

A Clustering Framework for Lexical Normalization of Roman Urdu

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Abstract

Roman Urdu is an informal form of the Urdu language written in Roman script. It is used widely in South Asia for online textual content. It lacks standard spelling and hence poses several normalization challenges during automatic language processing. In this article, we present a feature-based clustering framework for lexical normalization of Roman Urdu corpora, which includes a phonetic algorithm *UrduPhone*, a string matching component, a feature-based similarity function, and a clustering algorithm *Lex-Var*. *UrduPhone* encodes Roman Urdu strings to their pronunciation-based representations. The string matching component handles character-level variations that occur when writing Urdu using Roman script. The similarity function incorporates various phonetic-based, string-based, and contextual features of words. The *Lex-Var* algorithm is a variant of the k-medoids clustering algorithm that groups lexical variations of words. It contains a similarity threshold to balance the number of clusters and their maximum similarity. The framework allows feature learning and optimization in addition to the use of pre-defined features and weights. We evaluate our framework extensively on four real-world datasets and show an F-measure gain of up to 15 percent from baseline methods. We also demonstrate the superiority of *UrduPhone* and *Lex-Var* in comparison to respective alternate algorithms in our clustering framework for lexical normalization of Roman Urdu.

1 Introduction

Urdu and Hindi, the national language of Pakistan, and an official language of India, respectively, are together the fourth most spoken languages in the world (Lewis, 2009). Urdu and Hindi are closely related in morphology and phonology but use different scripts: Urdu is written in Perso-Arabic script and Hindi is written in Devanagari script. Interestingly, for social media and short messaging service (SMS) texts, a large number of Urdu and Hindi speakers use an informal form of these languages written in Roman script, *Roman Urdu*.

Since Roman Urdu does not have standardized spellings and is mostly used in informal communication, there exist many spelling variations for any given word. For example, the Urdu word زندگی [life] is written as *zindagi*, *zindagee*, *zindagy*, *zaindagee* and *zndagi*. The lack of standard spellings inflates the vocabulary of the language and causes sparsity problems. This results in poor performance of natural language processing (NLP) and text mining tasks, such as word segmentation (Durrani and Hussain, 2010), part of speech tagging (Sajjad and Schmid, 2009), spell checking (Naseem and Hussain, 2007), machine translation (Durrani et al., 2010), and sentiment analysis (Paltoglou and Thelwall, 2012). For example, neural machine translation models are generally trained on a limited vocabulary. Non-standard spellings would result in a large number of words unknown to the model, which would result in poor translation quality.

Our goal is to perform *lexical normalization*, which maps all spelling variations of a word to a unique form that corresponds to a single lexical entry. This reduces data sparseness and improves the performance of NLP and text mining applications.

One challenge of Roman Urdu normalization is lexical variations, resulting from a variety of reasons, such as informal writing, inconsistent phonetic mapping, and non-unified transliteration. Compared to the lexical normalization of languages with a similar script like English, the problem is more complex than writing a language informally in the original script. For example, in English, the word *thanks* can be written colloquially as *thanx* or *thx*, where the shortening of words and sounds into fewer characters is done in the same script. In Roman Urdu, in addition to phonetically mapping various Urdu characters to one or more Latin characters, the transliteration of Perso-Arabic script to Roman script takes place at the same time. Since transliteration is a non-deterministic process, it also introduces spelling variations. Fig. 1 shows an example of an Urdu word لڑکے [boys] that can be transliterated into Roman Urdu in three different ways (*larke*, *ladkay*, or *larkae*) depending on the user’s preference. Lexical normalization of Roman Urdu aims to map transliteration variations of a word to one standard form.

