 2: Line clustering. The refined lines produced by step 1 are clustered into paragraphs. A GCN edge classifier takes line boxes to predict clustering operations on pairs of neighboring lines.

Output of each model is applied to the OCR text lines, with some additional error-correction heuristics (e.g. lines too far apart should not be clustered).

3.1. \( \beta \)-skeleton on Boxes

A graph is a key part of the GCN model input. We want a graph with high connectivity for effective message passing in graph convolutions, while also being sparse for computational efficiency.

Visibility graphs have been used in previous studies [7] [26], where edges are made by “lines-of-sight”. However, they are unsuitable for our models because of the edge density. Fig. 4(a) shows the visibility graph built on two rows of boxes, where any pairs of boxes on different rows are connected. This means word connections between text lines may get \( O(n^2) \) number of edges. If we limit the lines-of-sight to be axis aligned like Fig. 4(b), then the graph becomes too sparse, even producing disconnected components.

![Graph Comparison](image)

Figure 4. Comparison among different types of graphs constructed on an example set of boxes.

![Skeleton Construction](image)

Figure 5. Building a box \( \beta \)-skeleton from point based \( \beta \)-skeleton. Left side: intersecting boxes are first connected with edges of length 0. Right side: Non-internal peripheral points (in green) are connected with \( \beta \)-skeleton edges which are then collapsed into box edges. Edge lengths are approximate. The middle line points are added so that no edges can go through the boxes.
in some cases. In comparison, k-nearest-neighbor graphs used in [38] [21] are more scalable, but can also produce dense and isolated components.

By changing “lines-of-sight” into “balls-of-sight” in visibility graphs, we get a β-skeleton graph [16] with β = 1. In such a graph, two boxes are connected if they can both touch a circle that does not intersect with any other boxes. It provides a good balance between connectivity and sparsity. As shown in Fig. 4(c), a β-skeleton graph does not have excessive connections between rows of boxes. With β = 1, it is a subgraph of a Delaunay triangulation [2] with number of edges bounded by O(n). Yet, it provides good connectivity within any local cluster of boxes, and the whole graph is guaranteed to be one connected component.

The original β-skeleton graph is defined on a point set. To apply it to rectangular boxes, we build a graph on peripheral points of all the box as in Fig. 5 and keep at most one edge between each pair of boxes.

3.2. Message Passing on Graphs

Our graph convolutional network is based on an early version of TF-GNN [9] which works like MPNN [10] and GraphSage [11]. We use the term “message passing phase” from [10] to describe the graph level operations in our models. In this phase, repeated steps of “message passing” are performed based on a message function $M$ and node update function $U$. At step $t$, a message $M(h_v^t, h_w^t)$ is passed along every edge $e_{vw}$ in the graph where $h_v^t$ and $h_w^t$ are the hidden states of node $v$ and $w$. Let $N(v)$ denote the neighbors of node $v$ in the graph, the aggregated message by average pooling received by $v$ is

$$m_v^{t+1} = \frac{\sum_{w \in N(v)} M(h_v^t, h_w^t)}{|N(v)|}$$

and the updated hidden state is

$$h_v^{t+1} = U(h_v^t, m_v^{t+1})$$

Alternatively, we can use attention weighted pooling [33] to enhance message aggregation. Consequently, the model is also called a graph attention network (GAT), where calculation of $m_v^{t+1}$ is replaced by

$$m_v^{t+1} = \frac{\sum_{w \in N(v)} \exp(e_{vw}^t) M(h_v^t, h_w^t)}{\sum_{w \in N(v)} \exp(e_{vw}^t)}$$

and $e_{vw}^t$, is computed from a shared attention mechanism $\alpha$, for which we use the dot product self-attention in [32]. So

$$e_{vw}^t = \alpha(h_v^t, h_w^t) = K(h_v^t) \cdot Q(h_w^t)$$

where $K$ is a shared key function and $Q$ is a shared query function.

3.3. Splitting Lines

When multi-column text blocks are present in a document page, splitting lines across columns is a necessary first step [4, 29]. Note that the horizontal spacings between words is not a reliable signal for this task, as when the typography alignment of the text is “justified,” i.e. the text falls flush with both sides, these word spacings may be stretched to fill the full column width. In Fig. 8 the 2nd-to-last left line has word spacings larger than the column gap. This is common in documents with tightly packed text such as newspapers.

We use the GCN model shown in Fig. 6 to predict the splitting points, or tab-stops as in [29]. Each graph node is a word bounding box. Graph edges are the β-skeleton edges built as described in section 3.1. The model output contains two sets of node classification results – whether each word is a “line start” and whether it is a “line end”.

