

# Improving LDA Topic Models for Microblogs via Automatic Tweet Labeling and Pooling

*Author*<sup>1</sup> *Author*<sup>2</sup>

(1) INSTITUTE\_1, address 1

(2) INSTITUTE\_2, address 2

mail-id, mail-id

## ABSTRACT

Twitter : the world of 140 characters poses serious challenges to the efficacy of topic models on short, messy text. While topic models such as Latent Dirichlet Allocation (LDA) have a long history of successful application to news articles and academic abstracts, they are often less coherent when applied to microblog content like Twitter. In this paper, we investigate methods to improve topics learned from Twitter content *without* modifying the basic machinery of LDA; we achieve this through various pooling schemes that aggregate tweets in a data preprocessing step for LDA. We empirically establish that a novel method of combining automatic hashtag labeling techniques with tweet pooling by hashtags leads to a vast improvement in a variety of measures of topic coherence across three diverse Twitter datasets in comparison to an unmodified LDA baseline and a variety of pooling schemes.

KEYWORDS: Topic modeling, LDA, Microblogs.

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## 1 Introduction

In the general area of information retrieval or information access, the *undirected informational task* (Rose and Levinson, 2004) is one where people seek to better understand the information available to them in a particular area. This is a form of information discovery that techniques such as multidocument summarisation (Radev et al., 2002) and topic modeling have been developed to address. Probabilistic topic models such as Latent Dirichlet Allocation (LDA) (Blei et al., 2003) are a class of Bayesian latent variable models developed for analysing the semantic content of document corpora. Topic models uncover the salient patterns of a collection under the mixed-membership assumption: each document can exhibit multiple patterns to different extents. When analysing text, these patterns are represented as distributions over words, called “topics”. Topic models have been adapted to model document genres as diverse as news articles (Yang et al., 2011), blogs, academic abstracts (Wang, 2011), and encyclopaedia entries.

To address the undirected informational task arising for the exploration of Twitter content, we propose the use of popular topic models like LDA. However, Twitter content poses unique challenges different to much of standard NLP content:

1. posts are short (140 characters or less),
2. mixed with contextual clues such as URLs, tags, and Twitter names, and
3. use informal language with misspelling, acronyms and nonstandard abbreviations.

Hence, effectively modeling content on Twitter requires techniques that can readily adapt

to this unwieldy data while requiring little supervision.

Unfortunately, it has been found that topic modeling techniques like LDA do *not* work well with the messy form of Twitter content (Zhao et al., 2011). Topics learned from LDA are formally a multinomial distribution over words, and by convention the top-10 words are used to identify the subject area or give an interpretation of a topic. The naive application of LDA to Twitter content produces mostly incoherent topics — some are vaguely interpretable but contain unrelated words in the top-10 word set. For example, Table 1 demonstrates poor topic words as compared to topic words which are much more coherent and interpretable.

Poor Topics	Coherent Topics
barack cool apple health iphone	flu swine news pandemic health
los barackobama video uma gop	death flight h1n1 vaccine confirmed

Table 1: Sample Topic Words

How can we extract better topics in microblogging environments with standard LDA without the need of any major modifications? An intuitive solution to this problem is tweet pooling (Weng et al., 2010; Hong and Davison, 2010): merging related tweets together and presenting them as a single document to the LDA model. In this paper we examine various tweet-pooling schemes and further enhancements to improve pooling quality. We compare the performance of these methods across different datasets; these are constructed so that they are representative of the diverse collections of content possible in the microblog environment.

Evaluation of the resultant topic model on this data is challenging because of the unsupervised nature of the problem. Hence, we look at a variety of topic coherence evaluation metrics including the ability of the topics obtained to reconstruct known clusters and the interpretability of topics via statistical information measures.

Given our diverse datasets and evaluation metrics, we wish to answer the following questions:

- Do the different proposed pooling strategies perform better than unpooled tweets?
- Which pooling scheme works best for which metric and why?
- What further improvements can be made to various pooling schemes so as to obtain topics which are coherent and interpretable?

In answering these questions, we make the following novel contributions:

- We show that different pooling schemes perform differently across different datasets and a few pooling schemes consistently outperform unpooled tweets.
- We show that a novel *hashtag-based pooling* approach leads to best results across *all* evaluation metrics. The performance is a substantial improvement over unpooled use.
- Given the prevalence of tweets without any hashtag, we present similarity metrics for automatic hashtag assignment for these tweets and demonstrate further improvement of hashtag-based pooling. We also observe that similarity metrics based on *inverse author frequency* (IAF) (Chan et al., 2006) offer some of the most robust performance for hashtag-based pooling across all datasets and evaluation metrics.