Another challenge is that Roman Urdu lacks a standard lexicon or labeled corpus for text normalization to use. Lexical normalization has been addressed for standardized or resource-rich languages like English, e.g., (Jin, 2015; Han et al., 2013; Gouws et al., 2011). For such languages, the correct or standard spelling of words is known, given the standard existence of lexicon. Therefore, lexical normalization typically involves finding the best lexical entry for a given word that does not exist in the standard lexicon. Proposed approaches therefore aim to find the best set of

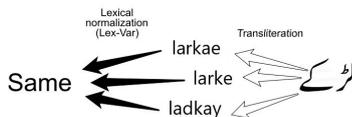


Fig. 1. The lexicon can be varied due to informal writing, non-unified definition of transliteration, phonetic mapping etc.

70 standard words for a given non-standard word. On the other hand, Roman Urdu is an under-resourced language that does not have a standard lexicon. Therefore, it is not possible to distinguish between an in-lexicon and an out-of-lexicon word, and each word can potentially be a lexical variation of another. Lexical normalization of such languages is computationally more challenging than that of resource-rich
 75 languages.

Since we do not have a standard lexicon or labeled corpus for Roman Urdu lexical normalization, we cannot apply a supervised method. Therefore, we introduce an unsupervised clustering framework to capture lexical variations of words. Different from the English text normalization by Rangarajan Sridhar (2015); Sproat and Jaitly (2017), our approach does not require prior knowledge on the number of
 80 lexical groups or group labels (standard spellings). Our method significantly outperforms the state-of-the-art Roman Urdu lexical normalization using rule-based transliteration Ahmed (2009).

In this work we give a detailed presentation of our framework (Rafae et al., 2015)
 85 with additional evaluation datasets, extended experimental evaluation, and analysis of errors. We develop an unsupervised feature-based clustering algorithm, *Lex-Var*, that discovers groups of words that are lexical variations of one another. *Lex-Var* ensures that each word has at least a specified minimum similarity with the cluster’s centroidal word. Our proposed framework incorporates phonetic, string, and contextual features of words in a similarity function that quantifies the relatedness
 90 among words. We develop knowledge-based and machine-learned features for this purpose. The knowledge-based features include UrduPhone for phonetic encoding, an edit distance variant for string similarity, and a sequence-based matching algorithm for contextual similarity. We also evaluate various learning strategies for string and contextual similarity such as weighted edit distance and word embed-
 95 dings. For phonetic information, we develop *UrduPhone*, an encoding scheme for Roman Urdu derived from Soundex. Compared to other available techniques that are limited to English sounds, UrduPhone is tailored for Roman Urdu pronunciations. For string-based similarity features, we define a function based on a combination of
 100 longest common subsequence and edit distance metric. For contextual information, we consider top-k frequently occurring previous and next words or word groups. Finally, we evaluate our framework extensively on four Roman Urdu datasets: two group-chat SMS datasets, one Web blog dataset, and one service-feedback SMS dataset and measure performance against a manually developed database of Roman Urdu variations. Our framework gives an F-measure gain of up to 15% as
 105 compared to baseline methods.

We make the following key *contributions* in this paper:

- We present a general framework for normalizing words in an under-resourced language that allows user-defined and machine learned features for phonetic, string, and contextual similarity.
- We propose two different clustering frameworks including a k-medoids based clustering (Lex-Var) and an agglomerative clustering (Hierarchical Lex-Var)
- We present the first detailed study of Roman Urdu normalization.
- We introduce UrduPhone for phonetic encoding of Roman Urdu words.
- We perform an error analysis of the results, highlighting the challenges of normalizing an under-resourced and non-standard language.
- We have provide the source code for our lexical normalization framework¹.

The remainder of this article is organized as follows. In Section 2, we present our problem statement for lexical normalization of an under-resourced language. In Section 3, We describe our clustering framework for lexical normalization of an under-resourced language, including UrduPhone and Lex-Var. In Section 4, we describe the evaluation criterion for lexical normalization of Roman Urdu, describe the research experiments and present the results and the error analysis. Section 5 discusses the related work in the lexical normalization of informal language, and Section 6 concludes the paper.

