

# A context-based model for Sentiment Analysis in Twitter

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## Abstract

Most of the recent literature on Sentiment Analysis over Twitter is tied to the idea that the sentiment is a function of an incoming tweet. However, tweets are filtered through streams of posts, so that a wider context, e.g. a topic, is always available. In this work, the contribution of this contextual information is investigated. We modeled the polarity detection problem as a sequential classification task over streams of tweets. A Markovian formulation of the Support Vector Machine discriminative model as embodied by the  $SVM^{hmm}$  algorithm has been here employed to assign the sentiment polarity to entire sequences. The experimental evaluation proves that sequential tagging effectively embodies evidence about the contexts and is able to reach a relative increment in detection accuracy of around 20% in F1 measure. These results are particularly interesting as the approach is flexible and does not require manually coded resources.

## 1 Introduction

Since in the Web 2.0 users can write about their life, personal experiences, share contents about facts and ideas, Social Networks became valuable sources of opinions and sentiments. This huge amount of data is crucial in the study of the interactions and dynamics of subjectivity on the Web, largely relevant for marketing tasks. Twitter is one among these microblogging services that counts about a billion of active users and 500 million of daily messages<sup>1</sup>. However, the analysis of this huge amount of information is still challenging, as language is very informal, affected by misspelling and characterized by slang and *#hashtags*, i.e. special user-generated tags used to contextualize different tweets around a specific topic.

Researches focused on the computational study and automatic recognition of opinions and sentiments as they are expressed in free texts. It gave rise to what is currently known as Sentiment Analysis, a set of tasks aiming to detect the subjective attitude of a writer with respect to some topic. Many Sentiment Analysis studies map sentiment detection in a *Machine Learning* (ML) setting (Pang and Lee, 2008), where labeled data, i.e. known examples, allow to induce the detection function from real world examples. In general, sentiment detection in tweets has been generally treated as any other text classification task, as proved by most papers participating to the *Sentiment Analysis in Twitter* task in SemEval-2013 challenge (Nakov et al., 2013): a computational representation for an incoming instance is generated by just considering one tweet at a time. The short length of the message and the resulting semantic ambiguity are critical limitations and make the task very complex. Let us consider the following example, in which a tweet from ColMustard cites SergGray:

ColMustard : @SergGray Yes, I totally agree with you about the substitutions! #Bayern #Freiburg

The tweet sounds like to be a reply to the previous one. Notice how no lexical nor syntactic property allows to determine the sentiment polarity. However, if we look at the entire conversation that follows:

ColMustard : Amazing match yesterday!!#Bayern vs. #Freiburg 4-0 #easyvictory

SergGray : @ColMustard Surely, but #Freiburg wasted lot of chances to score.. wrong substitutions by #Guardiola during the 2nd half!!

ColMustard : @SergGray Yes, I totally agree with you about the substitutions! #Bayern #Freiburg

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<sup>1</sup><http://expandeddrablings.com/>

it is easy to establish that a first positive tweet has been produced, followed by a second negative one so that the third tweet is negative as well. It is the conversation that allows us here to disambiguate even a very short message and properly characterize it according to its author and posting time.

We want here to capitalize such a richer set of observations (i.e. entire conversations) and to define a context-sensitive SA model along two lines: first, by enriching a tweet representation to include the conversation information, and then introducing a more complex classification model that works over an entire tweet sequence and not on one tweet (i.e. the target) at a time. Accordingly, in the paper we will first focus on different representations of tweets that can be made available to the sentiment detection process. They will also account for contexts, that are *conversations*, as chains of tweets that are reply to the previous ones, and *topics*, built around hashtags. These are in fact topics made explicit by users, such as events (*#easyvictory*) or people (*#Guardiola*). It represents a wider notion of conversation that enforces the sense of belonging to a community. From a computational perspective, the polarity detection of a tweet in a context is here modeled as a sequential classification task. In fact, both conversation and topic-based context are arbitrarily long sequences of messages, ordered according to *time* with the target tweet being the last. The  $SVM^{hmm}$  learning algorithm (Altun et al., 2003) has been employed, as it allows to classify an instance (here, a tweet) within an entire sequence. While SVM based classifiers allow to recognize the sentiments from one specific tweet at a time, the  $SVM^{hmm}$  learning algorithm collectively labels all tweets in a sequence. It is thus expected to capture patterns within a conversation and apply them in novel sequences, through a standard decoding task.