In the following sections we first provide a brief overview of topic modeling and LDA followed by a proposal for different tweet pooling schemes in Section 2. We next discuss

Twitter dataset construction in Section 3 followed by evaluation metrics in Section 4. After discussing initial results in Section 5 where hashtag-based pooling emerges as a leading approach, we discuss further analysis and improvements to hashtag-based pooling in Section 6, followed by an in-depth evaluation of labeling methods and a final overall comparison of the best methods in Section 7. Related work is described in Section 8 and Section 9 summarises and concludes.

## 2 Tweet Pooling for LDA Topic Modeling

### 2.1 Latent Dirichlet Allocation and Topic Modeling

Latent Dirichlet allocation (LDA) (Blei et al., 2003) is a generative model for text. In LDA, each document may be viewed as a mixture of various topics. The generative process is that documents are represented as random mixtures over latent topics, where each topic is characterized by a distribution over words. Learning the various distributions (the set of topics, their associated word probabilities, the topic of each word, and the particular topic mixture of each document) is a problem of Bayesian inference, and many algorithms are available. We use the Mallet (McCallum, 2002) implementation of LDA for performing our experiments.

### 2.2 Tweet Pooling Schemes

The goal of this paper is to obtain better LDA topics from Twitter content without modifying the basic machinery of standard LDA. As noted in Section 1, microblog messages differ from conventional text. They feature many unique symbols like mentions, hashtags and urls, and the popular use of colloquial words and Internet slang. Message quality varies greatly, from newswire-like utterances to babble (e.g. O o haha wow). In terms of text processing, these issues pose significant research challenges for LDA, which has been observed to perform poorly on Twitter (Zhao et al., 2011).

To address these challenges, we present various pooling schemes to aggregate tweets together for use as training data for building better LDA models. The motivation behind tweet pooling is that individual tweets are very short ( $\leq 140$  characters) and hence treating each tweet as a document does not present very rich term co-occurrence data that is crucial to effective topic modeling. Aggregating tweets which are similar in some sense (semantically, temporally, etc.) enriches the content present in a single document from which the LDA can learn a better topic model. We next describe an unpooled baseline LDA model and four different tweet pooling schemes and compare the resulting models against the unpooled baseline.

**Basic scheme – Unpooled Tweets:** The default way of training models involves treating each tweet as a single document and training LDA on all tweets. This serves as our baseline and we compare results of other pooling schemes against this unpooled scheme.

**Author-wise Pooling:** Pooling tweets according to author is the standard away of aggregating Twitter data to improve LDA topic modeling and has been previously proposed in the literature (Weng et al., 2010; Hong and Davison, 2010) and shown to be superior to unpooled Tweets. To use this method, we train LDA on aggregated author profiles, each of which combines all tweets posted by the same author.

**Burst-score wise Pooling:** A *trend* on Twitter (Naaman et al., 2011) (sometimes referred to as a trending topic) consists of one or more terms and a time period, such that the volume of messages posted for the terms in the time period exceeds some expected level of activity. In order to identify trends in Twitter posts, "bursts" of interest and attention can be detected in the data. We run a simple burst detection algorithm to detect such trending topics and aggregate tweets containing those terms having high burst scores. To identify terms that appear more frequently than expected, we will assign a score to terms according to their deviation from an expected frequency. Assume that  $M$  is the set of all messages in our Tweets dataset,  $R$  is a set of one or more terms to which we wish to assign a score, and  $y$  represents a day of the total  $z$  days. We then define  $M(R, y)$  as the set of every Twitter message in  $M$  such that (1) the message contains all the terms in  $R$  and (2) the message was posted during day  $y$ . With this information, we can compare the volume in a specific day to the other days. Let  $Mean(R) = \Sigma_d M(R, y)/z$ . Correspondingly,  $SD(R)$  is the standard deviation of the number of messages with the terms in  $R$  posted over all the days. The *burst-score* is defined as:

$$burst\_score(R, y) = \frac{|M(R, y) - Mean(r)|}{SD(R)}$$

Let us denote the terms having burst-scores greater than 5 as *burst-term*. For each burst-term, aggregate tweets which contain this term and train LDA on this aggregation of tweets. The tweets which do not contain any of the burst-term were ignored for the purpose of training the LDA model. We then use the trained model to infer a topic mixture for each of the individual tweets. This scheme is henceforth referred to as Burst Score-wise pooling.

**Temporal Pooling:** The fourth scheme, known as Temporal Pooling, utilizes the temporal information of the tweets. It is noted that whenever a major event occurs a large number of users start tweeting about the event. Temporal pooling of tweets might help us in extracting useful information from the LDA topics. We train the LDA on an aggregate of tweets posted within the same hour and use this model to infer a topic mixture for each of the individual tweets.