2 Task Definition

Roman Urdu is a transliterated form of the Urdu language written in Roman script. It does not have a standardized lexicon. That is, there is no standard spelling for words. Therefore, each word observed in a corpus can potentially be a variant of one or more of the other words appearing in the corpus. The goal of lexical normalization is to identify all spelling variations of a word in a given corpus. This challenging task involves normalizations associated with the following three issues: (1) different spellings for a given word (e.g., *kaun* and *kon* for the word [who]); (2) identically spelled words that are lexically different (e.g., *bahar* can be used for both [outside] and [spring]); and (3) spellings that match words in English (e.g., *had* [limit] for the English word *had*). The last issue arises because of code-switching between Roman Urdu and English, which is a common phenomenon in informal Urdu writing. People often write English phrases and sentences in Urdu conversations or switch language mid-sentence, e.g., *Hi everyone. Kese ha aap log?* [Hi everyone. How are you people?]. In our work, we focus on finding common spelling variations of words (issue (1)), as this is the predominant issue in lexical normalization of Roman Urdu and do not address issues (2) or (3) explicitly.

With respect to issue (1), we note that Urdu speakers transliterate Urdu script into Roman script, but often move away from the transliteration in favor of a phonetically closer alternative. A commonly observed example is the replacement of one or more vowels with another set of the vowels that has a similar pronunciation

¹ <https://github.com/abdulrafae/normalization>

(e.g., *janeaeey* [to know] can also be written as *janeey*). Here, the final characters 'aeey' and 'ey' give the same pronunciation. Another variation of the previous word is *janiey*. Now the character 'i' is replacing the character 'e'. In some cases users will omit a vowel if it does not impact pronunciation, e.g., *mehnga* [expensive] becomes *mhnga* and similarly *bohut* [very] becomes *bht*. Another common example of this type of omission occurs with nasalized vowels. For example, the Roman Urdu word *kuton* [dogs] is the transliteration of the Urdu word کتوں. But often the final nasalized Urdu character ں is omitted during conversion, and the Roman Urdu word becomes [kuto]. A similar case is found for words like *larko* [boys], *daikho* [see], *nahi* [no] with final 'n' omitted. We incorporate some of these characteristics in our encoding scheme UrduPhone (See Section 3.3.1 and Table 2 for more details on UrduPhone, its rules, and for complete steps to generate encoding).

We define the identification of lexical variations in an under-resourced language like Roman Urdu as follows: Given words w_i ($i = 1, \dots, N$) in a corpus, find the lexical groups ℓ_j ($j = 1, \dots, K$) to which they belong. Each lexical group can contain one or more words corresponding to a single lexical entry and representing spelling variations of that entry in the corpus. In general, for a given corpus, the number of lexical groups K is not known since no standardized lexicon is available. Therefore, we estimate it using normalization.

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Clustering is expensive in the specific case of Roman Urdu normalization. Considering an efficient algorithm like k-means clustering, the computational complexity of lexical normalization is $O(NKT)$, where T is the number of iterations required for clustering. In comparison, for languages like English with standardized lexicons, each out-of-vocabulary (OOV or not in the dictionary) word can be a variant of one or more in-vocabulary (IV) words. The computational complexity of lexical normalization in English (given by $O(K(N - K))$ where K and $(N - K)$ are the numbers of IV and OOV words, respectively) is computationally less expensive than the lexical normalization of Roman Urdu.

3 Method

In this section, we describe different components of our clustering framework. Section 3.1 formalizes our clustering framework including the algorithm developed. Section 3.2 defines a similarity function used in our clustering algorithm. In Section 3.3 we describe the features used in our system.

