Inferring Document Similarity from Hyperlinks

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ABSTRACT

Assessing semantic similarity between text documents is a crucial aspect in Information Retrieval systems. In this work, we propose to use hyperlink information to derive a similarity measure that can then be applied to compare any text documents, with or without hyperlinks. As linked documents are generally semantically closer than unlinked documents, we use a training corpus with hyperlinks to infer a function $a, b \rightarrow sim(a, b)$ that assigns a higher value to linked documents than to unlinked ones. Two sets of experiments on different corpora show that this function compares favorably with *OKAPI* matching on document retrieval tasks.

Categories and Subject Descriptors:
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1. INTRODUCTION

Automatic techniques to access and organize document collections are essential to fully benefit from large text corpora. Several of these methods require a measure to quantify semantic similarities between text items: e.g. clustering relies on document comparisons, while Information Retrieval (IR) depends on document/query similarities.

In this work, our goal is to infer a measure of similarity relying on the semantic relationships contained in a hyperlinked corpus. In such a corpus, links can be considered as indicators of topic relatedness, i.e. linked documents tend to be semantically closer than unlinked documents [1]. Therefore, we propose to identify a measure of similarity $a, b \rightarrow sim(a, b)$ such that, for any document d, the documents which are linked to it are considered more similar than those which are not:

$$\forall d \in D_{train}, \forall l^+ \in L(d), \forall l^- \notin L(d), sim(d, l^+) > sim(d, l^-) \quad (1)$$

where $L(d)$ is the set of documents linked with d. For that purpose, a gradient descent strategy [2] is adopted: we first introduce a parameterized measure of similarity $a, b \rightarrow sim_\theta(a, b)$ and a cost C which indicates how far sim_θ is from the condition (1), then gradient descent optimization is used to select the parameters θ^* which minimize C for a given training corpus D_{train}.

The inferred measure sim_{θ^*} can then be applied to any pair of text documents, with or without hyperlinks, in any context where a text similarity measure is needed. In order to evaluate this approach, we compared the inferred measure with the state-of-the-art *OKAPI* matching measure [3] over two retrieval tasks (see Section 3). In this context, our model *LinkLearn* is shown to improve both precision at top 10 and average precision with respect to *OKAPI*.

In the remainder of this paper, Section 2 describes the proposed method, Section 3 presents the experiments and results, and Section 4 draws some conclusions.

2. THE *LINKLEARN* MODEL

This section describes the two main parts of the *LinkLearn* Model: the parameterized measure of similarity sim_θ is first defined and the cost C related to condition (1) is then introduced.

2.1 Model Parameterization

Our model relies on the Vector Space Model (VSM): each document d is represented with a vector $(d_1, \ldots, d_V)$, V being the vocabulary size, and the documents are then compared according to the inner product of their vectors,

$$sim(d, d') = \sum_{i=1}^{V} d_i \cdot d'_i \ .$$

The weight d_i of a term i in a document d is a function of $tf_{d,i}$ (the number of occurrences of i in d), idf_i (the inverse document frequency of i) and ndl_d (the length of document d divided by the average document length):

$$d_i = f(tf_{d,i}, idf_i, ndl_d).$$

This choice is motivated by the fact that functions of those three variables have led to the best performances in TREC IR benchmarks[1], *OKAPI BM25* being the most used of those functions:

$$d_i^{OKAPI} = \frac{(K+1) \cdot tf_{i,d} \cdot idf_i}{K \cdot ((1-B) + B \cdot ndl_d) + tf_{i,d}}$$

where K and B are hyperparameters. In our case, the function g is chosen to be the product of three Multi-Layer Perceptron (MLP) functions:

$$\begin{aligned} d_i &= f(tf_{d,i}, idf_i, ndl_d) \\ &= MLP_{tf}(tf_{d,i}) \cdot MLP_{idf}(idf_i) \cdot MLP_{ndl}(ndl_d). \quad (2) \end{aligned}$$

[1] NIST Text Retrieval Conference, trec.nist.gov

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This parameterization makes the simplifying assumption that $tf_{d,i}$, idf_i and ndl_d variables are independent. Such a hypothesis improves greatly the model efficiency (see [4] for further explanations) while still allowing for good performance (see Section 3).