While all the above contexts extend a tweet representation, they are still *local* to a specific notion of conversation. In this work, we also explore the somehow more abstract notion of contexts given by the emotional attitude shown by each user in his overall usage of Twitter. In the above example, ColMustard shows a specific attitude while discussing about the Bayern Munchen. We can imagine that this feature characterizes most of its future messages at least about football. We suggest to enrich the tweet representation with features that *synthesize* a user's profile, in order to catch possible biases towards a particular sentiment polarity. This is quite interesting as it has been shown that communities behave in a coherent way and users tend to take stable standing points. Experimental evaluation (Chapter 4) proves the effectiveness of this proposed sequential tagging approach combined with the adopted contextual information, improving the percentage of correctly recognized tweets up to 12%.

A survey of the existing approaches is presented into Section 2. Then, Section 3 provides an account of the context-based models: conversation, topic-based and user sentiment profiling. The experimental evaluation into Section 4 prove the positive impact of social dynamics on the SA task.

## 2 Related Work

Sentiment Analysis has been described as a *Natural Language Processing* task at many levels of granularity. Starting from being mapped into a *document level* classification task (Turney, 2002; Pang and Lee, 2004), it has been also applied at *sentence level* (Hu and Liu, 2004; Kim and Hovy, 2004) and more recently at the *phrase level* (Wilson et al., 2005; Agarwal et al., 2009).

The spreading of microblog services where users post real-time opinions about “everything”, poses newer and different challenges. Indeed, classical approaches to Sentiment Analysis (Pang et al., 2002; Pang and Lee, 2008) are not directly applicable to tweets: while most of them focus on relatively large texts, e.g. movie or product reviews, tweets are very short and fine-grained lexical analysis is required. Nevertheless, the great prominence of Social Media during the last few years encouraged a focus on the sentiment detection over a microblogging domain. Recent works tried to model the sentiment in tweets (Go et al., 2009; Pak and Paroubek, 2010; Kouloumpis et al., 2011; Davidov et al., 2010; Bifet and Frank, 2010; Croce and Basili, 2012; Barbosa and Feng, 2010; Zanzotto et al., 2011; Si et al., 2013; Agarwal et al., 2011). Specific approaches and feature modeling are used to improve accuracy levels in tweet polarity recognition. For example, the use of *n*-grams, POS tags, polarity lexicons and tweet specific features (e.g. hashtags, re-tweets) are some of the component exploited by these works, in combination with different machine learning algorithms: among these latter, probabilistic paradigms, e.g. Naive Bayes (Pak and Paroubek, 2010), or Kernel-based machines, as discussed in (Barbosa and Feng,

2010; Agarwal et al., 2011; Castellucci et al., 2013), are mostly employed. An interesting perspective, where a kind of contextual information is studied, is presented in (Mukherjee and Bhattacharyya, 2012): the sentiment detection of tweets is here modeled according to lexical features as well as discourse relations like the presence of connectives, conditionals and semantic operators like *modals* and *negations*. Nevertheless, in all the above approaches, features are derived only from lexical resources or from the tweet itself and no contextual information is exploited. However, given one tweet targeted for sentiment detection, more awareness about its content is available to writers and readers by the entire stream of related posts immediately preceding it. In order to exploit this wider information, a Markovian extension of a Kernel-based categorization approach is proposed in the next section.

### 3 A context based model for Sentiment Analysis in Twitter

As discussed in the introduction, contextual information about one tweet stems from various aspects: an explicit conversation, the user attitude or the overall set of recent tweets about a topic (for example an hashtag like #Bayern). As individual perspectives on the context are independent (a conversation may or may not depend on user preference or cheer) and they also obey to different notion of analogies or similarity, we should avoid a unified feature vector, but employ independent representations. A structured view on a tweet can thus be provided by considering it as multifaceted entity where a set of vectors, each one contributing to one aspect of the overall representation, exhibits a specific similarity metrics. Notice how this is exactly what Kernel-based learning supports, whereas the combination of the different Kernel functions can be easily made a Kernel function itself (Shawe-Taylor and Cristianini, 2004). Kernel functions are used to capture specific aspects of the semantic relatedness between two tweets and are easily integrated in various Machine Learning algorithms, such as SVM.

#### 3.1 Representing tweets through different Kernel functions

Many Machine Learning approaches for Sentiment Analysis in Twitter benefited by complex ways of modeling of individual tweets, as discussed in many works (Nakov et al., 2013). The representation we propose makes use of individual Kernels as models of different aspects usable within a SVM paradigm.

**Bag of Word Kernel (BoWK).** The simplest Kernel function describes the lexical overlap between tweets, thus represented as vectors, whose dimensions correspond to the different words. Components denote the presence or not of the corresponding word in the text and Kernel function corresponds to the *cosine similarity* between vector pairs. Even if very simple, the BoW model is one of the most informative representation in Sentiment Analysis, as emphasized since (Pang et al., 2002).

