Sentiment Retrieval using Generative Models

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Abstract

Ranking documents or sentences according to both topic and sentiment relevance should serve a critical function in helping users when topics and sentiment polarities of the targeted text are not explicitly given, as is often the case on the web. In this paper, we propose several sentiment information retrieval models in the framework of probabilistic language models, assuming that a user both inputs query terms expressing a certain topic and also specifies a sentiment polarity of interest in some manner. We combine sentiment relevance models and topic relevance models with model parameters estimated from training data, considering the topic dependence of the sentiment. Our experiments prove that our models are effective.

1 Introduction

The recent rapid expansion of access to information has significantly increased the demands on retrieval or classification of sentiment information from a large amount of textual data. The field of sentiment classification has recently received considerable attention, where the polarities of sentiment, such as positive or negative, were identified from unstructured text (Shanahan et al., 2005). A number of studies have investigated sentiment classification at document level, e.g., (Pang et al., 2002; Dave et al., 2003), and at sentence level, e.g., (Hu and Liu, 2004; Kim and Hovy, 2004; Nigam and Hurst, 2005); however, the accuracy is still less than desirable. Therefore, ranking according to the likelihood of containing sentiment information is expected to serve a crucial function in helping users. We believe that our work is the first attempt at sentiment retrieval that aims at finding sentences containing information with a specific sentiment polarity on a certain topic.

Intuitively, the expression of sentiment in text is dependent on the topic. For example, a negative view for some voting event may be expressed using ‘flaw’, while a negative view for some politician may be expressed using ‘reckless’. Moreover, sentiment polarities are also dependent on topics or domains. For example, the adjective ‘unpredictable’ may have a negative orientation in an automotive review, in a phrase such as ‘unpredictable steering’, but it could have a positive orientation in a movie review, in a phrase such as ‘unpredictable plot’, as mentioned in (Turney, 2002) in the context of his sentiment word detection.

We propose sentiment retrieval models in the framework of generative language modeling, not only assuming query terms expressing a certain topic, but also assuming that the polarity of sentiment interest is specified by the user in some manner, where the topic dependence of the sentiment is considered. To the best of our knowledge, there have been no other studies on a retrieval model unifying both topic and sentiment, and further, there have been no other studies on sentiment retrieval. The sentiment information often appears as local in a document, and therefore focusing on finer levels, i.e., sentence or passage levels rather than document level, is crucial. We thus experiment on sentiment retrieval at the sentence level in this paper.

The rest of this paper is structured as follows. Section 2 introduces the work related to this study. Section 3 describes a generative model of sentiment, which is proposed here as a theoretical framework for our work. Section 4 describes the task definition and our sentiment retrieval model.
Section 5 explains the data we used for our experiments, and gives our experimental results. Section 6 concludes the paper.

2 Related Work

Some efforts for the TREC Novelty Track were related to our work. Although some of the topics used in the Novelty Track in 2003 and 2004 (Soboroff and Harman, 2003; Soboroff, 2004) were related to opinions, most of the efforts were focused on topic, such as studies using term distribution within each sentence, e.g., (Allan et al., 2003; Losada, 2005; Murdock and Croft, 2005). Amongst the participants in the TREC Novelty Track, only (Kim et al., 2004) proposed a method specialized to opinion-bearing sentence retrieval, by making use of lists of words with positive or negative polarities. They aimed to find opinions on a given topic but did not distinguish or did not care about sentiment polarities that should be represented in some sentences (hereafter, opinion retrieval). We focus on finding positive views or negative views according to a given topic and sentiment of interest (hereafter, sentiment retrieval). Our work is the first work on sentiment retrieval, to the best of our knowledge.

In the context of sentiment classification, some researchers have conducted studies on the topic dependence of sentiment polarities. (Nasukawa and Yi, 2003) and (Yi et al., 2003) extracted positive or negative expressions on a given product name using handmade lexicons. (Engström, 2004) studied how the topic dependence influences the accuracy of sentiment classification and attempted to reduce the influence to improve the accuracy. (Wilson et al., 2005) investigated how context influences sentiment polarity at the phrase level in a corpus, beginning with a predefined list of words with polarities. Their focus on the phenomena of topic dependence of sentiment can be shared with our work; however, their work is not directly related to ours, because we focus on a different task, sentiment retrieval, where different approaches are required.

3 A Generative Model of Sentiment

In this section we will provide a formal underpinning for our approach to sentiment retrieval. The approach is based on the generative paradigm: we describe a statistical process that could be viewed, hypothetically, as a source of every statement of interest to our system. We stress that this generative process is to be treated as purely hypothetical; the process is only intended to reflect those aspects of human discourse that are pertinent to the problem of retrieving affectively appropriate and topic-relevant texts in response to a query posed by our user.