2.2 Similarity Constraint Criterion

As mentioned above, it is desirable that, for any document d, the documents which are linked to it (i.e. the documents of $L(d)$) are considered more similar to d than any other documents (1). A simple cost would hence be the proportion of document triplet $d \in D_{train}$, $l^+ \in L(d)$, $l^- \notin L(d)$ for which the above property is not satisfied:

$$C^{0/1} = \frac{1}{|D_{train}|} \sum_{d \in D_{train}} C_d^{0/1} \quad (3)$$

where

$$C_d^{0/1} = \frac{1}{|L(d)| \cdot |\overline{L(d)}|} \sum_{\substack{l^+ \in L(d) \\ l^- \in \overline{L(d)}}} I\{sim(d, l^+) < sim(d, l^-)\},$$

$I\{\cdot\}$ is the indicator function, i.e. $I\{c\} = 1$ if c is true and zero otherwise and $L(d)$ is the set of documents linked with d (i.e. the documents referring to d and the documents referred to by d).

Similarly to the 0/1 loss (i.e. error rate) in the case of classification, $C^{0/1}$ cannot be directly minimized through gradient descent [2]. Hence, we propose to minimize an upper bound of this quantity:

$$C = \frac{1}{|D_{train}|} \sum_{d \in D_{train}} C_d \quad (4)$$

where

$$C_d = \frac{1}{|L(d)| \cdot |\overline{L(d)}|} \sum_{\substack{l^+ \in L(d) \\ l^- \in \overline{L(d)}}} \|1 - sim(d, l^+) + sim(d, l^-)\|_+,$$

and $x \rightarrow \|x\|_+$ is 0 for $x < 0$ and x otherwise. C is actually an upper bound of $C^{0/1}$ since $\forall x \in \mathbb{R}, I\{x < 0\} \leq \|1 - x\|_+$. This function C is derivable almost everywhere and we can hence select the parameters of the MLPs (2) which minimize C through gradient descent [2] (see [4] for further details).

3. EXPERIMENTS AND RESULTS

The following section describes the two sets of retrieval experiments performed in order to assess the proposed method. In both cases, *LinkLearn* is compared with *OKAPI*.

3.1 Wikipedia Experiments

The experiments presented in the following are performed over the Wikipedia corpus [5]. This dataset consists of $\sim 450,000$ encyclopedia articles, each article referring to other related articles using hyperlinks.

The corpus has been randomly split into 3 subsets of $150,625$ documents: *train*, *valid* and *test*. The *train* set is used for gradient descent (i.e. C is minimized over this set) and *valid* is used to select the hyperparameters for both *LinkLearn* (the number of hidden units in the MLPs, the number of training iterations and the learning rate of the gradient descent) and *OKAPI* (K and B).

Table 1: Wikipedia Results

	OKAPI	*LinkLearn*
Precision at top 10	21.5%	25.2% (+18%)
Break Even Point	36.6%	42.1% (+15%)
Average Precision	37.3%	43.8% (+17%)

Table 2: TDT-2 Results

	OKAPI	*LinkLearn*
Precision at top 10	38.8%	43.2% (+11%)
Break Even Point	30.3%	35.2% (+16%)
Average Precision	29.3%	34.5% (+18%)

The *test* set is used only for evaluation, in which we perform a related document search: each document is considered to be a query whose relevant documents are the documents linked with d. Table 1 shows that, according to all performance measures, *LinkLearn* outperforms *OKAPI*.

3.2 TDT-2 Experiments

To have a more complete evaluation, we also compared *LinkLearn* and *OKAPI* matching measure on TREC queries for the TDT-2 corpus [6]. Without re-training or adaptation, the measure inferred from the hyperlinked Wikipedia data has been applied as a query/document matching measure to the non-hyperlinked TDT-2 corpus.

The results obtained over TDT-2 confirm those obtained over Wikipedia (see Table 2): the use of *LinkLearn* leads to an improvement with respect to *OKAPI* matching according to the different performance measures used.

4. CONCLUSIONS

In this paper, we introduced *LinkLearn*, a gradient descent approach to derive a document similarity measure from a hyperlinked training corpus: the measure is selected such that, in most cases, a document is considered more similar to the documents with which it is linked than to the other documents. This approach has shown to be effective in an IR context: the use of the similarity measure inferred by *LinkLearn* has led to higher retrieval performances when compared to the state-of-the-art *OKAPI* matching measure.

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