**Lexical Semantic Kernel (LSK).** Lexical information in tweets can be very sparse, as we will also show in the next Section 4. In order to extend the BoW model, we provide a further vector representation aiming to generalize the lexical information. It can be obtained for every term of a dictionary by a co-occurrence Word Space built according to the Distributional Analysis described in (Sahlgren, 2006). A word-by-context matrix,  $M$ , is built through large scale corpus analysis and then processed through *Latent Semantic Analysis* (Landauer and Dumais, 1997). The dimensionality of the space represented by  $M$  can be reduced through Singular Value Decomposition (SVD) (Golub and Kahan, 1965). The original statistical information about  $M$  is captured by the new  $k$ -dimensional space, which preserves the global structure while removing low-variance dimensions, i.e. distribution noise. The result is that every word is projected in the reduced Word Space and a vector for each tweet is represented through the linear combination of the co-occurring word vectors (also called *additive linear combination* in (Mitchell and Lapata, 2010)). The resulting Kernel function is the *cosine similarity* between tweet vector pairs, in line with (Cristianini et al., 2002). Notice that the adoption of a distributional approach does not limit the overall application, as it can be automatically applied without relying on any manually coded resource.

**User Sentiment Profile Context (USPK).** A source of evidence about a tweet is its author, with his attitude towards some polarities. Specific features based on the users' previous tweets can be derived as follows. Let  $t_i \in \mathcal{T}$  be a tweet and  $i \in \mathbb{N}^+$  its identifier. The *User Profile Context* ( $U_i$ ) can be defined as the set of the last  $H$  tweets posted by the author of  $t_i$ , hereafter denoted by  $u_i$ . This information is a body of evidence about the opinion holder's profile on which a further tweet representation can be defined. A tweet  $t_i$  is here mapped into a three dimensional vector  $\vec{\mu}_i = (\mu_i^1, \mu_i^2, \mu_i^3)$ , where each component  $\mu_i^j$  is

the indicator of polarity inclination, i.e. *positive*, *negative* and *neutral*, expressed through the conditional probability  $P(j | u_i)$  for the polarity labels  $j \in \mathcal{Y}$  given the user  $u_i$ . We can suppose that, for each  $t_k \in U_i$ , its corresponding label  $y_k$  is available either as a gold standard annotation or predicted in a semi-supervised fashion by trained classifiers. The estimation of  $\mu_i^j \approx P(j | u_i)$ , is a  $\sigma$ -parameterized *Laplace smoothed version* of the observations in  $U_i$ :  $\mu_i^j = \sum_{k=1}^{|U_i|} (\mathbb{1}_{\{y_k=j\}}(t_k) + \sigma) / (|U_i| + \sigma|\mathcal{Y}|)$  where  $\sigma \in \mathbb{R}$  is the smoothing parameter,  $j \in \mathcal{Y}$ , i.e. the set of polarity labels. The Kernel function, called User Sentiment Profile Kernel (USPK), is the *cosine similarity* between two vectors  $(\vec{\mu}_i, \vec{\mu}_m)$ .

**The multiple Kernel approach.** Whenever the different Kernels are available, we can apply a linear combination  $\alpha\text{BoWK} + \beta\text{LSK}$  or  $\alpha\text{BoWK} + \beta\text{LSK} + \gamma\text{USPK}$  in order to exploit lexical and semantic properties captured by BoWK and LSK, or user properties as captured by USPK.

### 3.2 Modeling tweet conversation as a sequential tagging problem

The User Sentiment Profile Kernel (USPK) can be seen as an implicit representation of a context describing the writer. However, contextual information is usually embodied by the stream of tweets in which the target one  $t_i$  is immersed. Usually, the stream is something available to a reader and includes an entire *conversation* (where links to the previous tweets are made explicit and are supposed to be all available) or a *topic*, i.e. a hashtag, the reader has searched for. In all cases, the stream give rise to an entire sequence on which sequence labeling can be applied: the target tweet is here always labeled within the entire sequence, where contextual constraints are provided by the preceding tweets. More formally, two types of context are defined:

**Conversational context.** For every tweet  $t_i \in \mathcal{T}$ , let  $r(t_i) : \mathcal{T} \rightarrow \mathcal{T}$  be a function that returns either the tweet to which  $t_i$  is a reply to, or *null* if  $t_i$  is not a reply. Then, the *conversation-based context*  $\Lambda_i^{C,l}$  of tweet  $t_i$  (i.e., the *target tweet*) is the sequence of tweet iteratively built by applying  $r(\cdot)$ , until  $l$  tweets have been selected or  $r(\cdot) = \text{null}$ . In other words,  $l$  allows to limit the size of the input context. An example of conversation-based context is given in Section 1.