Fig. 8 shows a β-skeleton graph constructed from the word bounding boxes. Since words are aligned on either side of the two text columns, a set of words with their left edges all aligned are likely on the left boundary of a column, i.e. these words are line starts. Similarly, a set of words with right edges aligned are likely on the right boundary, i.e. they are line ends. The β-skeleton edges can connect aligned words in neighboring lines, and pass box alignment signals for the effective learning of the GCN model.

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**Figure 6.** Overview of the line splitting model. In the output, line start nodes are marked green and line end nodes are marked orange.
3.4. Clustering Lines

After splitting all the lines into “true” lines, the remaining task is to cluster them into paragraphs. Again we use a GCN, but each graph node is a line bounding box, and the output is edge classification similar to link predictions in [20, 37]. We define a positive edge to connect two consecutive lines in the same paragraph. Note that it is possible to have non-consecutive lines in the same paragraph being connected by a β-skeleton edge. Such edges are defined as negative to make the task easier to learn.

Fig. 7 is an overview of the line clustering model. The input consists of line bounding boxes, and an additional “node-to-edge” step is added for the final edge output:

\[ m'_{e=(v,w)} = \frac{M'(h_v, h_w) + M'(h_w, h_v)}{2} \]  

(5)

The model predicts whether two lines belong to the same paragraph on each pair of lines connected with a β-skeleton edge. The predictions are made from multiple types of context like indentations (Fig. 9) and line spacings.

4. Experiments

We experiment with the 2-step GCN models and evaluate the end-to-end performance on both the open PubLayNet dataset, our synthetic web-scraped set, and a human annotated image set. The OCR engine is from Google Cloud Vision API DOCUMENT_TEXT_DETECTION v2021, and GCN setup details are in the appendix.

The GCN models are compared against other approaches. Besides the F-RCNN and M-RCNN from [39], we train an F-RCNN model with additional quadrilateral outputs for rotated boxes, denoted by “F-RCNN-Q” in following subsections. It uses a ResNet-101 [13] backbone at ∼200MB in size. In contrast, the GCN models are only ∼100KB each. A rule-based heuristic algorithm in our production system is also used as baseline.

4.1. Datasets

4.1.1 PubLayNet

PubLayNet [39] contains a large amount of document images with ground truth annotations: 340K in the training set and 12K in the development/validation (dev) set. The testing set ground truth has not been released at the time of this writing, so we use the dev set for evaluation.

4.1.2 Web Synthetic Page Layout

Data diversity is a crucial necessity for handling all types of inputs. By taking advantage of high quality and publicly available web documents, as well as a powerful rendering engine used in modern browsers, we can generate synthetic training data with a web scraper.

We use a browser-based web scraper to retrieve a list of Wikipedia [1] pages, where each result includes the image rendered in the browser as well as the HTML DOM (document object model) tree. The DOM tree contains the...
**4.1.3 Human Annotated Paragraph Dataset**

We have a human annotated set with real-world images – 25K in English for training and a few hundred for testing in each available language. The images are collected from books, documents or objects with printed text, and sent to a team of raters who draw ground truth polygons for paragraphs. Example images are shown in Fig. 13, 14 and 15.

**4.2. Evaluation Metrics**

We measure the end-to-end performance of our OCR-GCN models by IoU based metrics such as the COCO mAP@IoU[.50:.95] used in [39] so the results are comparable. The average precision (AP) for mAP is usually calculated on a precision-recall curve. But since our models produce binary predictions, we have only one output set of paragraph bounding boxes, i.e. only one point on the precision-recall curve. So \( AP = \text{precision} \times \text{recall} \).

For a better evaluation on paragraphs, we introduce an F1-score of variable IoU thresholds (F1\(_{\text{var}}\) for short). As shown in Fig. 11, a single-line paragraph has a lower IoU even though it is correctly detected, while a 4-line detection (in red) has a higher IoU with a missed line. This is caused by boundary errors at character scale rather than at paragraph scale. This error is larger for post-OCR methods since the OCR engine is not trained to fit the paragraph training data. If we have line-level ground truth in each paragraph, and adjust IoU thresholds \( T_{\text{iou}} \) by

\[
T_{\text{iou}} = \min(1 - \frac{1}{1 + \#\text{lines}}, 0.95)
\]

the single-line paragraph will have IoU threshold 0.5, the 5-line one will have IoU threshold 0.833, and both cases in Fig. 11 can be more reasonably scored.

Both PubLayNet [39] and our web synthetic dataset have line level ground truth to support this F1\(_{\text{var}}\) metric. For the human annotated set without line annotations, we fall back to a fixed IoU threshold of 0.5.

**4.3. PubLayNet Evaluations**

The PubLayNet dataset has five types of layout elements: text, title, list, figure and table. For our task, we take text and title bounding boxes as paragraph ground truth, and set all other types as “don’t-care” for both training and testing.

