

Fine-Grained Citation Span Detection for References in Wikipedia

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Abstract

Verifiability is one of the core editing principles in Wikipedia, editors being encouraged to provide citations for the added content. For a Wikipedia article, determining the *citation span* of a citation, i.e. what content is covered by a citation, is important as it helps decide for which content citations are still missing.

We are the first to address the problem of determining the *citation span* in Wikipedia articles. We approach this problem by classifying which textual fragments in an article are covered by a citation. We propose a sequence classification approach where for a paragraph and a citation, we determine the citation span at a fine-grained level.

We provide a thorough experimental evaluation and compare our approach against baselines adopted from the scientific domain, where we show improvement for all evaluation metrics.

1 Introduction

Citations uphold the crucial policy of *verifiability* in Wikipedia. This policy requires Wikipedia contributors to support their additions with citations from authoritative external sources (web, news, journal etc.). In particular, it states that “*articles should be based on reliable, third-party, published sources with a reputation for fact-checking and accuracy*”¹. Not only are citations essential in maintaining reliability, neutrality and authoritative assessment of content in such a collaboratively edited platform; but lack of citations are

¹https://en.wikipedia.org/wiki/Wikipedia:Identifying_reliable_sources

At the summit of the climb, carpet tacks^[1] were thrown onto the road causing as many as thirty riders to puncture,^{[2][3]} including Gilbert's teammates Cadel Evans and Steve Cummings,^[39] while race leader Bradley Wiggins [...] precaution.^[42] As a result, [...] and eventually soloed his way to a fourth career stage victory at the Tour.^[47] Sagan led home a group of four riders almost a minute behind, [...] behind Sánchez.^[39]

Figure 1: Sub-sentence level span for citation ^[1] in a citing paragraph in a Wikipedia article.

essential signals for core editors for unreliability checks.

However, there are two problems when it comes to citing facts in Wikipedia. First, there is a long tail of Wikipedia pages where citations are missing and hence facts might be unverified. Second, citations might have different span *granularities*, i.e., the text encoding the fact(s), for which a citation is intended, might span less than a sentence (see Figure 1) to multiple sentences. We denote the different *pieces of text* which contain a citation marker as *fact statements* or simply *statements*. For example, Table 1 shows different *statements* for several citations. The aim of this work is to automatically and accurately determine *citation spans* in order to improve coverage (Fetahu et al., 2015b, 2016) and to assist editors in verifying citation quality at a fine-grained level.

Earlier work on span determination is mostly concerned with scientific texts (O'Connor, 1982; Kaplan et al., 2016), operates at sentence level and exploits explicit authoring cues specific to scientific text. Although Wikipedia has well formed text, it does not follow explicit scientific guidelines for placing citations. Moreover, most statements can only be inferred from the citation text.

In this work, we operate at a sub-sentence level, loosely referred to as text fragments, and take a sequence prediction approach using a *linear chain CRF* (Lafferty et al., 2001). We limit our work to citations referring to *web* and *news* sources, as

they are accessible online and present the most prominent sources in Wikipedia (Fetahu et al., 2015a). By using recent work on moving window language models (Taneva and Weikum, 2013) and the structure of the paragraph that includes a citation, we classify sequences of text fragments as text that belong to a given citation. We are able to tackle all citation span cases as shown in Table 1.

sub sentence	Obama was born on August 4, 1961 ^[c1] , at Kapi’olani Maternity ... Honolulu ^[c2] ; he is the first ... been born in Hawaii. ^[c3] .
sentence	He was reelected to the Illinois Senate in 1998, ... in 2002. ^[c1]
multi sentence	On May 25, 2011, Obama ... to address ... UK Parliament in Westminster Hall, London. This was ... Charles de Gaulle ... and Pope Benedict XVI. ^[c1]

Table 1: Varying degrees of citation span granularity in Wikipedia text.

2 Problem Definition and Terminology

In this section, we describe the terminology and define the problem of determining the *citation span* in text in Wikipedia articles.

Terminology. We consider Wikipedia articles $W = \{e_1, \dots, e_n\}$ from a Wikipedia snapshot. We distinguish *citations* to *external references* in text and denote them with $\langle p_k, c_i \rangle$, where c_i represents a citation which occurs in paragraph p_k with positional index k in an entity $e \in W$. We will refer to p_k as the *citing paragraph*. Furthermore, with *citing sentence* we refer to the sentence in $s \in p_k$, which contains c_i . Note that p_k can have more than one citation as shown in Table 1.