Algorithm 1: Lex-Var

```

Input:  $\mathcal{L}^* = \{\ell_1^*, \ell_2^*, \dots, \ell_{K^*}^*\}$  (initial clusters; see Table 4),  $\mathcal{W} = \{w_1, w_2, \dots, w_N\}$  (words),  $t$ 
(similarity threshold)
Output:  $\mathcal{L} = \{\ell_1, \ell_2, \dots, \ell_K\}$  (predicted clusters)
1  $\mathcal{L} = \mathcal{L}^*$ ;
2 repeat
   /* Find cluster centroidal word */
3    $\mathcal{C} = \emptyset$ ;
4   for  $\forall \ell_i \in \mathcal{L}$  do
5      $\mathcal{R} = \emptyset$ ;
6     for  $\forall w_j \in \ell_i$  do
7        $r_j = 0$ ;
8       for  $\forall w_k \in \ell_i$  do
9          $r_j = r_j + S(w_j, w_k)$ ;
10      end
11       $\mathcal{R} = \mathcal{R} \cup \{r_j\}$ ;
12    end
13     $m = \arg \max_j (r_j \in \mathcal{R})$ ;
14     $c_i = w_m$ ;
15     $\mathcal{C} = \mathcal{C} \cup \{c_i\}$ ;
16     $\ell_i = \emptyset$ ;
17  end
   /* Assign word to clusters */
18  for  $\forall w_i \in \mathcal{W}$  do
19     $closest = \text{null}$ ;
20     $maxSim = 0$ ;
21    for  $\forall c_j \in \mathcal{C}$  do
22      if  $S(w_i, c_j) > t$  and  $S(w_i, c_j) > maxSim$  then
23         $maxSim = S(w_i, c_j)$ ;
24         $closest = c_j$ ;
25      end
26    end
27    if  $closest \neq \text{null}$  then // Move word  $w_i$  to cluster  $\ell_j$ 
28       $\ell_j = \ell_j \cup \{w_i\}$  |  $closest \in \ell_j$ ;
29    else // Move word  $w_i$  to new cluster  $\ell_{|\mathcal{L}|+1}$ 
30       $\ell_{|\mathcal{L}|+1} = \{w_i\}$ ;
31       $\mathcal{L} = \mathcal{L} \cup \{\ell_{|\mathcal{L}|+1}\}$ ;
32    end
33  end
34 until stop condition Satisfied;

```

3.1 Clustering Framework: Lex-Var

We develop a new clustering algorithm, Lex-Var, for discovering lexical variations in informal texts. This algorithm is a modified version of the k-medoids algorithm (Han, 2005) and incorporates an assignment similarity threshold, $t > 0$, for controlling the number of clusters and their similarity spread. In particular, it ensures that all words in a group have a similarity greater than or equal to some threshold, t . It is important to note that the k-means algorithm cannot be used here because it requires that the means of numeric features describe the clustered objects. The standard k-medoids algorithm, on the other hand, uses the most centrally located object as a cluster's representative.

Algorithm 1 gives the pseudo-code for Lex-Var. Lex-Var takes as input words (\mathcal{W}) and outputs lexical groups (\mathcal{L}) for these words. UrduPhone segmentation of the words gives the initial clusters. Lex-Var iterates over two steps until it achieves convergence. The first step finds the centroidal word c_i for cluster ℓ_i as the word for which the sum of similarities of all other words in the cluster is maximal. In the second step, each non-centroidal word w_i is assigned to cluster ℓ_j if $S(w_i, c_j)$