Before giving a formal specification of our model, we will provide a high-level overview of the main ideas. We are trying to model a collection of natural-language statements, some of which are relevant to a user’s query. In our experiments, these statements are individual sentences, but the model can be applied to textual chunks of any length. We assume that the content of an individual statement can be modeled independently of all other statements in the collection. Each statement consists of some topic-bearing and some sentiment-bearing words. We assume that the topic-bearing words represent exchangeable samples from some underlying topic language model. Exchangeability means that the relative order of the words is irrelevant, but the words are not independent of each other—the idea often stated as a bag-of-words assumption. Similarly, sentiment-bearing words are viewed as an order-invariant ‘bag’, sampled from the underlying sentiment language model. We will explicitly model dependency between the topic and sentiment language models, and will demonstrate that treating them independently leads to sub-optimal retrieval performance. When a sentiment polarity value is observed for a given statement, we will treat it as a ternary variable influencing the topic and sentiment language models.

We represent a user’s query as just another statement, consisting of topic and sentiment parts, subject to all the independence assumptions stated above. We will use the query to estimate the topic and sentiment language models that are representative of the user’s interests. Following (Lavrenko and Croft, 2001), we will use the term relevance models to describe these models, and will use them to rank statements in order of their relevance to the query.

3.1 Definitions

We start by providing a set of definitions that will be used in the remainder of this section. The task of our model is to generate a collection of statements $w_1 \ldots w_n$. A statement $w_i$ is a string of
words \( w_{i1} \ldots w_{im} \), drawn from a common vocabulary \( \mathcal{V} \). We introduce a binary variable \( b_{ij} \in \{S, T\} \) as an indicator of whether the word in the \( j \)th position of the \( i \)th statement will be a topic word or a sentiment word. For our purposes, \( b_{ij} \) is either provided by a human annotator (manual annotation), or determined heuristically (automatic annotation).

The sentiment polarity \( x_i \) for a given statement is a discrete random variable with three outcomes: \( \{-1, 0, +1\} \), representing negative, neutral, and positive polarity values, respectively. As a matter of convenience we will often denote a statement as a triple \( \{w^T_{ij}, w^S_{ij}, x_i\} \), where \( w^T_{ij} \) contains the sentiment words and \( w^S_{ij} \) contains the topic words. As we mentioned above, the user’s query is treated as just another statement. It will be denoted as a triple \( \{q^T_i, q^S_i, q^C_i\} \), corresponding to sentiment words, topic keywords, and the desired polarity value. We will use \( \mathcal{P} \) to denote a unigram language model, i.e., a function that assigns a number \( p(v) \in [0, 1] \) to every word \( v \) in our vocabulary \( \mathcal{V} \), such that \( \sum v p(v) = 1 \). The set of all possible unigram language models is the probability simplex \( \mathcal{P} \). Similarly, \( \mathcal{P}_x \) will denote a distribution over the three possible polarity values, and \( \mathcal{P}_x \) is the corresponding ternary probability simplex. We define \( \pi : \mathcal{P} \times \mathcal{P} \times \mathcal{P}_x \rightarrow [0, 1] \) to be a measure function that assigns a probability \( \pi(p_1, p_2, p_x) \) to a pair of language models \( p_1 \) and \( p_2 \) together with a polarity model \( p_x \).

### 3.2 Generative model

Using the definitions presented above, and assuming that \( \pi() \) is given, we hypothesize that a new statement \( w_{i1} \ldots w_{im} \) containing words \( w_{i1} \ldots w_{im} \) with sentiment polarity \( x_i \) can be generated according to the following mechanism.

1. Draw \( p_t, p_s \) and \( p_x \) from \( \pi(\cdot, \cdot, \cdot) \).
2. Sample \( x_i \) from a polarity distribution \( p_x(\cdot) \).
3. For each position \( j = 1 \ldots m \):
   (a) if \( b_{ij} = T \): draw \( w_{ij} \) from \( p_t(\cdot) \);
   (b) if \( b_{ij} = S \): draw \( w_{ij} \) from \( p_s(\cdot) \).

The probability of observing the new statement \( w_{i1} \ldots w_{im} \) under this mechanism is given by:

\[
\sum_{p_t, p_s, p_x} \pi(p_t, p_s, p_x) p_x(x_i) \prod_{j=1}^{m} \begin{cases} p_t(w_{ij}) & \text{if } b_{ij} = T \\ p_s(w_{ij}) & \text{otherwise} \end{cases}
\]

(1)

The summation in equation (1) goes over all possible pairs of language models \( p_t, p_s \), but we can avoid integration by specifying a mass function \( \pi() \) that assigns nonzero probabilities to a finite subset of points in \( \mathcal{P} \times \mathcal{P} \times \mathcal{P}_x \). We accomplish this by using a nonparametric estimate for \( \pi() \), the details of which are provided below.