Problem Definition. The task of determining the *citation span* for a citation c and a paragraph p , respectively $\langle p, c \rangle$ (or simply p_c), is subject to the citing paragraph and the citation content. In particular, we refer with *citation span* to the *textual fragments* from p which are covered by c . The fragments correspond to the sequence of *sub-sentences* $\mathcal{S}(p) = \langle \delta_1^1, \delta_1^2, \dots, \delta_1^k, \dots, \delta_n^m \rangle$. We obtain the sequence of sub-sentences from p by splitting the sentences into sub-sentences or text fragments based on the following punctuation delimiters ($\{, !, ;, : ?\}$). These delimiters do not always provide a perfect semantic segmentation of sentences into facts. A more involved approach could be taken akin to work in text summarization,

such as Zhou and Hovy (Zhou and Hovy, 2006) or (Nenkova et al., 2007) who consider *summary units* for a similar purpose.

Formally, we define the *citation span* in Equation 4 as the function of finding the subset $\mathcal{S}' \subseteq \mathcal{S}$ where the fragments in \mathcal{S}' are covered by c .

$$\varphi(p, c) \rightarrow \mathcal{S}' \subseteq \mathcal{S}, \text{ s.t. } \delta \in \mathcal{S}' \wedge c \vdash \delta \quad (1)$$

where $c \vdash \delta$ states that δ is covered in c .

3 Related Work

Scientific Text. One of the first attempts to determine the citation span in text (O’Connor, 1982) was carried out in the context of document retrieval. The citing statements from a document were used as an index to retrieve the *cited* document. The citing statements are extracted based on heuristics starting from the citing sentence and are expanded with sentences in a window of ± 2 sentences, depending on them containing cue words like ‘*this*’, ‘*these*’, ... ‘*above-mentioned*’. We consider the approach in (O’Connor, 1982) as a baseline.

Kaplan et al. (2016) proposed the task of determining the *citation block* based on a set of *textual coherence* features (e.g. grammatical or lexical coherence). The citation block *starts* from the citing sentence, with succeeding sentences classified (through SVMs or CRFs) according to whether they belong to the block. Abu-Jbara and Radev (2012) determine the citation block by first segmenting the sentences and then classifying individual words as being *inside/outside* the citation. Finally, the segment is classified depending on the word labels (majority of words being inside, at least one, or all of them). This approach is not applicable in our case due to the fact that words in Wikipedia text are not domain or genre-specific as one expects in scientific text, and as such their classification does not work.

Citations in IR. The importance of determining the citation span has been acknowledged in the field of Information Retrieval (IR). The focus is on building citation indexes (Garfield, 1955) and improving the retrieval of scientific articles (Ritchie et al., 2008, 2006). Citing sentences on a fixed window size are used to index documents and aid the retrieval process.

Summarization. Citations have been successfully employed to generate summaries of scientific articles (Qazvinian and Radev, 2008; Elkiss et al.,

2008). In all cases, citing statements are either extracted manually or via heuristics such as extracting only citing sentences. Similarly (Nanba and Okumura, 1999) expand the summaries in addition to the citing sentence based on cue words (e.g. ‘In this’, ‘However’ etc.). The work in (Qazvinian and Radev, 2010) goes one step beyond and considers sentences which do not *explicitly* cite another article. The task is to assign a binary label to a sentence, indicating whether it contains context for a cited paper. We use this approach as one of our competitors. Again, the premise is that citations are marked explicitly and additional citing sentences are found dependent on them.

Comparison to our work. The language style and the composition of citations in Wikipedia and in scientific text differ significantly. Citations are *explicit* in scientific text (e.g. *author names*) and are usually the first word in a sentence (Abu-Jbara and Radev, 2012). In Wikipedia, citations are *implicit* (see Table 1) and there are no cue words in text which link to the provided citations. Therefore, the proposed methodologies and features from the scientific domain do not perform optimally in our case.

Both (Qazvinian and Radev, 2010) and (O’Connor, 1982) work at the sentence level. As, in Wikipedia, citation span detection needs to be performed at the sub-sentence level (see Table 1), their method introduces erroneous spans as we will show in our evaluation.

Related to our problem is the work on addressing quotation attribution. Pareti et al. (2013) propose an approach for *direct* and *indirect* quotation attribution. The task is mostly based on lexical cues and specific *reporting verbs* that are the signal for the majority of direct quotations. However, in the case of quotation attribution the task is to find the *source*, *cue*, and *content* of the quotation, whereas in our case, for a given citing paragraph and reference we simply assess which text fragment is covered by the reference. We also do normally not have access to specific lexical links between the citation and its citation span.

4 Citation Span Approach

We approach the problem of citation span detection in Wikipedia as a *sequence classification* problem. For a citation c and a citing paragraph p , we chunk the paragraph into textual fragments at the *sub-sentence* granularity, shown in Equation 4.