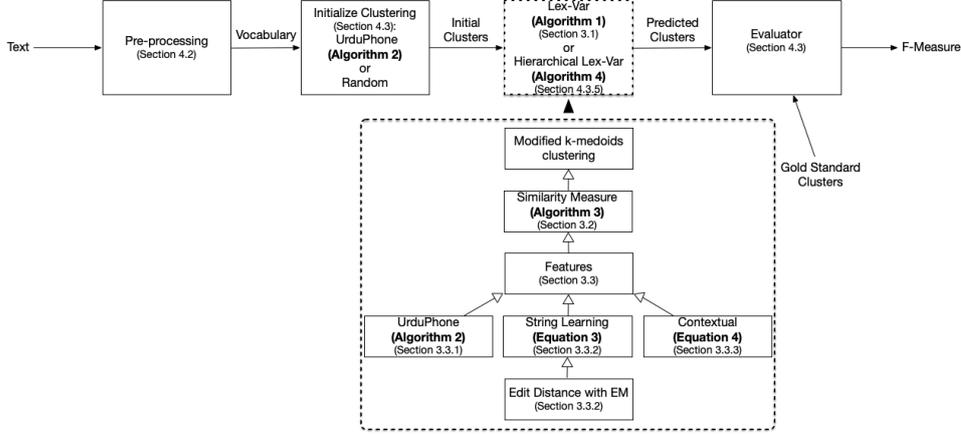


Fig. 2. Flow Diagram for Lex-Var

(see Section 3.2) is maximal among all clusters and $S(w_i, c_j) > t$. If the latter condition is not satisfied (i.e., $S(w_i, c_j) \leq t$), then instead of assigning word w_i to cluster ℓ_j , it starts a new cluster. We repeat these two steps until a stop condition is satisfied (e.g., a fraction of words that change groups becomes less than a specified threshold). The computational complexity of Lex-Var is $O((n^2 + N)KT)$, where n is the maximum number of words in a cluster, which is typically less than N .

Fig. 2 shows the details of our clustering framework. The first row of boxes shows the workflow of the system, and the area in the dotted square includes the modules used in our clustering method. The filled arrows indicate the outputs of the algorithms, and the unfilled arrows show modules that apply sub-modules.

After pre-processing the text, we normalize each word in the vocabulary. First, we initialize the clustering using random clustering or UrduPhone clusters. Then, based on the initial clusters, we apply (Hierarchical) Lex-Var algorithm to predict clusters. Finally, we compute the F-Measure based on the gold standard clusters to evaluate our prediction.

The Lex-Var algorithm applies a modified version of the k-medoids clustering, which uses a similarity measure that is further consisted of different features including UrduPhone, String Learning, and Contextual feature. The edit distance is a sub-module of the string learning. We learn the substitution cost with various methods such as EM.

3.2 Similarity Measure

We compute the similarity between two words w_i and w_j using the following similarity function:

$$S(w_i, w_j) = \frac{\sum_{f=1}^F \alpha^{(f)} \times \sigma_{ij}^{(f)}}{\sum_{f=1}^F \alpha^{(f)}} \quad (1)$$

Table 1. *UrduPhone vs Soundex Encodings*

Word	Soundex Encoding	UrduPhone Encoding
<i>mustaqbil</i> [future]	M.2.3.2	M.1.2.7.9.17
<i>mustaqil</i> [constant]	M.2.3.2	M.1.2.7.17.0
<i>khirki</i> [window]	K.6.2.0	K.19.14.7.0.0
<i>kursi</i> [chair]	K.6.2.0	K.14.1.0.0.0
<i>ronak</i> [brightness]	R.5.2.0	R.11.7.0.0.0
<i>rung</i> [color]	R.5.2.0	R.11.13.0.0.0
<i>dimaagh</i> [brain]	D.5.2.0	D.12.13.19.0.0
<i>dimaag</i> [brain]	D.5.2.0	D.12.13.0.0.0
<i>please</i>	P.4.2.0	P.17.1.0.0.0
<i>plx</i>	P.4.2.0	P.17.3.0.0.0