#### 3.2.1 A nonparametric generative mass function

We use a nonparametric estimate for \( \pi(\cdot, \cdot, \cdot) \), which makes our generative model similar to kernel-based density estimators or Parzen-window classifiers (Silverman, 1986). The primary difference is that our model operates over discrete events (strings of words), and accordingly the mass function is defined over the space of distributions, rather than directly over the data points. Our estimate relies on a collection of paired observations \( C = \{w^T_{ij}, w^S_{ij}, x_i : i=1 \ldots n\} \), which represent statements for which we know which words are topic words \( (w^T_{ij}) \), and which are sentiment words \( (w^S_{ij}) \). Each of these observations corresponds to a unique point \( p_{ti}, p_{si}, p_{xi} \) in the space of paired distributions \( \mathcal{P} \times \mathcal{P} \times \mathcal{P}_x \), defined by the following coordinates:

\[
\begin{align*}
p_{ti}(v) &= \lambda_t \#(v, w^T_{ij}) / \#(w^T_{ij}) + (1-\lambda_t) c_{tv} \\
p_{si}(v) &= \lambda_s \#(v, w^S_{ij}) / \#(w^S_{ij}) + (1-\lambda_s)c_{sv} \\
p_{xi}(x) &= \lambda_x 1_{x=x_i} + (1-\lambda_x).
\end{align*}
\]

(2)

Here, \( \#(v, w^T_{ij}) \) represents the number of times the word \( v \) was observed in the topic part of statement \( i \), the length of which is denoted by \( \#(w^T_{ij}) \). \( c_{tv} \) stands for the relative frequency of \( v \) in the topic part of the collection. The same definitions apply to the sentiment parameters \( \#(v, w^S_{ij}) \), \( \#(w^S_{ij}) \) and \( c_{sv} \). The Boolean indicator function \( 1_y \) returns one when the predicate \( y \) is true and zero otherwise. Metaparameters \( \lambda_t, \lambda_s, \lambda_x \) specify the amount of Dirichlet smoothing (Zhai and Lafferty, 2001) applied to the topic, sentiment and polarity estimates respectively; values for these parameters are determined empirically.

We define \( \pi(p_t, p_s, p_x) \) to have mass \( \frac{1}{n} \) when its argument \( p_t, p_s, p_x \) corresponds to some observation \( p_{ti}, p_{si}, p_{xi} \), and zero otherwise:

\[
\pi(p_t, p_s, p_x) = \frac{1}{n} \sum_{i=1}^{n} 1_{p_{ti}=p_{ti}} \times 1_{p_{si}=p_{si}} \times 1_{p_{xi}=p_{xi}}.
\]

(3)

Equation (3) maintains empirical dependencies between the topic language model \( p_t \) and the sentiment model \( p_x \), because we assign nonzero prob-
ability mass only to pairs of models that actually co-occur in our observations.

3.2.2 Limitations of the model

Our model represents each statement \( w_i \) as a bag of words, or more formally an order-invariant sequence. This representation is often confused with word independence, which is a much stronger assumption. The generative model defined by equation (1) ignores the relative ordering of the words, but it does allow arbitrarily strong unordered dependencies among them. To illustrate, consider the probability of observing the words ‘unpredictable’ and ‘plot’ in the same statement. Suppose we set \( \lambda_t, \lambda_s=1 \) in equation (2), reducing the effects of smoothing. It should be evident that \( P(\text{unpredictable}, \text{plot}) \) will be non-zero only when the two words actually co-occur in the training data. By carefully selecting the smoothing parameters, the model can preserve dependencies between topic and sentiment words, and is quite capable of distinguishing the positive sentiment of ‘unpredictable plot’ from the negative sentiment of ‘unpredictable steering’. On the other hand, the model does ignore the ordering of the words, so it will not be able to differentiate the negative phrase ‘gone from good to bad’ from its exact opposite. Furthermore, our model is not well suited for modeling adjacency effects: the phrase ‘unpredictable plot’ is treated in the same way as two separate words, ‘unpredictable’ and ‘plot’, co-occurring in the same sentence.

3.3 Using the model for retrieval

The generative model presented above can be applied to sentiment retrieval in the following fashion. We start with a collection of statements \( C \) and a query \( \{q^t, q^s, q^e\} \) supplied by the user. We use the machinery outlined in Section 3.2 to estimate the topic and sentiment relevance models corresponding to the user’s information need, and then determine which statements in our collection most closely correspond to these models of relevance. The topic relevance model \( R_t \) and sentiment relevance model \( R_s \) are estimated as follows. We assume that our query \( q^t, q^s, q^e \) is a random sample from a distribution defined by equation (1), and then for each word \( v \) we estimate the likelihood that \( v \) would be observed if we sampled one more topic or sentiment word:

\[
R_t(v) = \frac{P(q^t, q^s, q^e, q^x)}{P(q^t, q^s, q^e)} \quad R_s(v) = \frac{P(q^s, q^t, q^e, q^x)}{P(q^t, q^s, q^e)}
\]