Figure 2 shows an overview of the sequence classification of textual fragments. We use a *linear chain CRF* (Lafferty et al., 2001), where for any fragment δ we predict the label corresponding to a random variable y which is either ‘covered’ or ‘not-covered’. We opt for CRFs since we can encode global dependencies between the text fragments and the actual citation, thus, ensuring the coherence and accuracy of the predicted labels.

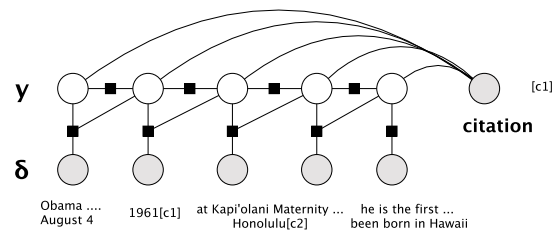


Figure 2: Linear chain CRF representing the sequence of text fragments in a paragraph. In the factors we encode the fitness to the given citation.

We now describe the features we compute for the factors $\Psi(y_i, y_{i-1}, \delta_i)$ for a fragment δ_i w.r.t the citation c . We determine the fitness of δ_i holding true or being covered by c . We denote with f_k the features for the factors $\Psi_i(y_i, y_{i-1}, \delta_i)$ for sequence δ_i for the linear-chain CRF in Figure 2.

4.1 Structural Features

An important aspect to consider for citation span detection is the structure of the citing paragraph, and correspondingly its sentences. For a textual fragment δ , we extract the following structural features shown in Table 2.

factor	description
$f_i^{c'}$	presence of other citations in δ_i where $c' \neq c$
$f_i^{\#s}$	the number of sentences in p
$f_i^{ \delta_i }$	the length in terms of characters of the sub-sequence
f_i^s	check if δ_i is in the same sentence as the citation c
$f_i^{s \neq s'}$	check if δ_i is in the same sentence as δ_{i-1}
f_i^c	the distance of fragment δ_i to the fragment which contains citation c

Table 2: Structural features for a fragment δ_i .

From the features in Table 2, we highlight f_i^c which specifies the distance of δ to the fragment that cites c . The closer a fragment is to the citation the higher the likelihood of it being covered

in c . In Wikipedia, depending on the citation and the paragraph length, the validity of a citation is densely concentrated in its nearby sub-sentences (preceding and succeeding).

Furthermore, the features $f^{\#s}$ and f_i^s (the number of sentences in p together with the feature considering if δ is in the same sentence as c) are strong indicators for accurate prediction of the label of δ . That is, it is more likely for a fragment δ to be covered by the citation if it appears in the same sentence or sentences nearby to the citation marker.

However, as shown in Table 1 there are three main citation span groups, and as such relying only on the structure of the citing paragraph does not yield optimal results. Hence, in the next group we consider features that tie the individual fragments in the citing paragraph with the citation as shown in Figure 2.

4.2 Citation Features

A core indicator as to whether a fragment δ is covered by c is based on the lexical similarity between δ and the content in c . We gather such evidence by computing two similarity measures. We compute the features f_i^{LM} and f_i^J between δ and paragraphs in the citation content c .

The first measure, f_i^{LM} , corresponds to a moving language window proposed in (Taneva and Weikum, 2013). In this case, for each word in either a paragraph in the citation c or the sequence δ , we associate a language model M_{w_i} based on its context $\phi(w_i) = \{w_{i-3}, w_{i-2}, w_{i-1}, w_i, w_{i+1}, w_{i+2}, w_{i+3}\}$ with a window of ± 3 words. The parameters for the model M_{w_i} are estimated as in Equation 2 for all the words in the context $\phi(w_i)$ and their frequencies denoted with tf . With M_δ and M_p we denote the overall models as estimated in Equation 2 for the words in the respective fragments.

$$P(w|M_{w_i}) = \frac{tf_{w, \phi(w_i)}}{\sum_{w' \in \phi(w_i)} tf_{w', \phi(w_i)}} \quad (2)$$

Finally, we compute the similarity of each word in $w \in \delta$ against the language model of paragraph $p \in c$ in Equation 3, which corresponds to the Kullback-Leibler divergence score.

$$f_i^{LM} = \min_{p \in c} \left[- \sum_{w \in \delta} P(w|M_\delta) \log \frac{P(w|M_\delta)}{P(w|M_p)} \right] \quad (3)$$

The intuition behind f_i^{LM} is that for the fragments δ we take into account the word similarity

and the similarity in the context they appear in w.r.t a paragraph in a citation. In this way, we ensure that the similarity is not by chance but is supported by the context in which the word appears. Finally, another advantage of this model is that we localize the paragraphs in c which provide evidence for δ .