Algorithm 2: UrduPhone

```

Input:  $w = \{w_1, \dots, w_n\}$ , a word of length  $n$ 
Output:  $e = \{e_1, \dots, e_6\}$ , an encoding of length 6
1  $e[0] = \text{uppercase}(w[0]);$ 
2  $j = 1;$ 
3 for  $i = 1 \rightarrow n$  do
  // Discard duplicates
4   if  $i + 1 \leq n$  &&  $w[i] == w[i + 1]$  then
5     |  $\text{continue};$ 
6   end
  // Discard Roman Urdu vowels (a,e,i,o,u,y)
7   if  $w[i] == 'a' || w[i] == 'e' || w[i] == 'i' || w[i] == 'o' || w[i] == 'u' || w[i] == 'y'$  then
8     |  $\text{continue};$ 
9   end
  // Encode character based on Table 2
10   $e[j] = \text{get\_encoding}(w[i]);$ 
11   $j ++;$ 
12 end
  // Add 0s if encoding length less than 6
13 while  $j \leq 6$  do
14   |  $e[j] = 0;$ 
15   |  $j ++;$ 
16 end

```

Here, $\sigma_{ij}^{(f)} \in [0, 1]$ is the similarity contribution made by feature f . F is the total number of features. We will describe each feature in Section 3.3 in detail. $\alpha^{(f)} > 0$ is the weight of feature f . These weights are set to one by default and are automatically optimized in Section 3.4 and 4.3.4. The similarity function returns a value in the interval $[0, 1]$ with higher values signifying greater similarity.

3.3 Features

The similarity function in Eq. 1 is instantiated with features representing each word. In this work, we use three features: phonetic, string, and contextual, which are computed based on rules or based on learning.

² https://en.wikipedia.org/wiki/Urdu_alphabet

Table 2. UrduPhone homophone mappings in Roman Urdu

Characters	Urdu Alphabets	IPA ²	Example
q,k	ق , ک	[q], [k]	<i>qainchi</i> [scissors], <i>kitab</i> [book]
e,sh,s	ث , ص , ش , س	[s], [ʃ], [s], [s]	<i>shadi</i> [wedding], <i>sadi</i> [simple]
z,x	ض , ظ , ذ , ز	[z], [z], [z], [z]	<i>zameen</i> [earth], <i>xar</i> [gold]
zh	ژ	[ʒ]	<i>zhalabari</i> [hail]
kh	خ	[x]	<i>zakhmi</i> [injured]
d	ڈ , د	[d̪], [d]	<i>dahi</i> [yogurt], <i>doob</i> [sink]
t	ط , ٹ , ت	[t̪], [t], [t̪]	<i>tareef</i> [praise], <i>timatar</i> [tomato]
m	م	[m]	<i>maut</i> [death]
j	ج	[dʒ]	<i>jism</i> [body]
g	گ	[g]	<i>gol</i> [circular]
f	ف	[f]	<i>fauj</i> [army]
b	ب	[b]	<i>bjli</i> [lightening]
p	پ	[p]	<i>pyaz</i> [onion]
l	ل	[l]	<i>lafz</i> [word]
ch	چ	[tʃ]	<i>chehra</i> [face]
h	ح , ہ , ه	[h, fi], [h, fi, ø], [h, fi]	<i>haal</i> [present], <i>bahar</i> [spring], <i>phal</i> [fruit]
n	ن	[n, ɲ, n, ŋ], [~]	<i>nazar</i> [sight], <i>larkioun</i> [girls]
r	ر	[r], [r̪]	<i>risala</i> [magazine], <i>guriya</i> [doll]
w,v	ع , و	[v, u:, o:, ɔ:], [a:, o:, e:, ʔ, ʕ, ø]	<i>waqt</i> [time], <i>vada</i> [promise]
bh	بھ	[b ^h]	<i>bhaag</i> [run]
ph	پھ	[p ^h]	<i>phool</i> [flower]
jh	جھ	[dʒ ^h]	<i>bojh</i> [weight], <i>boj</i> [weight]
th	تھ	[t ^h], [t ^h]	<i>thapki</i> [pat], <i>thokar</i> [stumble]
dh	ڈھ , دھ	[d̪ ^h], [d ^h]	<i>udhar</i> [loan], <i>dhool</i> [drum]
rh	رھ , ژھ	[r ^h], [t ^h]	<i>rhnuma</i> [guide], <i>barhna</i> [to grow]
gh	غ	[ɣ]	<i>ghalat</i> [wrong]
a,i,e,o,u,y	ا , ع , و , ی , اُ	[a:, ʔ, ø], [j, i:, a:], [e:, e:], [v, u:, o:, ɔ:], [a:, o:, e:, ʔ, ʕ, ø], [ʔ, ø]	<i>aam</i> [mango], <i>ilm</i> [knowledge], <i>ullu</i> [owl]