**Topical context.** Hashtags allow to aggregate different tweets around a specific topic. An entire tweet sequence can be derived including the  $n$  tweets preceding the target  $t_i$  that contain the same hashtag set. This is usually the output of a search in Twitter and it is likely the source information that influenced the writer's opinion. Let  $t_i \in \mathcal{T}$  be a tweet and  $h(i) : \mathcal{T} \rightarrow \mathcal{P}(\mathcal{H})$  be a function that returns the entire hashtag set  $H_i \subseteq \mathcal{H}$  observed into  $t_i$ . Then, the *hashtag-based context*  $\Lambda_i^{H,l}$  for a tweet  $t_i$  (i.e., *target tweet*) is a sequence of the most recent  $l$  tweets  $t_j$  such that  $H_j \cap H_i \neq \emptyset$ , i.e.  $t_j$  and  $t_i$  share at least one hashtag, and  $t_j$  has been posted before  $t_i$ . As an example, the following hashtag-based context of size 4 has been obtained about #Bayern:

MrGreen : Fun fact: #Freiburg is the only #Bundesliga team #Pep has never beaten in his coaching career. #Bayern  
MrsPeacock : Young starlet Xherdan #Shaqiri fires #Bayern into a 2-0 lead. Is there any hope for #Freiburg?  
pic.twitter.com/krzbfJFJyN  
ProfPlum : It is clear that #Bayern is on a rampage leading by 4-0, the latest by Mandzukic... hoping for  
another 2 goals from #bayernmunich  
MissScarlet : Noooo! I cant believe what #Bayern did!

It is clear that MissScarlet expressed an opinion, but the corresponding polarity is easily evident when the entire stream is available about the #Bayern hashtag. As well as in a conversational context, a specific context size  $n$  can be imposed by focusing only on the last  $n$  tweets of the sequence. Once different representations and contexts are available a structured learning-based approach can be applied to Sentiment Analysis. Firstly, we will discuss a discriminative learning approach that follows the multi-classification schema proposed in (Joachims et al., 2009), namely  $SVM^{multiclass}$ . Then a sequence labeling approach, based on the  $SVM^{hmm}$  learning algorithm (Altun et al., 2003), will be introduced, as an explicit account of both *conversational* and *topical* contexts.

**The multi-class approach.** The  $SVM^{multiclass}$  schema described in (Joachims et al., 2009) is applied<sup>2</sup> to implicitly compare all polarity labels and select the most likely one, using the multi-class formulation described in (Crammer and Singer, 2001). The algorithm thus acquires a specific function  $f_y(x)$  for

<sup>2</sup>[http://svmlight.joachims.org/svm\\_multiclass.html](http://svmlight.joachims.org/svm_multiclass.html)

each sentiment polarity label  $y \in \mathcal{Y}$ , where  $\mathcal{Y} = \{\text{positive}, \text{negative}, \text{neutral}\}$ . Given a feature vector  $x \in \mathcal{X}$  representing a tweet  $t_i$ ,  $SVM^{\text{multiclass}}$  allows to predict a specific polarity  $y^* \in \mathcal{Y}$  by applying the discriminant function  $y^* = \arg \max_{y \in \mathcal{Y}} f_y(x_i)$ , where  $f_y(x) = w_y \cdot x$  is a linear classifier associated to each label  $y$ . Given a training set  $(x_1, y_1) \dots (x_n, y_n)$ , the learning algorithm determines each classifier parameters  $w_y$  by solving the following optimization problem:

$$\min \frac{1}{2} \sum_{i=1 \dots k} \|w_i\|^2 + \frac{C}{n} \sum_{i=1 \dots n} \xi_i \quad \text{s.t. } \forall i, \forall y \in \mathcal{Y} : x_i \cdot w_{y_i} \geq x_i \cdot w_y + 100\Delta(y_i, y) - \xi_i$$

where  $C$  is a regularization parameter that trades off margin size and training error, while  $\Delta(y_i, y)$  is the loss function that returns 0 if  $y_i$  equals  $y$ , and 1 otherwise.