As an additional feature we compute f_i^J which corresponds to the maximal *jaccard* similarity between δ_i and paragraphs $p \in c$.

Finally, as we will show in our experimental evaluation in Section 5, there is a high correlation between the citation span length and the length of citation content in terms of sentences. Hence, we add as an additional feature f^c the number of sentences in c .

4.3 Discourse Features

Sentences and fragments within a sentence can be tied together by discourse relations. We annotate sentences with explicit discourse relations based on an approach proposed in (Pitler and Nenkova, 2009), using discourse connectives as cues. The explicit discourse relations belong to one of the following: *temporal*, *contingency*, *expansion*, *comparison*.

After extracting a discourse connective in a sentence, we determine by its position to which fragment it belongs and mark the fragment accordingly. We denote with f_i^{disc} the discourse feature for the fragment δ_i .²

4.4 Temporal Features

An important aspect that we consider here is the temporal difference between two consecutive fragments δ_i and δ_{i-1} . If there exists a temporal date expression in δ_i and δ_{i-1} and they point to different time-points, this presents an indicator on the transitioning between the states y_i and y_{i-1} . That is, there is a higher likelihood of changing the state in the sequence \mathcal{S} for the labels y_i and y_{i-1} .

We compute the temporal feature $f_i^{\lambda(i, i-1)}$, indicating the difference in *days* between any two temporal expression extracted from δ_i and δ_{i-1} . We extract the temporal expression through a set of hand-crafted regular expressions. We use the following expressions: (1) DD Month YYYY, (2) DD MM YYYY, (3)

²Note that, although discourse relations hold between at least two fragments or sentences, we only mark the individual fragment in which the connective occurs with the discourse relation type.

<i>type</i>	<i>avg. s </i>	<i>avg. δ </i>	<i>avg 'covered'</i>
<i>news</i>	7.76	22.55	0.28
<i>web</i>	8.67	23.07	0.30

Table 3: Dataset statistics for citing paragraphs, distinguishing between *web* and *news* references, showing the average number of sentences, fragments, and covered fragments.

MM DD YY (YY), (4) YYYY, with delimiters (whitespace, ‘-’, ‘.’).

5 Experimental Setup

We now outline the experimental setup for evaluating the citation span approach and the competitors for this task. The data and the proposed approaches are made available at the paper URL³.

5.1 Dataset

We evaluate the citation span approaches on a random sample of Wikipedia entities (snapshot of 20/11/2016). For the sampling process, we first group entities based on the number of *web* or *news* citations⁴). We then sample from the specific groups. This is due to the inherent differences in citation spans for entities with different numbers of citations. For instance, entities with a high number of citations tend to have shorter spans per citation. Figure 3 shows the distribution of entities from the different groups. From each sampled entity, we extract all *citing paragraphs* that contain either a *web* or *news* citation. Our sample consists of 509 citing paragraphs from 134 entities.

Furthermore, since a paragraph may have more than one citation, in our sampled citing paragraphs, we have an average of 4.4 citations per paragraph, which finally resulted in 408 unique paragraphs. Table 3 shows the stats of the dataset.

5.2 Ground Truth

Setup. For the ground truth, the citation span of *c* in paragraph *p* was manually determined by labeling each fragment in *p* with the binary label *covered* or *not-covered*.

We set strict guidelines that help us generate reliable ground-truth annotations. We follow two main guidelines: (i) requirement to read and comprehend the content in *c*, and (ii) matching of the

³<http://13s.de/~fetahu/emnlp17/>

⁴Wikipedia has an internal categorization of citations based on the reference they point to.

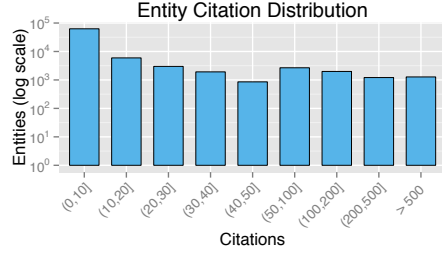


Figure 3: Entity distribution based on the number of news citations.

textual fragments from *p* as either being supported *explicitly* or *implicitly* in *c*.⁵

The entire dataset was carefully annotated by the first author. Later, a second annotator annotated a 10% sample of the dataset with an inter-rater agreement of $\kappa = .84$. We chose not to use crowd-sourcing as the task is very complex and hard to divide into small independent tasks. Since the task requires reading and comprehending the entire content in *c* and *p*, it takes on average up to 2.4 minutes to perform the evaluation for a single item. In future, it would be worthwhile to conduct more large-scale annotation exercises.