**Hashtag-based Pooling:** A Twitter *hashtag* is a string of characters preceded by the hash (#) character. In many cases hashtags can be viewed as topical markers, an indication to the context of the tweet or as the core idea expressed in the tweet, therefore hashtags are adopted by other users that contribute similar content or express a related idea. A few examples of the use of hashtags are: "ask GAGA anything using the tag #GoogleGoesGaga for her interview! RT so every monster learns about it!! " referring to an exclusive interview for Google by Lady Gaga (singer), "Whoever said 'youth is wasted on the young' must be eating his words right now. #March15 #Jan25 #Feb14 ", referring to the protest movements in the Arab world. For the hashtag-based pooling scheme, for each hashtag we aggregate tweets containing this hashtag and train LDA on this collection. Each hashtag pooled tweet collection thus represents a document. If any tweet has more than one hashtag, this tweet gets added to the tweet-pool of each of those hashtags. This results in tweets being repeated across documents. We notice that this tweet pooling scheme outperforms the rest. We discuss hashtag-based pooling in detail in a later section.

While a few other combinations of pooling schemes (eg.author-time, keyword-time, etc) are possible but the initial results obtained were not as good as those presented below.

This may be due to the lack of data in each pool alongside other reasons. These and other combinations of pooling schemes can be further explored.

### 3 Twitter Dataset Construction

Focusing on the messy text of microblogs, the primary goal of this work is to get topics which have better coherence and interpretability using standard LDA. We discuss the following five tweet pooling schemes as previously proposed: Unpooled, Author-wise pooling, Temporal pooling, Burst-score wise pooling, and Hashtag-based pooling.

The different pooling schemes and their proposed modifications result in different topic models, the evaluation of which is a major concern. We wish to answer questions like: Which scheme performs better on which aspects and on what kinds of data? Due to the large number of tweets ( 360K) in any of the twitter specific datasets, manual labelling of topics is not feasible. To circumvent this problem of unsupervised evaluation we carefully construct our datasets keeping the following point in mind: The datasets should cover diverse collections of content, but also the known source of the content should help in evaluation of the different schemes.

We construct three datasets which we believe are representative of the diverse collections of content found on Twitter. We choose single/double word queries to search a tweet collection and each resulting set of tweets was labelled by the query. Since the number of queries (equivalently the number of clusters) is known beforehand, we could use this knowledge to evaluate how well the topics output by LDA match with known clusters. A brief description of the three datasets is as follows:

**Generic Dataset:** 359478 tweets from 11 Jan'09 to 30 Jan'09. A general dataset with tweets containing generic terms which represent a broader sense.

**Specific Dataset:** 214580 tweets from 11 Jan'09 to 30 Jan'09. A dataset composed of tweets which have specific terms which refer to named entity topics.

**Event Dataset:** 207128 tweets from 1 June 2009 to 30 June 2009. An event related dataset which contains tweets which were posted about some particular events. The query terms are terms which represent events.

Each of these datasets was created by querying a collection of 100 million tweets spanning 2 months (January'09 & June'09) with terms that relate to generic queries (broad topic words like music, business, *etc.*), specific queries(named entity topics like Obama, McDonalds, *etc.*) and event related queries(actual events in that timeframe like recession, Flight 447, Iran elections, *etc.*). Table 2 give the terms and the percentage tweets in the datasets which contain that term.

Dataset	Term/%
Generic	music/17.9 business/15.8 movie/14.5 design/10.8 food/9.6 fun/9.1 health/6.9 family/6.4 sport/4.9 space/3.2
Specific	Obama/23.2 Sarkozy/0.4 baseball/3.5 cricket/1.8 Mcdonalds/1.5 Burgerking/0.5 Apple/16.3 Microsoft/6.8 United-states/40.7 France/4.9
Events	Flight-447/0.9 Jackson/13.9 Lakers/13.8 attack/13.8 scandal/4.1 swine-flu/13.8 recession/12.3 conference/14.1 T20/4.4 Iran-election/8.6

Table 2: Datasets

Note that the three datasets span three different scenarios in which tweets would be posted. Evaluating our methods on each of these would give us useful insights as to which methods work well for which type of data.

## 4 Evaluating Topic Models - Metrics used

Evaluation of the different topic models based on the features of interpretability, usability and coherence is an important issue, but the unsupervised nature of topic models makes this difficult. For some applications there may be extrinsic tasks, such as information retrieval or document classification, for which performance can be evaluated. However, such tasks are not applicable for evaluating topics models in the *undirected informational task*.

We evaluate our topic models based on the following two approaches:

**Clustering based metrics:** We would like to measure the quality of topics found by the models. The dataset we used is a classification dataset containing 10 categories. Since we know the ground truth label of all the tweets in the dataset (their categories), we can measure the quality by how likely the topics agree with the true category labels. To measure how well the topics produced by LDA reconstruct known clusters, we use clustering based measures of purity and normalized mutual information (NMI).