**The markovian approach.** The sentiment prediction of a target tweet can be seen as a sequential classification task over a context, and the  $SVM^{\text{hmm}}$  algorithm can be thus applied. Given an input sequence  $\mathbf{x} = (x_1 \dots x_l) \subseteq \mathcal{X}$ , where  $\mathbf{x}$  is a tweet context, e.g. the *conversational* and the *hashtag-based* one (i.e.  $\Lambda_i^{C,l}$  and  $\Lambda_i^{H,l}$ , respectively) and  $x_i$  is a feature vector representing a tweet, the model predicts a tag sequence  $\mathbf{y} = (y_1 \dots y_l) \in \mathcal{Y}^+$  after learning a linear discriminant function  $F : \mathcal{P}(\mathcal{X}) \times \mathcal{Y}^+ \rightarrow \mathbb{R}$  over input/output pairs. The labeling  $f(\mathbf{x})$  is thus defined as:  $f(\mathbf{x}) = \arg \max_{\mathbf{y} \in \mathcal{Y}^+} F(\mathbf{x}, \mathbf{y}; \mathbf{w})$ . It is obtained by maximizing  $F$  over the response variable,  $\mathbf{y}$ , for a specific given input,  $\mathbf{x}$ . In these models,  $F$  is linear in some combined feature representation of inputs and outputs  $\Phi(\mathbf{x}, \mathbf{y})$ , i.e.  $F(\mathbf{x}, \mathbf{y}; \mathbf{w}) = \langle \mathbf{w}, \Phi(\mathbf{x}, \mathbf{y}) \rangle$ . As  $\Phi$  extracts meaningful properties from an observation/label sequence pair  $(\mathbf{x}, \mathbf{y})$ , in  $SVM^{\text{hmm}}$  it is modeled through two types of features: interactions between attributes of the observation vectors  $x_i$  and a specific label  $y_i$  (i.e. **emissions** of  $x_i$  by  $y_i$ ) as well as interactions between neighboring labels  $y_i$  along the chain (**transitions**). In other words,  $\Phi$  is defined so that the complete labeling  $\mathbf{y} = f(\mathbf{x})$  can be computed efficiently from  $F$ , using a *Viterbi-like decoding algorithm*, according to the linear discriminant function

$$\mathbf{y}^* = \arg \max_{\mathbf{y} \in \mathcal{Y}^+} \left\{ \sum_{i=1 \dots l} \left[ \sum_{j=1 \dots k} (x_i \cdot w_{y_{i-j} \dots y_i}) + \Phi_{tr}(y_{i-j}, \dots, y_i) \cdot w_{tr} \right] \right\}$$

In the training phase,  $SVM^{\text{hmm}}$  solves the following optimization problem given training examples  $(\mathbf{x}^1, \mathbf{y}^1) \dots (\mathbf{x}^n, \mathbf{y}^n)$  of sequences of feature vectors  $\mathbf{x}^j$  with their correct tag sequences  $\mathbf{y}^j$

$$\begin{aligned} \min \quad & \frac{1}{2} \|w\|^2 + \frac{C}{n} \sum_{i=1 \dots n} \xi_i \\ \text{s.t.} \quad & \forall \mathbf{y}, n : \left\{ \sum_{i=1 \dots l} (x_i^n \cdot w_{y_i^n}) + \Phi_{tr}(y_{i-1}^n, y_i^n) \cdot w_{tr} \right\} \geq \left\{ \sum_{i=1 \dots l} (x_i^n \cdot w_{y_i}) + \Phi_{tr}(y_{i-1}, y_i) \cdot w_{tr} \right\} + \Delta(\mathbf{y}^n, \mathbf{y}) \end{aligned}$$

where  $\Delta(\mathbf{y}^n, \mathbf{y})$  is the loss function, computed as the number of misclassified tags in the sequence,  $(x_i \cdot w_{y_i})$  represents the emissions and  $\Phi_{tr}(y_{i-1}, y_i)$  the transitions. Indeed, through  $SVM^{\text{hmm}}$  learning the label for the target tweet is made dependent on its context history. The markovian setting thus acquires patterns across tweet sequences to recognize sentiment even for truly ambiguous tweets.

## 4 Experimental Evaluation

The aim of the experiments is to estimate the contribution of the proposed contextual models to the accuracy reachable in different scenarios, whereas rich contexts (e.g. popular hashtags) are possibly made available or just singleton tweets, with no context, are targeted.

We adopted the “*Sentiment Analysis in Twitter*” dataset<sup>3</sup> as it has been made available in the *ACL SemEval-2013* (Nakov et al., 2013). However, in order to rely on tweet identifiers (needed to retrieve contexts from Twitter servers), only the Training and Development portions of the data (11,338 examples), for which id’s were made available, have been employed. As about 10,045 tweets were available from the servers,<sup>4</sup> a static split 80/10/10 in *Training/Held-out/Test* respectively, has been carried out as reported in Table 1. As the performance evaluation is always carried out against one target tweet (in analogy with the benchmark of SemEval-2013), the multi-classification may happen when no context is available (i.e. there is no conversation nor hashtag to built the context from) or when a rich conversational or topical context is available. In Table 1 different datasets are shown in columns 2-4, 5-7 and 8-10

<sup>3</sup><http://www.cs.york.ac.uk/semeval-2013/task2/index.php?id=data>

<sup>4</sup>Several original messages were no longer reachable during the experiment time of March-June 2013

respectively: the entire corpus of 10,045 is represented in columns 2-4, while 5-7 and 8-10 represents the subsets of target tweets for which a conversational or topical context, respectively, was available. Conversational contexts are available only for 1,391 tweets (columns 5-7), while hashtag-based contexts include 1,912 instances (columns 8-10).