Citation Span Stats. Following the definition in Equation 4, we determine the citation span at the sub-sentence granularity level. Table 4 shows the distribution of citations falling into the specific spans for the citing paragraphs. We note that the majority of citations have a span between half a sentence and up to a sentence, yet, the remainder of more than 20% of citation span across multiple sentences in such paragraphs.

We define the citation span as the ratio of sub-sentences which are covered by a given citation over the total number of sub-sentences in the sentence, consequentially in the citing paragraph. That is, a citation is considered to have a span of one sentence if it covers all its sub-sentences.

$$span(c, p) = \sum_{s \in p} \frac{\#\delta^s \in \mathcal{S}'}{\#\delta^s} \quad (4)$$

where δ^s represents a sequence in sentence $s \in p$, which are part of the the ground-truth.

In Figure 4, we analyze a possible factor in the variance of the citation span. It is evident that for longer cited documents the span increases. This is

⁵We excluded cases where the citation is not appropriate for the paragraph at all. This is, for example, the case when the language of *c* is not English.

	total	$\leq .5$	$(.5, 1]$	$(1, 2]$	$(2, 5]$	> 5
news	318	35	201	54	22	6
web	191	13	121	27	25	6

Table 4: Citation span distribution based on the number of sub-sentences in the citing paragraph.

intuitive since such documents carry more information and consequentially their span in the citing paragraphs can be larger. An example is the Wikipedia article 2008 US Open (tennis) which has a citing paragraph with a citation span of 7 sentences for an article of 30k characters long⁶. We encoded this in the *citation* features f^c .

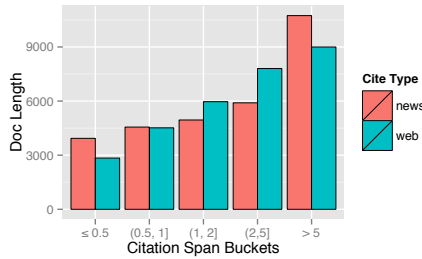


Figure 4: Average document length for the different span buckets for citation types *web* and *news*.

Additionally, within the different citation spans we analyze how many of them contain *skips* for two cases: (i) skip a fragment within a sentence, and (ii) skip sentences in p . The results for both cases are presented in Table 5.

span	news		web	
	skip δ	skip s	skip δ	skip s
≤ 0.5	6%	-	-	-
$(0.5, 1]$	-	-	-	1%
$(1, 2]$	-	8%	-	19%
$(2, 5]$	5%	18%	-	21%
> 5	-	20%	-	67%

Table 5: The percentage of citations in a span with *fragment skips* and *sentence skips*.

From the results in Table 4 and 5 we see that simple heuristics on selecting complete sentences or selecting consecutive sequences do not account for the different citation span cases and skips at the sentence and paragraph level. This leads to suboptimal results and introduces erroneous spans. Furthermore, we find that in 3.7% of the cases in our

⁶<http://news.bbc.co.uk/sport1/hi/tennis/7601195.stm>

ground-truth, the citation spans include fragments after the citation marker.

5.3 Baselines

We consider the following baselines as competitors for our citation span approach.

Inter-Citation Text – IC. The span consists of sentences which start either at the beginning of the paragraph or at the end of a previous citation. The granularity is at the sentence level.

Citation-Sentence-Window – CSW. The span consists of sentences in a window of ± 2 sentences from the citing sentence (O’Connor, 1982). The other sentences are included if they contain specific cue words in fixed positions.

Citing Sentence – CS. The span consists of only the *citing sentence*.

Markov Random Fields – MRF. MRFs (Qazvinian and Radev, 2010) model two functions. First, *compatibility*, which measures the similarity of sentences in p , and as such allows to extract non-citing sentences. Second, the *potential*, which measures the similarity between sentences in c with sentences in p . We use the provided implementation by the authors.

Citation Span Plain – CSPC. A plain classification setup using the features in Section 4, where the sequences are classified in isolation. We use Random Forests (Breiman, 2001) and evaluate them with 5-fold cross validation.

5.4 Citation Span Approach Setup – CSPS

For our approach *CSPS* as mentioned in Section 4, we opt for linear-chain CRFs and use the implementation in (Okazaki, 2007). We evaluate our models using 5-fold cross validation, and learn the optimal parameters for the CRF model through the L-BFGS approach (Liu and Nocedal, 1989).