**Metrics measuring topic coherence:** Learnt topics should be coherent and interpretable. Topic coherence – meaning semantic coherence – is a human judged quality that depends on the semantics of the words, and cannot be measured by model-based statistical measures that treat the words as exchangeable tokens. It is possible to automatically measure topic coherence with near-human accuracy (Newman et al., 2010) using a score based on pointwise mutual information (PMI). We use this to measure coherence of the topics from different tweet-pooling schemes.

### 4.1 Purity Scores

To compute purity (Manning et al., 2008), each cluster is assigned to the class which is most frequent in the cluster, and then the accuracy of this assignment is measured by counting the number of correctly assigned documents and dividing by N. For each tweet  $d$ , we use the maximum value in topic mixture  $\theta_d$  to determine its class/topic.

We interpret  $t_k$  as the set of tweets in cluster  $t_k$  and  $g_k$  as the set of tweets in category-label  $g_k$ .  $m$  is the total number of tweets;  $T = \{t_1, ..., t_k\}$  is the set of  $k$  clusters and  $G = \{g_1, ..., g_k\}$  is the set of  $k$  category-labels (e.g. Obama, Microsoft).

$$purity(T, G) = \frac{1}{N} \sum_k \max_j |t_k \cap g_j|$$

where  $t_k = \{d \mid \operatorname{argmax}_t \theta_d^* = t\}$ . As the number of correctly assigned tweets increases for each cluster, the overall purity score increases. hence high purity scores reflect better cluster reconstruction, hence a topic model with high purity score is considered better.

## 4.2 Normalized Mutual Information

Since we know the ground truth label of all the tweets in the dataset, i.e., their categories, we can measure the quality by how likely the topics agree with the true category labels.

$$NMI(T, G) = \frac{2I(T; G)}{H(T) + H(G)}$$

where  $I(T, G)$  is Mutual Information and  $H(T)$  gives the entropy. The corresponding values are:

$$I(T, G) = \sum_k \sum_j \frac{|t_k \cap g_j|}{N} \log \frac{|t_k \cap g_j|}{|t_k| |g_j|} \quad H(T) = - \sum_k \frac{|t_k|}{N} \log \frac{|t_k|}{N}$$

NMI (Manning et al., 2008) is always a number between 0 and 1. NMI score will be 1 if the clustering results exactly match the category labels while 0 if the two sets are independent. For each tweet  $d$ , we use the maximum value in topic mixture  $\theta_d$  to determine its cluster. After this mapping process, we compute NMI scores with the labels.

High purity is easy to achieve when the number of clusters is large. The normalization by the denominator in the NMI fixes this problem as entropy tends to increase with the number of clusters.

## 4.3 Pointwise Mutual Information

One of the goals of our work is to get topics that are more coherent. We measure topic coherence using PMI defined as follows:  $PMIScore(w) = Mean(PMI(w_i, w_j))_{i, j \in \{1, \dots, 10\}}$ . A key aspect of this score is that it uses external data. (Newman et al., 2010) used the Wikipedia corpus as their external data. We eliminate the need of this external data source by using our own dataset to calculate the probabilities used in this score.

## 5 Initial Results for Pooling Schemes

In this section we discuss the results of the experimental evaluation of the tweet pooling schemes introduced in Section 2. The datasets used were described in Section 3 while the evaluation metrics used were described in Section 4.

### 5.1 Document Characteristics for Different Pooling Schemes

Here we look at the document characteristics of the documents in the different pooling schemes for the three datasets. The characteristics like the number of documents affect LDA directly and hence it will be interesting to look at what the training data consists of. Table 3 presents the required statistics.

Pooling Scheme	#of docs			Avg # of words/doc			Max # of words/doc		
	Generic	Specific	Events	Generic	Specific	Events	Generic	Specific	Events
Authorwise	208300	118133	67387	17.6	20.4	15.4	4893	3586	2775
Unpooled	359478	214580	207128	10.2	10.9	9.7	35	49	32
Burst Score	7658	7436	5434	76.5	154.2	71.6	61918	420249	57794
Hourly	465	464	463	8493.4	5387.5	2422	20144	18869	38893
Hashtag	8535	7029	4099	70.4	187.2	78.4	61918	420249	57794

Table 3: Document Characteristics for different schemes

The statistics presented above highlight the differences in the characteristics of the documents on which LDA models have been trained. The number of documents decreases as we

move from Unpooled scheme to Authorwise and Hashtagwise pooling scheme, while the corresponding size of the documents in each case increases. On an average the document size increases by a factor of 7 in hashtag-based pooling when compared against unpooled or authorwise pooling schemes. Thus each document in hashtag-based pooling contains more content from which LDA could possibly extract latent semantics. On the other extreme lies the temporal pooling with very less number of documents and hence each document of a much larger size. Such large documents might impact the topic model in an unpleasant manner. These statistics highlights that hashtag-based pooling scheme lies mid-way between both the extremes (small documents in unpooled tweets vs large documents in temporal pooling) and hence suggests that hashtag-based pooling should perform optimally in comparison to other schemes.