Both the numerator and denominator are computed according to equation (1), with the mass function \( \pi() \) given by equations (3) and (2). We use the notation \( q^x \) to denote appending word \( v \) to the string \( q \). Estimation is done over the training corpus, which may or may not include numeric values of sentiment polarity.\(^1\) Once we have estimates for the topic and sentiment relevance models, we can rank testing statements \( w \) by their similarity to \( R_t \) and \( R_s \). We rank statements using a variation of cross-entropy, which was proposed by (Zhai, 2002):

\[
\alpha \sum_v R_t(v) \log p_t(v) + (1-\alpha) \sum_v R_s(v) \log p_s(v).
\]

Here the summations extend over all words \( v \) in the vocabulary, \( R_t \) and \( R_s \) are given by equation (4), while \( p_t \) and \( p_s \) are computed according to equation (2). A weighting parameter \( \alpha \) allows us to change the balance of topic and sentiment in the final ranking formula; its value is selected empirically.

4 Sentiment Retrieval Task

4.1 Task definition

We define two variations of the sentiment retrieval task. In one, the user supplies us with a numeric value for the desired polarity \( q^e \). In the other, the user supplies a set of seed words \( q^e \), reflecting the desired sentiment. The first task requires us to have polarity observations \( x_i \) in our training data, while the second does not.

**Task with training data:**

Input: (1) a set of topic keywords \( q^t \) and (2) a sentiment specification \( q^e \in \{-1, 0, 1\} \). In this case we assume \( q^s = \) the empty string.

Output: a ranked list of topic-relevant and sentiment-relevant sentences from the test data.

**Task with seed words:**

Input: (1) a set of topic keywords \( q^t \) and (2) a set of sentiment seed words \( q^s \). In this case our model ignores \( q^e \) and \( x_i \).

\(^1\)When the training corpus does not contain numeric polarity values \( x_i \), we assume \( \pi(p_t, p_s) = \pi(p_t, p_s) \) and force \( p_e(x_i) \) to be a constant.
Output: a ranked list of topic-relevant and sentiment-relevant sentences from the test data.

In the first task, we split our corpus into three parts: (i) the training set, which was used for estimating the relevance models $R_t$ and $R_s$; (ii) the development set, which was used for tuning the model parameters $\lambda_t$, $\lambda_s$ and $\alpha$; and (iii) the testing set, from which we retrieved sentences in response to the query. In the second task, we split the corpus into two parts: (i) the training set, which was used for tuning the model parameters; and (ii) the testing set, which was used for constructing $R_t$ and $R_s$ and from which we retrieved sentences in response to queries.\(^2\) The testing set was identical in both tasks. Note that the sentiment relevance model $R_s$ can be constructed in a topic-dependent fashion for both tasks.

4.2 Variations of the retrieval model

**sln**: the retrieval model as described in Section 3.3.

**lmt**: the standard language modeling approach (Ponte and Croft, 1998; Song and Croft, 1999) on the topic keywords $q^t$ for the topic part of the text $w^t$.

**lms**: the standard language modeling approach on the sentiment keywords $q^s$ for the sentiment part of the text $w^s$.

**base**: the weighted linear combination of lmt and lms.

**rmt**: only the topic relevance model was used for ranking using $q^t$ and for $w^t$.\(^3\)

**rms**: only the sentiment relevance model was used for ranking using $q^s$ and for $w^s$.

**rmt-base**: the slm model with $\alpha = 1$, ignoring the sentiment relevance model.

**rms-base**: the slm model with $\alpha = 0$, ignoring the topic relevance model.

**rmt-rms**: the rmt and rms models are treated independently.

**rmt-slm**: the rmt and rms-base models are combined.

**lmtf**: the standard language modeling approach using $q^t$ for the nonsplit text, as baseline.

**rmtf**: the conventional relevance model was used for ranking using $q^t$ for the nonsplit text, as baseline.

**lmtsf**: the standard language modeling approach using both $q^t$ and $q^s$ for the nonsplit text, for reference.

**rmtsf**: the conventional relevance model was used for ranking using both $q^t$ and $q^s$ for the nonsplit text, for reference.

Note that the relevance models are constructed using training data for the training-based task, but are constructed using test data for the seed-based task, as mentioned in Section 4.1. Therefore, the base model is only used for the training data, not for the test data, in the training-based task, while it can be performed for the test data in the case of the seed-based task. Moreover, the lms, lmtsf and rmtsf models are based on the premise of using seed words to specify sentiments, and so they are only applicable to the seed-based task.

In the models described in this subsection, $\lambda_t$ and $\lambda_s$ in equation (2) were set to Dirichlet estimates (Zhai and Lafferty, 2001), $\frac{\#(w^t_i)}{(\#(w^t_i) + \mu_t)}$ and $\frac{\#(w^s_i)}{(\#(w^s_i) + \mu_s)}$ for the relevance models $R_t$ and $R_s$, respectively, in equation (4), and were fixed at 0.9 for ranking as in equation (5) for our experiments in Section 5. Here, $\mu_t$ and $\mu_s$ were selected empirically according to the tasks described in Section 4.1. The model parameter $\alpha$ in equation (5) was also selected empirically in the same manner. The number of ranked documents used in the relevance models $R_t$ and $R_s$, in equation (4), was selected empirically in the same manner as above; however, we fixed the number of terms used in the relevance models as 1000.