Table 1 shows that F-RCNN-Q matches the mAP scores in [39]. The GCN models are worse in this metric because there is only one point in the precision-recall curve, and the OCR engine is not trained to produce bounding boxes that match the ground truth. In the bottom row of Table 1, “OCR + Ground Truth” is computed by clustering OCR words into paragraphs based on ground truth boxes, which is the upper bound for all post-OCR methods. For mAP scores, even the upper bound is lower than the scores of image based models. However, if we measure by F1\(_{\text{var}}\) scores defined above, OCR + GCNs can match image based models with a slight advantage. Fig. 12 shows some GCN produced examples.
Table 1. Paragraph mAP@IoU[0.50:.95] score and F1 var score comparisons. All models are tested on the PubLayNet development set. Numbers for mAP in the first 2 rows are from [39].

| Model         | Training Set                  | mAP  | F1 var |
|---------------|-------------------------------|------|--------|
| F-RCNN        | PubLayNet training            | 0.910| -      |
| M-RCNN        | PubLayNet training            | 0.916| -      |
| F-RCNN-Q      | PubLayNet training            | 0.914| 0.945  |
| Tesseract     | -                             | 0.571| 0.707  |
| OCR + Heuristic| Augmented web synthetic     | 0.302| 0.364  |
| OCR + GCNs    | Augmented web synthetic       | 0.748| 0.867  |
| OCR + GCNs    | PubLayNet training            | 0.842| 0.959  |
| OCR + Ground Truth | -                             | 0.892| 0.997  |

Table 2. Paragraph F1 var score comparison across different types of models and datasets. Data difficulty increases monotonically from PubLayNet to Augmented web synthetic.

| Model         | Data Source for Training & Test | F1 var |
|---------------|---------------------------------|--------|
| F-RCNN-Q      | PubLayNet                        | 0.945  |
| F-RCNN-Q      | Web synthetic                    | 0.722  |
| F-RCNN-Q      | Augmented web synthetic          | 0.547  |
| OCR + GCNs    | PubLayNet                        | 0.959  |
| OCR + GCNs    | Web synthetic                    | 0.830  |
| OCR + GCNs    | Augmented web synthetic          | 0.827  |

Table 3. Paragraph F1-scores tested on the real-world test set with paragraph annotations. Fixed IoU threshold 0.5 is used since there is no line-level ground truth to support variable thresholds.

| Model         | Training Data                  | F1@IoU0.5 |
|---------------|--------------------------------|-----------|
| F-RCNN-Q      | Augmented web synthetic        | 0.030     |
| F-RCNN-Q      | Annotated data (pre-trained on PubLayNet) | 0.607     |
| OCR + Heuristic| -                             | 0.602     |
| OCR + GCNs    | Augmented web synthetic        | 0.614     |
| OCR + GCNs    | Annotated data                 | 0.671     |
| OCR + GCNs    | Augmented synthetic + Annotated | 0.671     |
| OCR + Ground Truth | -                             | 0.960     |

4.4. Web Synthetic Evaluations

The synthetic dataset from web scraping gives a more difficult test for these models by its aggressive style variations. Data augmentation further increases the difficulty especially for image based detection models.

In Table 2 we can see the F1 var score of the image based F-RCNN-Q model decreases sharply as the task difficulty increases. At “Augmented web synthetic” with images like Fig. 12 detection is essentially broken, not only from non-max suppression drops shown in Fig. 2 but also from worse box predictions.

In contrast, the GCN models are much less affected by layout style variations and data augmentations. The F1 var score change is minimal between augmented and non-augmented datasets. So GCN models will have a greater advantage for scene text when input images are rotated.

4.5. Real-world Dataset Evaluations

The human annotated dataset can potentially show the models’ performance in real-world applications. The annotated set is relatively small, so the F-RCNN-Q model needs to be pre-trained on PubLayNet, while the GCN models are small enough to be trained entirely on this set. Evaluation metric for this set is F1@IoU0.5.

Table 3 shows comparisons across different models and different training sets. Note that Faster R-CNN trained from synthetic web data does not work at all for real-world images, whereas the OCR+GCN models can generalize well.

Fig. 13 and Fig. 14 show some examples of OCR + GCNs produced paragraphs. The right image in Fig. 13 shows the effectiveness of the augmented web synthetic data, as there are no similar images in the annotated set. On the other hand, the right table in Fig. 14 is not recognized since our models only takes bounding box coordinates as input. Using GCNs for table detection like [26] is another interesting topic but out of the scope of this paper.