	whole dataset			conversation-filtered			hashtag-filtered		
	train	dev	test	train	dev	test	train	dev	test
<i>Positive</i>	2984	359	387	454	51	56	621	83	66
<i>Negative</i>	1271	147	142	197	31	24	245	28	22
<i>Neutral</i>	3790	495	470	455	68	55	688	79	80
	8045	1001	999	1106	150	135	1554	190	168

Table 1: Whole dataset composition

As tweets are noisy texts, a pre-processing phase has been applied to improve the quality of linguistic features observable and reduce data sparseness. In particular, a normalization step is applied to each post: fully capitalized words are converted in lowercase; reply marks are replaced with the pseudo-token USER, hyperlinks by LINK, *hashtags* by HASHTAG and emoticons by special tokens<sup>5</sup>. Afterwards, an almost standard NLP chain is applied through the *Chaos* parser (Basili et al., 1998; Basili and Zanzotto, 2002). In particular, each tweet, with its pseudo-tokens produced by the normalization step, is mapped into a sequence of POS tagged lemmas. Emoticons are treated as nouns. In order to feed the LSK, lexical vectors correspond to a Word Space derived from a corpus of about 1.5 million tweets, downloaded during the experimental period and using the topic names from the trial material as query terms. Every word  $w$  in such corpus is represented as one co-occurrence vector as in (Sahlgren, 2006) with the setting discussed in (Croce and Previtali, 2010): left and right co-occurrence scores are obtained in a window of size  $n = \pm 5$  around each  $w$ . Vector components  $w_f$  correspond to Pointwise Mutual Information values  $pmi(w, f)$  between the word  $w$  (the row) and the feature  $f$ . Dimensionality reduction is applied to the co-occurrence matrix, through SVD, with a dimensionality cut of  $k = 250$ .

Existing state-of-the-art approaches neglect the tweet context, so that datasets with labeled contexts are not available: USPK or the markovian approach would not be applicable. The solution consisted in creating a *semi-supervised Gold-Standard* by training the multi-class classifier (not employing any context) fed through a combination of BoWK and LSK Kernel functions and get the classification of all tweets within the context of at least one target tweet. Unfortunately, this can introduce noise, but it is a realistic solution to a cold-start approach, easily portable to other datasets.

Performance scores report the classification accuracy in terms of Precision, Recall and standard F-measure. However, in line with SemEval-2013, we also report the  $F_1^{mn}$  score as the arithmetic mean between the  $F_1$ s of *positive*, *negative* and *neutral* classes.

#### 4.1 Experiment 1: Using contexts in a general tweet classification setting

A first experiment has been run to validate the impact of contextual information over generic tweets, independently from the availability of the context. In this case, the entire data set is used. The different settings adopted are reported in independent rows, corresponding to different classification approaches:

- *multi-class* refers to the application of the multi-classification of  $SVM^{multiclass}$ , that does not require any context and can be considered as a baseline for the employed Kernel combinations;
- *conversation* refers to the  $SVM^{hmm}$  classifier observing the conversation-based contexts. The training and testing of the classifier is here run with different *context sizes*, by parameterizing  $l$  in  $\Lambda_i^{C,l}$ ;
- likewise, *hashtag* refers to the  $SVM^{hmm}$  classifier observing the topic-based contexts, when hashtags are considered. Different *context sizes* have been considered, by parameterizing  $l$  in  $\Lambda_i^{H,l}$ .

In both *conversation* and *hashtag* models, when no context is available, the  $SVM^{hmm}$  classifier acts on a sequence of length one, and no transition is used. Table 2 shows the empirical results over the whole test dataset. The first general outcome is that algorithmic baselines, i.e. context-free models that use no contextual information, in the multi-class rows are better performing whenever richer representations are provided. The LSA information (+8.29%) as well as the user profiling (+10.73%) seem beneficial in

<sup>5</sup>We normalized 113 well-known emoticons in 13 classes.