5 Experiments

5.1 Data set and evaluation measure

We used the MPQA Opinion Corpus version 1.2 (Wilson et al., 2005; Wiebe et al., 2005) to measure the effectiveness of our sentiment re-
5.2 Extracting sentiment expressions

5.2.1 Using manual annotation

Because the MPQA corpus was annotated with phrase-level sentiments, we can use these annotations to split a sentence into a topic part $w^t$ and a sentiment part $w^s$. The Krovetz stemmer (Krovetz, 1993) was applied to the topic part, the sentiment part and to the query terms$^6$ and, for the retrieval experiments in Sections 5.3 and 5.4, a total of 418 stopwords from a standard stopword list were removed when they appeared.

5.2.2 Using automatic annotation

In automatic extraction of sentiment expressions in this study, we detected sentiment-bearing words using lists of words with established polarities. At this stage, topic dependence was not considered; however, at the stage of sentiment modeling, the topic dependence can be reflected, as described in Sections 3 and 4.

We first prepared a list of words indicating sentiments. We used Hatzivassiloglou and McKeown’s sentiment word list (Hatzivassiloglou and McKeown, 1997), which consists of 657 positive and 679 negative adjectives, and The General Inquirer (Stone et al., 1966), which contains 1621 positive and 1989 negative words.\textsuperscript{7} By merging these lists, we obtained 1947 positive and 2348 negative words. After stemming these words in the same manner as in Section 5.2.1, we were left with 1667 positive and 2129 negative words, which we will use hereafter in this paper.

The sentiment polarities are sometimes sensitive to the structural information, for instance, a negation expression reverses the following sentiment polarity. To handle negation, every sentiment-bearing word was rewritten with a ‘NEG’ suffix, such as ‘good\_NEG’, if an odd number of negation expressions was found within the five preceding words in the sentence. To detect negation expressions, we used a predefined negation expression list. This negation handling is similar to that used in (Das and Chen, 2001; Pang et al., 2002). We extracted sentiment-bearing expressions using the list of words with established polarities.

\textsuperscript{6}We used the topic labels attached to the MPQA corpus as the topic query terms $q^t$ in all the experiments in Sections 5.3 and 5.4.

\textsuperscript{7}We extracted positive and negative words from the General Inquirer basically in the same manner as in (Turney and Littman, 2003); however, we did not exclude any words, unlike (Turney and Littman, 2003), where some seed words were excluded for the evaluation of their work.


### 5.3 Experiments on training-based task

We conducted experiments on the training-based task described in Section 4.1, using either manual annotation as described in Section 5.2.1 or automatic annotation as described in Section 5.2.2. Table 1 contrasts sample probabilities from topic-independent sentiment relevance models and those from topic-dependent sentiment relevance models. In the left two columns of this table, two sets of sample probabilities using the topic-independent model are presented. One was computed from the manual annotation and the other was computed from the automatic annotation. In the remaining columns, samples using the topic-dependent model are shown according to the three topics: (1) “reaction to President Bush’s 2002 State of the Union Address”, (2) “2002 presidential election in Zimbabwe”, and (3) “Israeli settlements in Gaza and West Bank”. A number of positive expressions appeared topic dependent, such as ‘promise’ (stemmed from ‘promising’ or not) and ‘support’ for Topic (1), ‘legitimate’ and ‘congratulate’ for Topic (2) and ‘justify’ and ‘secure’ for Topic (3); while negative expressions appeared topic-dependent, such as ‘critic’ (stemmed from ‘criticism’) and ‘eyesore’ for Topic (1), ‘flaw’ and ‘condemn’ for Topic (2) and ‘mistake’ and ‘secure_NEG’ (i.e., ‘secure’ was negated) for Topic (3).

Some expressions were unexpectedly generated regardless of the types of annotation, e.g., ‘palestinian’ for Topic (3); however, we found some characteristics in the results using automatic annotation. Some expressions on opinions that did not convey sentiments, such as ‘state’, frequently appeared regardless of topic. This sort of expression may effectively function as degrading sentences only conveying facts, but may function harmfully by catching sentences conveying opinions without sentiments in the task of sentiment retrieval. Some topic expressions, such as ‘settle’ (stemmed from ‘settlement’ or not) for Topic (3), were generated, because such words convey positive sentiments in some other contexts and thus they were contained in the list of sentiment-bearing words that we used for automatic annotation. This will not cause a topic relevance model to drift, because we modeled the topic relevance using whole sentences, as described in Section 5.2.2; however, it may harm the sentiment relevance model to some extent.

The upper and lower tables correspond to positive and negative sentiments, respectively. The topic-independent sentiment relevance models (in the left two columns) correspond to \( r_{ms} \), and the topic-dependent models (in the rest of the columns) correspond to \( r_{ms-base} \), which is used for \( slm \).