## 5.2 Comparison of Pooling Schemes

For each of the three datasets (viz. Generic, Specific and Events) we next present the Purity scores, the NMI scores and the PMI scores in Table 4.

Scheme	Purity			NMI Score			PMI score		
	Generic	Specific	Events	Generic	Specific	Events	Generic	Specific	Events
Unpooled	0.49	0.64	0.69	0.28	0.22	0.39	-1.27	0.47	0.47
Author	0.54	0.62	0.60	0.24	0.17	0.41	0.21	0.79	0.51
Hourly	0.45	0.61	0.61	0.07	0.09	0.32	-1.31	0.87	0.22
Burstwise	0.42	0.60	0.64	0.18	0.16	0.33	0.48	0.74	0.58
Hashtag	<b>0.54</b>	<b>0.68</b>	<b>0.71</b>	<b>0.28</b>	<b>0.23</b>	<b>0.42</b>	<b>0.78</b>	<b>1.43</b>	<b>1.07</b>

Table 4: Initial results of different pooling schemes

Based on these results we conclude that hashtag-based pooling scheme performs better than unpooled scheme as well as other pooling schemes. An obvious question to ask is: Can we do better? In the next section we look into hashtag-based pooling in detail and devise methods which further improve the results and provide better topics.

## 6 General Study of Hashtags & Hashtag Pooling

Hashtag-based tweet pooling outperforms other pooling schemes and unpooled tweets in terms of both: reconstructing known clusters as well as extracting coherent topic words. In this section we look into hashtags and hashtag-based pooling in detail and analyse the prominence of hashtags in our datasets and look at ways to further improve the results.

### 6.1 How Many Tweets have Hashtags?

Among all tweet pooling schemes hashtag-based pooling gives the best results in terms of purity scores, NMI and PMI values. There are two obvious questions to ask at this stage include: How common are the hashtags? Do all tweets have hashtags? Table 5 presents few statistics on the percentage of tweets which do not have any hashtag in the three datasets.

In this section we look at the number of tweets which do not have any hashtag and posit problems which arise due to this.

As is evident from the figures a large number of tweets do not contain any hashtag, with the percentages varying from 77.7% to a surprising 91.6%. This suggests that a large portion of the training data does not participates in the hashtag pooling scheme. Since a large portion



Dataset	% tweets having hashtags
Generic	22.3%
Specific	9.4%
Event	19.5%

Table 5: % tweets haing hashtags

of the data is getting ignored we need to figure out ways of incorporating this data while training LDA models. We next address this issue and present a brute force way of doing so.

## 6.2 Incorporating Other Tweets :: Brute Force Way

As discussed in the previous section, at least 77% of tweets do not have any hashtags. One ways of incorporating this left out part of the dataset could be to include the entire remaining portion as is alongside hashtag pooled collection of tweets. Table 6 shows the results on different datasets when the entire remaining part of tweets which do not have any hashtag are included alongside hashtag pooled tweets and the percentage improvement.

Metric	Generic		Specific		Events	
	Full	% improvement	Full	% improvement	Full	% improvement
Purity	0.60	+13.2%	0.69	+1.4%	0.68	-1.5%
NMI	0.29	+3.5%	0.23	+0.1%	0.40	+2.5%
PMI	0.42	-46.1%	0.59	-58%	1.2	+155%

Table 6: Results of incorporating other tweets on different datasets. % improvements are measured in comparison with simple hashtag pooling results.

The results in the above table suggests that this technique harms the topic coherence in a very bad manner(lower PMI scores) but improves cluster reconstruction(higher purity scores). We need to look at ways in which we could improve cluster reconstruction without adversely affecting the topic coherence. In the next section we present a way of doing so and show that our proposed method performs better than the results so far.

## 6.3 Assigning Hashtags

The brute force way of incorporating tweets without hashtags terribly degrades the PMI scores alongside improving the purity scores. In this subsection we wish to look into another ways of incorporating these tweets so as to balance out improvements in cluster reconstruction and degradation of topic coherence.Since a large number of tweets do not have hashtags we propose that assigning hashtags to some of those tweets help in improving overall results. We discuss here an algorithm which assigns a hashtag to some of the tweets and hence increases the number of tweets having at least one hashtag.