	Context size $l$	Precision			Recall			$F_1$			$F_1^{pnn}$
		<i>pos</i>	<i>neg</i>	<i>neu</i>	<i>pos</i>	<i>neg</i>	<i>neu</i>	<i>pos</i>	<i>neg</i>	<i>neu</i>	
<b>BoWK</b>											
<i>multi-class</i>	-	.713	.496	.680	.649	.401	.770	.679	.444	.723	<b>.615</b> (-)
<i>conversation</i>	3	.761	.493	.695	.651	.465	.789	.702	.478	.739	.640 (+4.07%)
	6	.728	.500	.718	.677	.479	.768	.701	.489	.742	.644 (+4.72%)
	$\infty$	.723	.511	.722	.695	.472	.762	.709	.491	.741	<b>.647</b> (+5.20%)
<i>hashtag</i>	3	.766	.533	.675	.633	.401	.821	.693	.458	.741	.631 (+2.60%)
	6	.727	.575	.711	.682	.514	.770	.704	.543	.740	.662 (+7.64%)
	16	.717	.561	.730	.693	.549	.755	.704	.555	.743	<b>.667</b> (+8.46%)
	31	.717	.533	.738	.705	.570	.732	.711	.551	.735	.666 (+8.29%)
<b>BoWK+LSK</b>											
<i>multi-class</i>	-	.754	.595	.704	.674	.486	.804	.712	.535	.751	<b>.666</b> (-)
<i>conversation</i>	3	.759	.595	.712	.682	.486	.811	.718	.535	.758	.670 (+0.60%)
	6	.760	.536	.737	.713	.521	.781	.736	.529	.758	.674 (+1.20%)
	$\infty$	.774	.554	.717	.682	.542	.791	.725	.548	.752	<b>.675</b> (+1.35%)
<i>hashtag</i>	3	.731	.541	.737	.729	.556	.732	.730	.549	.734	.671 (+0.75%)
	6	.770	.580	.736	.700	.585	.789	.733	.582	.762	<b>.693</b> (+4.05%)
	16	.742	.519	.732	.693	.570	.751	.717	.544	.742	.667 (+0.15%)
	31	.751	.537	.729	.685	.556	.774	.716	.547	.751	.671 (+0.75%)
<b>BoWK+LSK+USPK</b>											
<i>multi-class</i>	-	.778	.612	.716	.680	.500	.830	.726	.550	.768	<b>.681</b> (-)
<i>conversation</i>	3	.771	.563	.689	.625	.507	.817	.690	.533	.748	.657 (-3.67%)
	6	.753	.654	.707	.693	.493	.806	.721	.562	.753	<b>.679</b> (-0.29%)
	$\infty$	.767	.566	.713	.690	.514	.791	.727	.539	.750	.672 (-1.32%)
<i>hashtag</i>	3	.753	.556	.735	.693	.599	.766	.721	.576	.750	.683 (+0.29%)
	6	.747	.594	.735	.711	.556	.779	.728	.575	.756	<b>.686</b> (+0.73%)
	16	.742	.519	.742	.700	.592	.745	.721	.553	.743	.672 (-1.32%)
	31	.738	.530	.739	.693	.556	.766	.715	.543	.752	.670 (-1.62%)

Table 2: Evaluation results on whole dataset.

their relative improvements with respect to the simple BoW Kernel accuracy. Second, almost all context-driven models (i.e.  $SVM^{hmm}$  operating on different context sizes) improve *wrt* their  $SVM^{multiclass}$  counterpart. Every polarity category benefits from the introduction of contexts, although this is particularly true for the negative (*neg*) case, where a 15.5% of the entire dataset examples are available: it seems clear that contexts allow to compensate against poor training conditions.

#### 4.2 Experiment 2: Measuring the full impact of context-based models over rich contexts

Given the above outcomes, a second set of experiments has been run against the subset of the test data restricted to tweets for which rich contexts are available, as introduced in Table 1. In Figure 1, the performances of different learning paradigms and Kernels trained and tested over these corpora are shown. On the Left of the figure, the performance over the conversation-filtered corpus (Table 1) are reported: these tweets are characterized by rich conversational contexts of different increasing sizes on the X-axis. On the Right of Figure 1, the corresponding performances obtained over the hashtag-filtered corpus are reported. As the number of available examples in both test corpora is much smaller, the baselines corresponding to the  $SVM^{multiclass}$  approach are lower.

On the contrary, such poorer training evidence does not seem to afflict the contextual models in both corpora, as the markovian modeling seems to bring a straight benefit. In particular, increasing amount of contextual information is usually beneficial to accuracy scores. In general, the  $SVM^{hmm}$  accuracy plots seem to increase up to a given context size, that is around 6 for conversational contexts vs. 16 previous tweets for topical contexts. It seems that a wider context (i.e. a window of 8 or 10 tweets) is not so beneficial, as the generalization emphasized by LSK and USPK tends to diverge. Different genres of discussions seem to provide different useful contexts for sentiment detection. The overall benefit reachable by  $SVM^{hmm}$  relatively to the  $SVM^{multiclass}$  baseline is striking as only rich contexts are used for training and testing. The BoW Kernel over the conversation corpus has an overall relative improvement of 18.26% in  $F_1^{pnn}$ , where the richer BoWK+LSK Kernel improves of about 5.94%. Boosts in  $F_1^{pnn}$  over topical contexts are more significant: 23.73% for the BoW Kernel vs. 17.93% for BoWK+LSK. This latter Kernel is optimal, suggesting that user profiling requires possibly a richer description that is not entirely captured by the vectors of the user sentiment profile. In fact USPK, when combined with