### Table 1: Sample probabilities from the sentiment relevance models

| Topic-independent | 2002 presidential election in Zimbabwe | Israeli settlements in Gaza and West Bank |
|-------------------|---------------------------------------|------------------------------------------|
|                    | w/ manual annot. | w/ automatic annot. | w/ manual annot. | w/ automatic annot. | w/ manual annot. | w/ automatic annot. |
| 0.009 yea         | 0.001 state     | 0.005 support      | 0.004 state     | 0.002 support      | 0.004 state     | 0.001 support      |
| 0.030 demand      | 0.0029 state    | 0.0030 support     | 0.0030 state    | 0.0030 support     | 0.0029 state    | 0.0029 support     |
| 0.030 expect      | 0.026 support   | 0.016 promise      | 0.034 support   | 0.034 support      | 0.0334 support  | 0.0334 support     |
| 0.030 aim         | 0.031 free      | 0.014 call         | 0.024 call      | 0.024 call         | 0.031 free      | 0.031 free         |
| 0.030 lead        | 0.013 call      | 0.014 excellent    | 0.019 meet      | 0.019 meet         | 0.029 congratulate | 0.029 congratulate |
| 0.033 human        | 0.013 minister  | 0.013 goal         | 0.017 minister  | 0.017 minister     | 0.028 fair       | 0.028 fair         |
| 0.031 lead        | 0.011 right     | 0.013 express      | 0.015 promise   | 0.023 praise        | 0.023 praise     | 0.023 praise       |
| 0.031 call        | 0.010 foreign   | 0.013 best         | 0.014 white     | 0.037 confident     | 0.017 congratulate | 0.024 key         |
| 0.011 hopeful      | 0.009 hope      | 0.012 count        | 0.013 foreign   | 0.017 call          | 0.015 call      | 0.022 expect       |
| 0.016 time         | 0.009 meet      | 0.012 cooperate    | 0.012 success   | 0.012 hopeful       | 0.015 meet      | 0.018 justify      |
| 0.018 say          | 0.008 interest  | 0.011 proposal     | 0.011 defense   | 0.012 express       | 0.013 unity      | 0.018 honour       |
| 0.009 evil         | 0.001 state     | 0.005 evil         | 0.004 state     | 0.0029 evil        | 0.0019 evil      | 0.0030 evil        |
| 0.008 axis         | 0.022 evil      | 0.049 axis         | 0.051 evil      | 0.018 curb          | 0.026 curb       | 0.013 protest       |
| 0.045 threat       | 0.015 right     | 0.022 critic       | 0.028 critic    | 0.015 true         | 0.023 state      | 0.002 decide        |
| 0.033 qualify      | 0.015 prison    | 0.011 prepare      | 0.017 call      | 0.014 critic        | 0.022 opposition | 0.011 peace        |
| 0.030 wrote        | 0.013 critic    | 0.010 recognize    | 0.012 interest  | 0.012 expect        | 0.019 reject     | 0.001 fatten        |
| 0.020 particular    | 0.010 human     | 0.010 reckless      | 0.011 move      | 0.011 reject        | 0.017 condemn    | 0.011 believe        |
| 0.020 word         | 0.008 support   | 0.010 country      | 0.011 reject    | 0.011 s            | 0.016 legal       | 0.009 plan         |
| 0.018 harsh        | 0.008 protest   | 0.009 upset        | 0.010 slam       | 0.011 fair          | 0.015 move       | 0.009 fear          |
| 0.015 reject       | 0.008 war       | 0.009 pick         | 0.010 right     | 0.011 free          | 0.015 democratic | 0.009 mistake       |
| 0.015 dangerous    | 0.008 force     | 0.009 eyesore       | 0.010 attack    | 0.010 angry         | 0.014 support     | 0.009 continue      |
|                    |                |                    |                |                    |                |                |
Table 2: Experimental results of training-based task using manually annotated data

| Models | 10% | 25% | 40% |
|--------|-----|-----|-----|
| lmt    | 0.1389 (0.1135) | 0.1389 (0.1135) | 0.1386 (0.1145) |
| lmt    | 0.1499 (0.1164) | 0.1499 (0.1164) | 0.1444 (0.1148) |
| rmtf   | 0.1712 (0.1191) | 0.1712 (0.1191) | 0.1922 (0.1705) |
| rmtf   | 0.2076* (0.1936) | 0.2252* (0.2139) | 0.2302* (0.2196) |
| rmsf   | 0.0464 (0.0384) | 0.0452 (0.0394) | 0.0375 (0.0320) |
| rmtf   | 0.0772 (0.0640) | 0.0869 (0.0704) | 0.0865 (0.0724) |
| rmtf   | 0.2025 (0.1413) | 0.2210 (0.1925) | 0.2117 (0.2003) |
| rmtf   | 0.2278* (0.1715) | 0.2249 (0.1676) | 0.1999 (0.1819) |
| srmf   | 0.2006 (0.1914) | 0.2247 (0.1824) | 0.2441* (0.2427) |

*"* indicates statistically significant improvement over rmtf where $p < 0.05$ with the two-sided Wilcoxon signed-rank test.