### 6.3.1 Algorithm

Our aim here is to assign hashtags to tweets which have none. Since this step is done after hashtag-based pooling of tweets, for each hashtag we have a collection of tweets each of which contain this particular hashtag. We make use of this collection to compare each tweet with each hashtag’s collection and compute the similarity scores. If the similarity score

crosses a certain threshold(burst score 5) we assign the hashtag to this tweet and add this tweet to the pool of tweets assigned to this hashtag. The similarity metric used here is the tf-cosine similarity. To avoid the bias caused by different document lengths, a common way to compute the similarity of two documents is using the cosine similarity measure. The inner product of the two vectors (sum of the pairwise multiplied elements) is divided by the product of their vector lengths. This has the effect that the vectors are normalized to unit length and only the angle, more precisely the cosine of the angle, between the vectors accounts for their similarity. Documents not sharing a single word get assigned a similarity value of zero because of the orthogonality of their vectors while documents sharing a similar vocabulary get higher values (up to one in the case of identical documents).

$$sim(d1, d2) = \frac{d1.d2}{||d1|| ||d2||}$$

where d1 is the tweet in consideration to which we intend to assign a hashtag and d2 is the collection of tweets for some hashtag. We iterate through all the hashtag for different d2 vectors and assign the hashtag which maximizes this similarity score. We use the term frequency of the words in the tweet to represent the tweet as a tf vector. Algorithm 1 describes the same algorithm in detail.

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**Algorithm 1: HASHTAG ASSIGNMENT**

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input :  $H_T$  : set of tweets having hashtags ( $N$  in total)
 $N_T$  : set of tweets with no hashtag ( $M$  in total)
 $T$  : set of hashtags
 $c$  = Threshold on the similarity score
output: hashtag  $h$  (in  $T$ ) for tweet  $n_t \in N_T$  if  $score(n_t, h) > c$ 