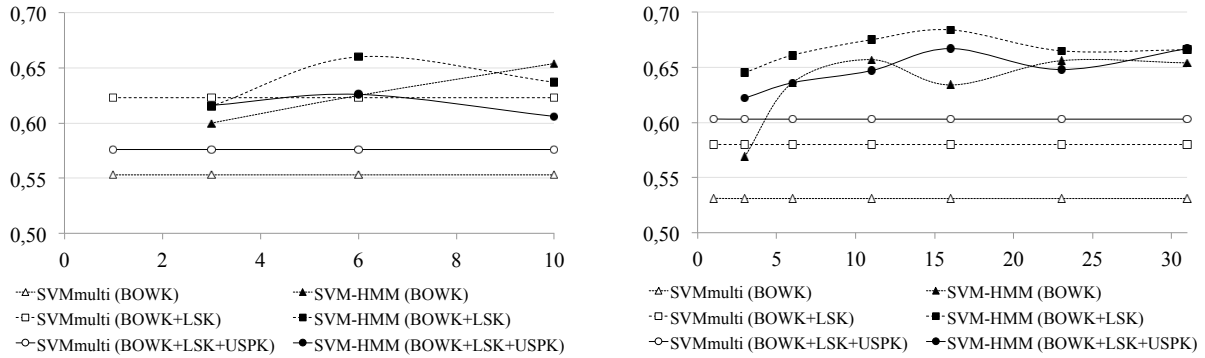


Figure 1: The  $F_1^{pnn}$  measure of the different classifiers vs. different context sizes. On the Left: performances when conversational contexts are employed. On the Right: topical contexts are adopted.

BOWK+LSK into the markovian approach, seems to not provide any useful contribution. A clash between the global information (as modeled by the USPK) and the local information (embedded in the recent tweets about a topic) is here observed: when these enter in an opposition, the contrast penalizes the accuracy of the linear combination of Kernels. In general, the improvements implied by contextual information are related to the treatment of particularly ambiguous tweets. In a conversation, such as

MrGreen : *Cannot wait to meet @therealjuicyj and @RealWizKhalifa with @Hill\_Gonzz*  
*November 29th #trippyniqqas* (positive)  
ColMustard : *@MrGreen where they gone be??* (neutral)  
MrGreen : *@ColMustard New Orleans!!!* (positive)  
ColMustard : *@MrGreen house of blues?* (neutral)  
MrGreen : *@ColMustard no it's at the UNO lakefront arena* (neutral)  
ColMustard : *@MrGreen I'm going Tuesday to the house of blues to see ASAP Rocky* (neutral)

the switch to a *neutral* mode characterizing the target tweet is a consequence of the entire sequence and captured as a pattern. The contribution of the topical contexts is finally evident in the following example:

... ..  
ProfPlum : *Can't wait to get out there with my boys Go Team! #goeagles* (positive)  
MrsPeacock : *GO my awesome team @WestCoastEagles!!!! #goeagles #weftyhigh :D* (positive)  
MissScarlet : *Let's go eagles :) #goeagles* (positive)  
SergGray : *keen for the eagles game today. #goeagles* (positive)

## 5 Conclusions

In this work the role of contextual information in supervised Sentiment Analysis over Twitter is investigated. While the task is eminently linguistic, as resources and phenomena lie in the textual domain, other semantic dimensions are worth to be explored. In this work, three types of context for a target tweet have been studied. Structured Learning through a markovian approach has been adopted to inject contextual evidence (e.g. the history of preceding posts) in the classification of the most recent, i.e. a target, tweet. The improvement of accuracy in the investigated task are striking as for the large applicability of the approach that does not require additional manually coded resources. The different employed contexts show specific but systematic benefits. On the one side, this proves the correctness of the initial intuitions. Moreover, the observed relative improvements around 20% over tweets characterized by rich topical or conversational contexts (see Fig. 1) suggest that larger training datasets can even provide better results. In these first experiments, user modeling has only been partially explored, whereas the USPK model does not seem very effective. In fact, USPK seems to express a more static notion of context (i.e. the attitude of the user as observed across a longer period than individual conversations) and two different notions (i.e. information embedded into recent tweets) risk to be incompatible. However, the learning of the optimal Kernel combination as well as a proper history size for the USPK are still worth of deeper investigation. Finally, user interaction dynamics are particularly complex in social networks and deserve better representations about reputation, authority and influence in future explorations.



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