We performed retrieval experiments in the steps described in Section 4.1. For this purpose, we split the data into three parts: (i) $x\%$ as the training data, (ii) $(50 - x)\%$ as the evaluation data, and (iii) $50\%$ as the test data.

The test results of training-based task using manually annotated data and automatically annotated data are shown in Tables 2 and 3, respectively. The scores were computed according to the bpref evaluation measure (Buckley and Voorhees, 2004), as mentioned in Section 5.1. In addition to the bpref, mean average precision values are presented as ‘AvgP’ in the tables, for reference. In these tables, the top row indicates the percentages of the training data $x$. It turned out that in all our experiments the appropriate fraction of training data was 40%. In this setting, our $slm$ model worked 76.1% better than the query likelihood model and 32.6% better than the conventional relevance model, when using automatic annotation, and both improvements were statistically significant according to the Wilcoxon signed-rank test. When using automatic annotation, the $slm$ model worked 67.2% better than the query likelihood model and 25.9% better than the conventional relevance model, where both improvements were statistically significant. The $rmt$-base model also worked well with automatic annotation.

5.4 Experiments on seed-based task

For experiments on the seed-based task that was described in Section 4.1, we used three groups of seed words: KAM, TUR and ORG. Each group consists of a positive word set $q^{+}_{i}$ and a negative word set $q^{-}_{i}$, as follows:

KAM: $q^{+}_{i} = \{\text{good}\}$, and $q^{-}_{i} = \{\text{bad}\}$.

TUR: $q^{+}_{i} = \{\text{good, nice, excellent, positive, fortunate, correct, superior}\}$, and $q^{-}_{i} = \{\text{bad, nasty, poor, negative, unfortunate, wrong, inferior}\}$.

ORG: $q^{+}_{i} = \{\text{support, demand, promise, want, hope}\}$, and $q^{-}_{i} = \{\text{refuse, accuse, criticism, fear, reject}\}$.

KAM and TUR were used in (Kamps and Marx, 2002) and (Turney and Littman, 2003), respectively. We constructed ORG considering sentiment-bearing words that may frequently appear in newspaper articles.

We experimented with the seed-based task, making use of each of these seed word groups, in the steps described in Section 4.1. For this purpose, we split the data into two parts: (i) $50\%$ as the estimation data and (ii) $50\%$ as the test data.

The test results using manually annotated data and automatically annotated data are shown in Tables 4 and 5, respectively, where the scores were computed according to the bpref evaluation measure. Mean average precision values are also presented as ‘AvgP’ in the tables, for reference.

When using the manually annotated approach, our $slm$ model worked well, especially with the seed word group ORG, as shown in Table 4. Using ORG, the $slm$ model worked 61.2% better than the query likelihood model and 15.2% better than the conventional relevance model, where both improvements were statistically significant according to the Wilcoxon signed-rank test. Even

Table 3: Experimental results of training-based task using automatically annotated data

| Models | 10% | 25% | 40% |
|--------|-----|-----|-----|
| lmt    | 0.1389 (0.1135) | 0.1389 (0.1135) | 0.1386 (0.1145) |
| lmt    | 0.1325 (0.0972) | 0.1315 (0.0976) | 0.1325 (0.0972) |
| rmtf   | 0.1811 (0.1706) | 0.1887 (0.1770) | 0.1841 (0.1691) |
| rmtf   | 0.1490 (0.1418) | 0.1762 (0.1854) | 0.1695 (0.1485) |
| rmtf   | 0.2076* (0.1936) | 0.2252* (0.2139) | 0.2302* (0.2196) |
| rmtf   | 0.0347 (0.0287) | 0.0501 (0.0408) | 0.0501 (0.0408) |
| rmtf   | 0.0943 (0.0733) | 0.1196 (0.0896) | 0.1241 (0.0979) |
| rmtf   | 0.1690 (0.1182) | 0.2063 (0.1938) | 0.1603 (0.1591) |
| rmtf   | 0.1980 (0.1426) | 0.2013 (0.1835) | 0.2148 (0.1882) |
| rmtf   | 0.2101 (0.1537) | 0.2261* (0.1716) | 0.2318* (0.1802) |

*"* indicates statistically significant improvement over rmtf where $p < 0.05$ with the two-sided Wilcoxon signed-rank test.

*As mentioned in Section 5.1, the bpref is more appropriate for the evaluation of our experiments than the mean average precision.

*Significance tests involved only 20 queries, which makes it difficult to achieve statistical significance.
using the other seed word groups, the \textit{slm} model worked 49–56% better than the query likelihood model and 6–12% better than the conventional relevance model; however, the latter improvement was not statistically significant. The \textit{rmt-slm} model also worked well with manual annotation.