5.5 Evaluation Metrics

We measure the performance of the citation span approaches through the following metrics. We will denote with W' the sampled entities, with $\mathbf{p} = \{p_c, \dots\}$ (p_c refers to $\langle p, c \rangle$) the set of sampled paragraphs from e , and with $|\mathbf{p}|$ the total items from e .

Mean Average Precision – MAP. First, we define *precision* for p_c as the ratio $P(p_c) = |\mathcal{S}' \cap \mathcal{S}^t| / |\mathcal{S}'|$ of fragments present in $\mathcal{S}' \cap \mathcal{S}^t$ over \mathcal{S}' . We measure MAP as in Equation 5.

$$MAP = \frac{1}{|W'|} \sum_{e \in W'} \frac{\sum_{p_c \in \mathbf{p}} P(p_c)}{|\mathbf{p}|} \quad (5)$$

Recall – R . We measure the recall for p_c as the ratio $|\mathcal{S}' \cap \mathcal{S}^t|$ over all fragments in \mathcal{S}^t , $R(p_c) = |\mathcal{S}' \cap \mathcal{S}^t|/|\mathcal{S}^t|$. We average the individual recall scores for $e \in W'$ for the corresponding \mathbf{p} .

$$R = \frac{1}{|W'|} \sum_{e \in W'} \frac{\sum_{p_c \in \mathbf{p}} R(p_c)}{|\mathbf{p}|} \quad (6)$$

Erroneous Span – Δ . We measure the number of extra *words* or extra *sub-sentences* (denoted with Δ_w and Δ_δ) added by text fragments that are not part of the ground-truth \mathcal{S}^t . The ratio is relative to the number of words or sub-sentences in the ground-truth for p_c . We compute Δ_w and Δ_δ in Equation 7 and 8, respectively.

$$\Delta_w = \frac{1}{|W'|} \sum_{e \in W'} \frac{1}{|\mathbf{p}|} \sum_{p_c \in \mathbf{p}} \frac{\sum_{\delta \in \mathcal{S}' \setminus \mathcal{S}^t} \text{words}(\delta)}{\sum_{\delta \in \mathcal{S}^t} \text{words}(\delta)} \quad (7)$$

$$\Delta_\delta = \frac{1}{|W'|} \sum_{e \in W'} \frac{1}{|\mathbf{p}|} \sum_{p_c \in \mathbf{p}} \frac{|\mathcal{S}' \setminus \mathcal{S}^t|}{|\mathcal{S}^t|} \quad (8)$$

6 Results and Discussion

6.1 Citation Span Robustness

Table 6 shows the results for the different approaches on determining the citation span for all span cases shown in Table 4.

Accuracy. Not surprisingly, the baseline approaches perform reasonably well. *CS* which selects only the citing sentence achieves a reasonable $MAP = 0.86$ and similar recall. A slightly different baseline *CSW* achieves comparable scores with $MAP = 0.85$. This is due to the inherent span structure in Wikipedia, where a large portion of citations span up to a sentence (see Table 4). Therefore, in approximately 64% of the cases the baselines will select the correct span. For the cases where the span is more than a sentence, the drawback of these baselines is in coverage. We show in the next section a detailed decomposition of the results and highlight why even in the simpler cases, a sentence level granularity has its shortcomings due to sequence skips as shown in Table 5.

Overall, when comparing *CS* as the best performing baseline against our approach *CSPS*, we achieve an overall score of $MAP = 0.83$ (a slight decrease of 3.6%), whereas in term of F1 score, we have a decrease of 9%. The plain-classification approach *CSPC* achieves similar score with $MAP = 0.86$, whereas in terms of F1 score, we have a decrease of 8%. As described above and as we will see later on in Table 7, the overall good performance of the baseline

approaches can be attributed to the citation span distribution in our ground-truth.

On the other hand, an interesting observation is that sophisticated approaches, geared towards scientific domains like *MRF* perform poorly. We attribute this to *language style*, i.e., in Wikipedia there are no explicit citation hooks that are present in scientific articles. Comparing to *CSPS*, we outperform *MRF* by a large margin with an increase in MAP by 84%.

When comparing the sequence classifier *CSPS* to the plain classifier *CSPC*, we see a marginal difference of 1.3% for $F1$. However, it will become more evident later that classifying jointly the text fragments for the different span buckets, outperforms the plain classification model.

	MAP	R	F1	Δ_w	Δ_δ
MRF	0.45	0.78	0.56	308%	278%
IC	0.72	0.94	0.77	113%	115%
CSW	0.85	0.84	0.82	38%	31%
CS	0.86	0.84	0.82	35%	27%
CSPC	0.86	0.68	0.76	26%	23%
CSPS	0.83	0.69	0.75	32%	24%

Table 6: Evaluation results for the different citation span approaches.