1 begin
2   // -Pooling Step-
3   foreach  $hashtag h \in T$  do
4     | collect all tweets containing hashtag  $h$ 
5    $max\_score = 0$ 
6   // -Assignment Step-
7   foreach  $tweet n_t \in N_T$  do
8     | foreach  $hashtag h \in T$  do
9       | calculate similarity score  $sim\_score$  b/w  $n_t$  and tweet pool of hashtag  $h$ 
10      | if ( $sim\_score > max\_score$ )
11      |   then  $temp\_assigned\_tag = h$  ;  $max\_score = sim\_score$ 
12
13      | if ( $max\_score > c$ )
14      |   then  $assigned\_tag = temp\_assigned\_tag$ 
15
16 end

```

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### 6.3.2 Hashtag Assignment Results

Table 7 presents the results of hashtag assignment based on the three metrics for different threshold varying from 0.5 to 0.9. We notice that as the threshold increases the corresponding value of PMI scores increases and purity scores decreases which is intuitive: on increasing the

threshold lesser number of tweets get assigned a hashtag and hence cluster reconstruction suffers while the topic coherence is improved because a tweet is assigned a hashtag only if its highly similar to the tweet collection of that hashtag(threshold = 0.9).

Threshold	Purity			NMI Score			PMI score		
	Generic	Specific	Events	Generic	Specific	Events	Generic	Specific	Events
0.5	0.59	<b>0.72</b>	<b>0.75</b>	<b>0.356</b>	<b>0.242</b>	<b>0.442</b>	0.70	1.10	0.92
0.6	0.59	0.68	0.73	0.334	0.221	0.437	0.59	1.11	0.96
0.7	<b>0.62</b>	0.70	0.72	0.31	0.222	0.431	0.66	1.12	0.98
0.8	0.55	0.69	0.72	0.295	0.225	0.429	0.72	1.16	1.0
0.9	0.53	0.69	0.71	0.28	0.227	0.42	<b>0.82</b>	1.21	1.05
1.0 (Simple Hashtag Pooling)	0.54	0.68	0.71	0.28	0.23	0.42	0.78	<b>1.43</b>	<b>1.07</b>

Table 7: Hashtag Assignment Results

The results obtained via hashtag assignment are better than those of simple hashtag-based pooling as well as unpooled scheme. These results were obtained on using tf-cosine similarity metric to compute the similarity between a tweet and the tweet collection of the hashtag in consideration. We next look at some other similarity metrics and see if we could further improve our results.

### 6.3.3 Other Similarity Metrics

The results presented in Table 7 use the tf-cosine similarity between tweet and tweet-collection of a hashtag to assign a hashtag to the tweet in consideration. We next answer the question of how other similarity metrics affect the results of hashtag assignments. We look at the following six metrics to be used to represent each document while calculating the cosine similarity scores:

**Term Frequency (TF):** Already discussed in the previous section.

**Inverse Document Frequency (IDF):** a measure of whether the term is common or rare across all documents. It is obtained by dividing the total number of documents by the number of documents containing the term, and then taking the logarithm of that quotient. Thus the idf of a rare term is high, whereas the idf of a frequent term is likely to be low.

**Inverse Author Frequency (IAF):** Each term used in a tweet has a relationship to the tweet’s author. The relationship of terms and authors could be harnessed using the inverse author frequency (IAF) (Chan et al., 2006) which is computed as follows:  $iaf_i = \log \frac{N}{n_i}$  where  $N$  : # of total authors and  $n_i$  : # of authors who use term i

**TF-IDF:** the product of the term frequency and inverse document frequency of each term.

**TF-IDF-IAF:** the product of the term frequency, inverse document frequency and the inverse author frequency of each term.

Figure 1 presents the results obtained for the three evaluation metrics on the three datasets for the different similarity metrics discussed in the previous section. It is interesting to note that the simplest of all: term-frequency based cosine similarity generally performs better than others. Inverse Author Frequency (IAF) gives almost comparable results when

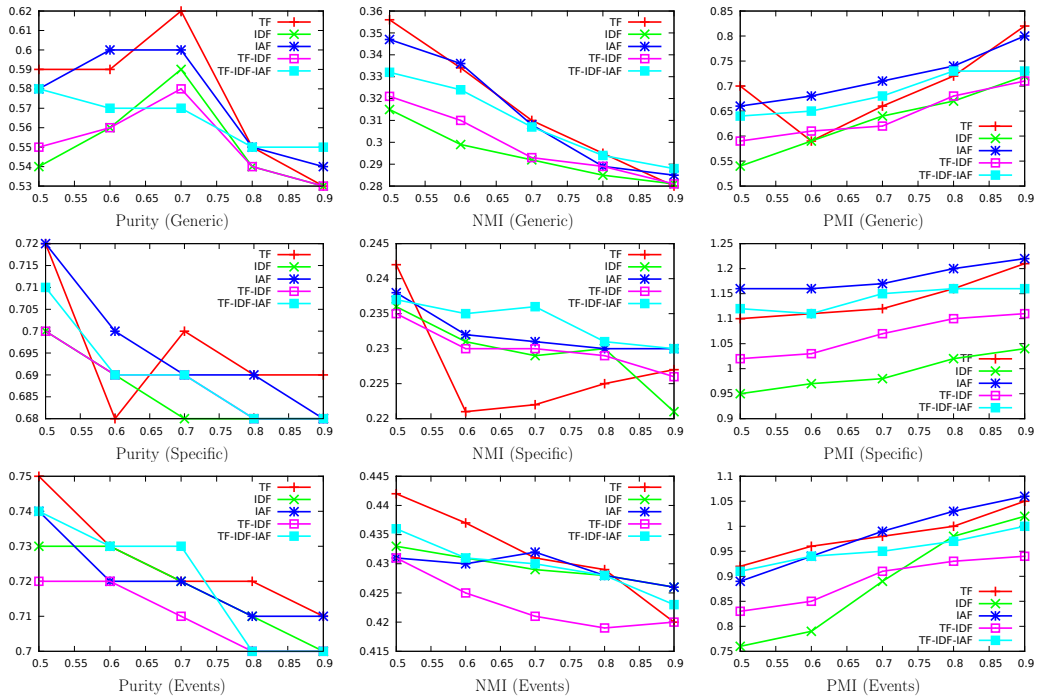


Figure 1: Comparison of Purity, NMI and PMI scores (y-axis) for five different similarity metrics (TF, IDF, IAF, TF-IDF, TF-IDF-IAF) for various Hashtag assignment confidence threshold limits (x-axis).

evaluating topic coherence using the PMI scores. When the task at hand is reconstruction of known clusters one should prefer using TF based cosine similarity to assign hashtags while both TF and IAF work well when one is interested in obtaining coherent topics.

## 7 Overall Comparison

The goal of this work was to get better topics which have better coherence without modifying the basic machinery of standard LDA. The default way of using tweets to train LDA was to treat each tweet as a single document (referred in this work as the Unpooled scheme). Simple hashtag-based pooling outperformed unpooled scheme and other pooling schemes while hashtag assignment further improved results. Table 8 provides an overall comparison of the best of the different schemes: Unpooled vs simple hashtag vs hashtag assignment on the three datasets.

Pooling Scheme	Purity			NMI Scores			PMI Scores		
	Generic	Specific	Events	Generic	Specific	Events	Generic	Specific	Events
Unpooled	0.49	0.64	0.69	0.29	0.22	0.39	-1.27	0.47	0.47
Basic Hashtagwise	0.53	0.68	0.71	0.28	0.23	0.42	0.78	<b>1.43</b>	<b>1.07</b>
Tag-Assignment	<b>0.62</b>	<b>0.72</b>	<b>0.75</b>	<b>0.36</b>	<b>0.24</b>	<b>0.44</b>	<b>0.82</b>	1.21	1.05

Table 8: Overall comparison of improvement

In Table 8, we see that the best Purity and NMI scores are obtained by hashtag assignment while even the simple hashtag-based pooling scheme works much better than the baseline method of unpooled tweets. When the dataset in consideration consists of generic terms