When using automatic annotation, the \textit{slm} model worked 46–48% better than the query likelihood model and 4–6% better than the conventional relevance model, as shown in Table 5. The improvements over the conventional relevance model were statistically significant only when using \textit{TUR} or \textit{KAM}; however, the score when using \textit{ORG} is almost comparable with the others.

6 Conclusion

We propose sentiment retrieval models in the framework of probabilistic generative models, not only assuming that a user inputs query terms expressing a certain topic, but also assuming that the user specifies a sentiment polarity of interest either as a sentiment specification $q^r$ or as a set of sentiment seed words $q^s$. For this purpose, we combine sentiment relevance models and topic relevance models, considering the topic dependence of the sentiment. In our experiments, our model worked significantly better than standard language modeling approaches, both when using $q^r$ and $q^s$, and with both manual and automatic annotation of the fragments expressing sentiments in text. With $q^f$ and automatic annotation, our model still worked significantly better than the standard approaches; however, the performance did not reach that achieved with other settings. We believe the performance can be improved with larger-scale data.

We experimented to find sentences that were relevant to a given topic and were appropriate to a given sentiment; however, our models can also be applied to textual chunks of any length, such as at document level or passage level. Our model can be easily extended to \textit{opinion retrieval}, if the opinion retrieval is defined as retrieving sentences or documents that contain either positive or negative sentiments. This issue is worth pursuing in future work. Approaches considering polarity strength or continuous values for the polarity specification, rather than using \{-1, 1\}, can also be considered in future work.

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Table 4: Experimental results of seed-based task using manually annotated data

| Models  | ORG Bpref (AvgP) | TUR Bpref (AvgP) | KAM Bpref (AvgP) |
|---------|-----------------|-----------------|-----------------|
| lmt     | 0.1385 (0.1119) | 0.1385 (0.1119) | 0.1385 (0.1119) |
| lmtsf   | 0.1182 (0.1035) | 0.1061 (0.0884) | 0.1330 (0.1062) |
| lmt     | 0.1501 (0.1171) | 0.1501 (0.1171) | 0.1501 (0.1171) |
| base    | 0.1615 (0.1319) | 0.1531 (0.1217) | 0.1514 (0.1180) |
| rmtsf   | 0.1884 (0.1775) | 0.1661 (0.1412) | 0.1927 (0.1754) |
| rmt     | 0.1974 (0.1826) | 0.1974 (0.1826) | 0.1974 (0.1826) |
| rmt-base| 0.1960 (0.1918) | 0.1931 (0.1703) | 0.1837 (0.1721) |
| rms     | 0.0434 (0.0262) | 0.0295 (0.0205) | 0.0280 (0.0170) |
| rms-base| 0.1142 (0.1022) | 0.1144 (0.0841) | 0.1226 (0.0973) |
| rmt-rms | 0.1705 (0.1117) | 0.1403 (0.1424) | 0.1405 (0.0842) |
| rmt-slm | 0.2266* (0.2034) | 0.2272* (0.2012) | 0.2264* (0.2016) |
| slm     | 0.2233* (0.2048) | 0.2160 (0.1945) | 0.2072 (0.1929) |

Table 5: Experimental results of seed-based task using automatically annotated data

| Models  | ORG Bpref (AvgP) | TUR Bpref (AvgP) | KAM Bpref (AvgP) |
|---------|-----------------|-----------------|-----------------|
| lmt     | 0.1385 (0.1119) | 0.1385 (0.1119) | 0.1385 (0.1119) |
| lmtsf   | 0.1182 (0.1035) | 0.1061 (0.0884) | 0.1330 (0.1062) |
| lmt     | 0.1325 (0.0972) | 0.1325 (0.0972) | 0.1325 (0.0972) |
| base    | 0.1550 (0.1369) | 0.1451 (0.1188) | 0.1416 (0.1142) |
| rmtsf   | 0.1884 (0.1775) | 0.1661 (0.1412) | 0.1927 (0.1754) |
| rmt     | 0.1757 (0.1578) | 0.1757 (0.1578) | 0.1757 (0.1578) |
| rmt-base| 0.1957 (0.1862) | 0.1976 (0.1882) | 0.1825 (0.1704) |
| rms     | 0.0421 (0.0236) | 0.0364 (0.0205) | 0.0217 (0.0147) |
| rms-base| 0.1268 (0.1096) | 0.1301 (0.1148) | 0.1326 (0.1158) |
| rmt-rms | 0.1465 (0.1514) | 0.1390 (0.1393) | 0.1252 (0.0757) |
| rmt-slm | 0.1977 (0.1811) | 0.2008 (0.1649) | 0.1959 (0.1677) |
| slm     | 0.2031 (0.1714) | 0.2055* (0.1668) | 0.2044* (0.1698) |

*‘* indicates statistically significant improvement over rmtf where $p < 0.05$ with the two-sided Wilcoxon signed-rank test.
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