Erroneous Span. One of the major drawbacks of competing approaches is the granularity at which the span is determined. This leads to erroneous spans. From Table 4 we see that approximately in $\sim 10\%$ of the cases the span is at sub-sentence level, and in 28% the span is more than a sentence.

The best performing baseline *CS* has an erroneous span of $\Delta_w = 35\%$ and $\Delta_\delta = 27\%$, in terms of extra words and sub-sentences, respectively. That is, nearly half of the determined span is erroneous, or in other words it is not covered in the provided citation. The *MRF* approach due to its poor MAP score provides the largest erroneous spans with $\Delta_w = 308\%$ and $\Delta_\delta = 278\%$. The amount of erroneous span is unevenly distributed, that is, in cases where the span is not at the sentence level granularity the amount of erroneous span increases. A detailed analysis is provided in the next section.

Contrary to the baselines, for *CSPS* and similarly for *CSPC*, we achieve the lowest erroneous spans with $\Delta_w = 32\%$ and $\Delta_\delta = 26\%$, and $\Delta_w = 24\%$ and $\Delta_\delta = 23\%$, respectively.

Compared to the remaining baselines, we

achieve an overall relative decrease of 9% for $\Delta_w(CSPS)$, and 34% for $\Delta_w(CSPC)$, when compared to the best performing baseline *CS*.

From the *skips* in sequences in Table 5 and the unsuitability of sentence granularity for citation spans, we analyze the locality of erroneous spans w.r.t to the sequence that contains *c*, specifically the distribution of erroneous spans *preceding* and *succeeding* it. For the *CS* baseline, 71% of the total erroneous spans are added by sequences preceding the citing sequence, contrary to 35% which succeed it. In the case of *CSPS*, we have only 9% of erroneous spans (for Δ_δ) preceding the citation.

6.2 Citation Span and Feature Analysis

We now analyze how the approaches perform for the different citation spans in Table 4⁷. Additionally, we analyze how our approach *CSPS* performs when determining the span without access to the content of *c*.

Citation Span. Table 7 shows the results for the approaches under comparison for all the citation span cases. In the case where the citation spans up to a sentence, that is $(0.5, 1]$, which presents the simplest citation span case, the baselines perform reasonably well. This is due to the heuristics they apply to determine the span, which in all cases includes the *citing sentence*. In terms of *F1* score, the baseline *CS* achieves a highly competitive score of $F1 = 0.97$. Our approach *CSPS* in this case has slight increase of 1% for *F1* and an increase of 3% for *MAP*. *CSPC* achieves a similar performance in this case.

However, for the cases where the span is at the sub-sentence level or across multiple sentences, the performance of baselines drops drastically. In the first bucket (≤ 0.5) which accounts for 9% of ground-truth data, we achieve the highest score with $MAP = 0.87$, though with lower recall than the competitors with $R = 0.56$. The reason for this is that the baselines take complete sentences, thus, having perfect recall at the cost of accuracy. In terms of *F1* score we achieve 21% better results than the best performing baseline *CS*.

For the span of $(1, 2]$ we maintain an overall high accuracy and recall, and have the highest *F1* score. The improvement is 8% in terms of *F1* score. Finally, for the last case where the span is more than 2 sentences, we achieve $MAP = 0.74$,

⁷The models were retrained and tested for the different buckets with 5-fold cross validation.

a marginal increase of 3%, however with lower recall, which results in an overall decrease of 4% for *F1*. The statistical significance tests are indicated with ** and * in Table 7.

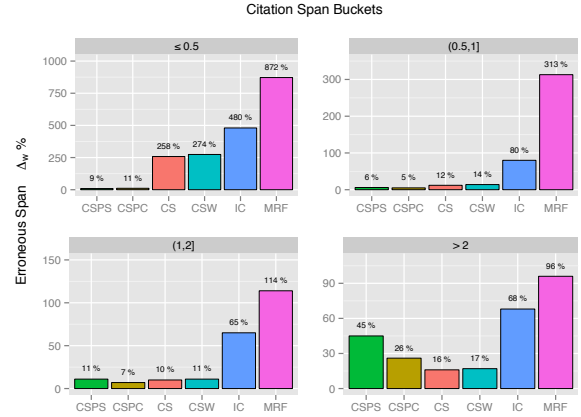


Figure 5: Erroneous spans for the different citation span buckets. The y-axis presents the Δ_w whereas in the x-axis are shown the different approaches.