To verify the robustness of the GCN models for language and script diversity, we test them on a multi-language evaluation set. The GCN models are trained with additional synthetic data from Wikipedia pages in Chinese, Japanese and Korean. Table 4 once again shows the generalizability of GCN models. F-RCNN-Q is not trained in the three Asian languages for the lack of training data.

The GCN models are also flexible in handling text lines written in vertical directions, which are common in
Japanese and Chinese, and also appear in Korean. Although we don’t have much training data with vertical lines, the bounding box structures of lines and symbols in these languages remain the same when the lines are written vertically, as if they were written horizontally while the image is rotated clockwise by 90 degrees. Fig. 15 shows such an example. Since our models are trained to handle all rotation angles, such paragraphs can be correctly recognized.

5. Conclusions and Future Work

We demonstrate that GCN models can be powerful and efficient for the task of paragraph recognition. Provided with a good OCR engine, they can match image based models with much lower requirement on training data and computation resources, and significantly beat them on non-axis-aligned inputs with complex layout styles. The graph convolutions in these models give them unique advantages in dealing with different levels of page elements and their structural relations.

Future work include extending the GCN models to find more types of entities and extract document structural information. Joining image based CNN backbones with GCN may work better for entities with non-text components like checkboxes and grid lines. In addition, reading order among entities will be helpful if we want to identify semantic paragraphs that span across multiple columns/pages.
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A. Algorithm to Construct the β-skeleton Graph on a Set of Boxes

1. For each box, pick a set of peripheral points at a preset density, and pick a set of internal points along the longitudinal middle line.

2. Build a Delaunay triangulation graph $G_D$ on all the points. (Time complexity $O(n \log n)$.)

3. Find all the “internal” points that are inside at least one of the boxes. (Time complexity $O(n)$ by traversing along $G_D$’s edges inside each box starting from any peripheral point. Internal points marked grey in Fig. 5.)

4. Add an edge of length 0 for each pair of intersecting boxes (containing each other’s peripheral points).

5. Pick β-skeleton edges from $G_D$ where for each edge $e = (v_1, v_2)$, both its vertices $v_1$, $v_2$ are non-internal points and the circle with $v_1v_2$ as diameter does not cover any other point.

   If there is such a point set $V_c$ covered by the circle, then the point $v_3 \in V_c$ closest to $v_1v_2$ must be the neighbor of either $v_1$ or $v_2$ (in Delaunay triangulation graphs). Finding such $v_3$ takes $O(\log n)$ time for each edge, since $G_D$ produced in step 2 have edges sorted at each point.

6. Keep only the shortest edge for each pair of boxes as the β-skeleton edge.

The overall time complexity of this box based β-skeleton graph construction is $O(n \log n)$, dominated by Delaunay triangulation. There are pathological cases where step 4 will need $O(n^2)$ time, e.g., all the $n$ boxes contain a common overlapping point. But such cases do not happen in OCR results.

B. Experimental GCN Setup

The 2-step GCN models are built as in Fig. 6 and Fig. 7, each carrying 8 steps of graph convolutions with hidden layer size 64 and 4-head self-attention weighted pooling.

At the models’ input, each graph node’s feature is a vector containing its bounding box information of the word/line. The first five values are width $w$, height $h$, rotation angle $\alpha$, $\cos \alpha$ and $\sin \alpha$. Then for each of its 4 corners $(x_p, y_p)$, we add 6 values $[x_p, x_p \cos \alpha, x_p \sin \alpha, y_p, y_p \cos \alpha, y_p \sin \alpha]$. For line clustering, an additional $w_1$ indicating the first word’s width is added to each line for better context of line breaks and list items.

We use cross-entropy loss for both node and edge classification tasks. We train the models from scratch using Momentum optimizer with batch size of 16. The learning rate is set to 0.0002 with a warm-up proportion of 0.01. The training is conducted on 8 Tesla P100 GPUs for approximately 10 hours each model.

C. Randomized Extension Script for Synthetic Data by Web Scraping

Almost all web pages use vertical spacing to separate paragraphs, and multi-column text is rare. We use randomly picked and randomly parameterized code pieces from the following table to diversity the web page layout styles.

| Table 5. Sample web script code for changing paragraph styles. |
|---------------------------------|---------------------------------|
| **Style Change**               | **Script Sample**               |
| Single-column to double-column | div.style.columnCount = 2;      |
| Vertical spacing to indentation| div.style.textIndent = 30px;    |
|                                | div.style.marginTop = 0;        |
|                                | div.style.marginBottom = 0;     |
| Typography alignment           | div.style.textAlign = “right”; |
| Text column width              | div.style.width = 50%;         |
| Horizontal text block position | div.style.marginLeft = 20%;     |
| Line height/spacing            | div.style.lineHeight = 150%;    |
| Font                            | div.style.fontFamily = “times”;|

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