simple hashtag pooling gives the best results in terms of topic coherence. On the other hand when we have tweets on specific named entities or events in general one might want to prefer hashtag assignment as it results in best PMI scores.

## 8 Related Work

Topic modeling is widely used in text mining communities with LDA being the benchmark. LDA has been extended in a variety of ways, and in particular for social networks and social media, a number of extensions to LDA have been proposed. For example, (Newman et al., 2011) proposed two methods to regularize the learning of topic models aimed at short text snippets. While the focus of this work was on blogs and search result snippets, it would be interesting to see how well they work on Twitter data. Also, the combination of the work proposed in (Newman et al., 2011) with the tweet pooling schemes we describe before could produce interesting results.

For automatic hashtag labeling (i.e., recommendation) that proved crucial to improving topics in our hashtag-based pooling model, (Zangerle et al., 2011) also uses tweet similarity as a criteria, but does not explore metrics based on inverse author frequency (IAF) (Chan et al., 2006) that we found to offer the most robust performance across datasets and evaluation metrics.

Our work is quite different from many pioneering studies on Twitter and topic modeling because we focus on how we could get better topic coherence over tweets with minimal modification to existing models. Prior work on topic modeling for tweets includes the work of (Ramage et al., 2010) which presents a scalable implementation of a partially supervised learning model (Labeled LDA) that maps the content of the Twitter feed into dimensions and characterizes users and tweets using this model. (Zhao et al., 2011) empirically compare the content of Twitter with a traditional news medium, New York Times, using unsupervised topic modeling. (Hong and Davison, 2010) use the topic modeling approach for predicting popular Twitter messages and classifying Twitter users and corresponding messages into topical categories.

The TwitterRank system (Weng et al., 2010) and (Hong and Davison, 2010) uses author-based pooling to apply LDA to tweets. (Zhao et al., 2011) compared topic characteristics between twitter and traditional news media (NY Times); they propose to use one topic per tweet (in a manner similar to PLSA), and argues (with some evidence) that this is better than no pooling, or the author-topic model. (Kireyev et al., 2009) used term weighting to tackle term sparseness in LDA, the weights are derived from LSA vector length. (Naveed et al., 2011) used LDA for tweet retrieval. In addition, they used retweet as an indicator of "interestingness" to improve retrieval quality, which suggests additional features we could incorporate in future extensions to our pooling framework.

Our work is different from these in the sense that we provide a simple yet effective way which greatly improves the quality of topics obtained without making any major complicated modifications to standard LDA. The detailed experiments on a variety of datasets highlight our novel contribution of hashtag-based pooling and automatic hashtag labeling using similarity metrics like IAF (Chan et al., 2006) as an approach that improves a range of topic coherence measures.

## 9 Summary and Conclusion

The work described in this paper presents a way of aggregating tweets in order to improve performance of topic models in terms of quality of topics obtained measures by the ability to reconstruct clusters and topic coherence. The initial results presented in Table 4 suggest that hashtag-based pooling outperforms all other pooling strategies including the default way of training topic models on Twitter data(unpooled).

Since a major portion of Twitter data does not contains hashtags we looked at ways of assigning hashtags to tweets. Insights from Hashtag Assignment results (Table 7) suggest that when the main aim is to use the topics obtained to extract different events mentioned in the Twitter data one should use hashtag assignment with a relaxed threshold( 0.5). The high values of Purity scores and NMI values for low threshold support this claim.

When the goal is to obtain interesting topics with topic words pertaining to the same common theme (coherent topic words), hashtag assignment with strict constraints (a threshold of  $\sim 0.9$ ) works well. The PMI scores in Table 7 highlight that topic coherence increases as we move down the column. Thus the threshold of 0.9 gives most coherent topics.

Overall, results shown in Table 8 compare unpooled scheme with simple hashtag pooling and hashtag assignment schemes. In short, across all datasets and metrics, the best hashtag assignment method performs optimally or near-optimally indicating the promise of this novel automatic hashtag labeling and pooling approach.

To this end, we have achieved our initial goal. We have introduced novel techniques for automatic tweet hashtag labeling and pooling that have produced topics representative of the events queried to construct the source data and have substantially improved various quantitative measures of topic coherence. Further, we have achieved this without modifying the LDA algorithm itself but rather by preprocessing its input.

This technique worked well across a diverse set of data and suggests that continued investigation into aggregation techniques for topic modeling on short text and microblog documents is warranted given its highly successful outcome demonstrated in this work.

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