Erroneous Span. Figure 5 shows the erroneous spans in terms of words for the metric Δ_w for all citation span cases. It is noteworthy that the amount of error can be well beyond 100% due to the ratio of the suggested span and the actual span in our ground-truth, which can be higher.

In the first bucket (span of ≤ 0.5) with granularity less than a sentence, all the competing approaches introduce large erroneous spans. For *CSPS* we have a $MAP = 0.87$, and consequently we have the lowest $\Delta_w = 9\%$, while for *CSPC* we have only $\Delta_w = 11\%$. In contrast, the non-ML competitors introduce a minimum of $\Delta_w(CS) = 182\%$, with MRFs having the highest error. We also perform well in the bucket $(0.5, 1]$. For larger spans, for instance, for $(1, 2]$, we are still slightly better, with roughly 3% less erroneous span when comparing *CSPC* and *CS*. However, only in the case of spans with > 2 , we perform below the *CS* baseline. Despite, the smaller erroneous span, the *CS* baseline never includes more than one sentence, and as such it does not include many erroneous spans for the larger buckets. However, it is by definition unable to recognize any longer spans.

Feature Analysis. It is worthwhile to investigate the performance gains in determining the citation span without analyzing the content of the citation. The reason for this is that there are several cita-

	≤ 0.5			$(0.5, 1]$			$(1, 2]$			> 2		
	MAP	R	F1	MAP	R	F1	MAP	R	F1	MAP	R	F1
MRF	0.15	0.88	0.27	0.44	0.80	0.61	0.59	0.74	0.57	0.59	0.63	0.55
IC	0.32	1.00	0.45	0.77	0.99	0.83	0.73	0.84	0.74	0.72	0.81	0.73
CSW	0.38	1.00	0.54	0.93	0.98	0.96	0.88	0.54	0.65	0.79	0.34	0.43
CS	0.40	1.00	0.56	0.94	0.98	0.97	0.90	0.53	0.65	0.80	0.32	0.42
CSPC	0.85	0.53	0.65	0.96	0.97	0.97	0.96	0.68	0.79	0.71	0.65	0.68
CSPS	0.87**	0.56	0.68**	0.96	0.98	0.98	0.88	0.73	0.80*	0.74	0.72	0.70
Δ_{F1} CSPS	▲21%			0%			▲8%			▼4%		

Table 7: Evaluation results for the citation span approaches for the different span cases. For the results of *CSPS* we compute the relative increase/decrease of *F1* score compared to the best result (based on *F1*) from the competitors. We mark in bold the best results for the evaluation metrics, and indicate with ** and * the results which are highly significant ($p < 0.001$) and significant ($p < 0.05$) based on *t-test* statistics when compared to the best performing baselines (CS, IC, CSW, MRF) based on *F1* score, respectively.

tion categories for which access to the source cannot be easily automated. Models which can determine the span accurately without the actual content have the advantage of generalizing to other citation sources (e.g. *books*) for which the evaluation is more challenging.⁸

Here, we disregard the citation features from Section 4.2. In terms of *MAP*, we have a slight decrease with *MAP* = 0.82 when compared to the model with the citation features. For recall we have a drop of 3%, resulting in *R* = 0.67.

This shows that by solely relying on the structure of the citing paragraph and other structural and discourse features we can perform the task with reasonable accuracy.

7 Conclusion

In this work, we tackled the problem of determining the fine-grained citation span of references in Wikipedia. We started from the *citing paragraph* and decomposed it into sequences consisting of sub-sentences. To accurately determine the span we proposed features that leverage the structure of the paragraph, discourse and temporal features, and finally analyzed the similarity between the citing paragraph and the citation content.

We introduce both a standard classifier as well as a sequence classifier using a linear-chain CRF model. For evaluation we manually annotated a ground-truth dataset of 509 citing paragraphs. We reported standard evaluation metrics and also in-

troduced metrics that measure the amount of erroneous span.

We achieved a *MAP* = 0.86, in the case of the plain classification model *CSPC*, and with a marginal difference for *CSPS* with *MAP* = 0.83, across all cases with an erroneous span of $\Delta_w = 26\%$ or $\Delta_w = 32\%$, depending on the model. Thus, we provide accurate means on determining the span and at the same time decrease the erroneous span by 34% compared to the best performing baselines. Moreover, we excel at determining citation spans at the sub-sentence level.

In conclusion, this presents an initial attempt on solving the citation span for references in Wikipedia. As future work we foresee a larger ground-truth and more robust approaches which take into account factors such as a reference being irrelevant to a citing paragraph and cases where the evidence for a paragraph is implied rather than explicitly stated in the reference.

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⁸At worst, one needs to read and comprehend the entire book to determine if a fragment is covered by the citation.

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