3.3.1 UrduPhone

We propose a new phonetic encoding scheme, *UrduPhone*, tailored for Roman Urdu. Derived from Soundex (Knuth, 1973; Hall and Dowling, 1980), UrduPhone encodes consonants by using similar sounds in Urdu and English. UrduPhone differs from Soundex in two ways:

- 1) UrduPhone's encoding of words contains six characters as opposed to four in Soundex. An increase in encoding length reduces the possibility of mapping semantically different words to one form. Soundex maps different words to a single encoding, which, due to the limited encoding length, can cause errors when trying to find correct lexical variations. (Table 1). For example, *mustaqbil* [future] and *mus-*

245 *taqil* [constant] encode to one form, *MSTQ*, in Soundex but to two different forms using UrduPhone encoding. In a limited number of cases, UrduPhone increases ambiguity by mapping lexical variations of the same word into different encodings, as in the case of *please* and *plx*. Since these words share similar context, we believe that they will map to one cluster with the addition of contextual information.

250 2) We introduce homophone-based groups, which are mapped differently in Soundex. There are several Urdu characters that map to the same Roman form. For example, *samar* [reward], *sabar* [patience], and *saib* [apple], all start with different Urdu characters that have an identical Roman representation: *s*. We group together homophones such as *w*, *v* as in *taweez*, *taveez* [amulet] and *z*, *x* as in *lolz*, *lolxx* 255 [laughter] or *zara*, *xara* [a bit]. One common characteristic with transliteration from Urdu to Roman script is the omission of the Roman character 'h'. For example, the same Urdu word maps to both the Roman words *samajh* & *samaj* [to understand]. This is especially true in the case of digraphs representing Urdu aspirates such as *dh*, *ph*, *th*, *rh*, *bh*, *jh*, *gh*, *zh*, *ch*, and *kh*. A problem arises when the longest common subsequence in words (if 'h' is omitted) causes overlaps such as (*khobar* [news], 260 *kabar* [grave]) and (*gari* [car], *ghari* [watch]). Also, when *sh* comes at the end of a word, as in *khawhish*, *khawhis* [wish]; when 'h' is omitted, the sound is mapped to the character *s*. Similarly, if there is a transcription error, such as *dushman* [enemy] becomes *dusman*, the UrduPhone encoding is identical. Here, the omission of 'h' 265 causes an overlap of the characters س and ش.

The second column of Table 1 shows a few examples of Soundex encodings of Roman Urdu words. In some cases, Soundex maps two semantically different words to one code, which is undesirable in the task of lexical normalization. Table 2 shows a complete list of homophone-based mapping introduced in UrduPhone, and 270 Algorithm 2 shows the process to encode a word into an UrduPhone encoding. The phonetic similarity of words w_i and w_j is then computed using Eq. 2.

$$\sigma_{ij}^P = \begin{cases} 1 & \text{if } UrduPhone(w_i) == UrduPhone(w_j) \\ 0 & \text{otherwise} \end{cases} \quad (2)$$

3.3.2 Learning String-similarity

The lexical variations of a word have a number of overlapping sub-word units, e.g., spelling variations of *zindagi* [life] include *zindagee*, *zindagy*, *zaindagee* and *zndagi* 275 with many overlapping sub-word units. To benefit from this overlap, we define a string similarity function as follows:

$$\sigma_{ij}^S = \frac{lcs(w_i, w_j)}{\min[len(w_i), len(w_j)] + edist(w_i, w_j)} \quad (3)$$

Here, $lcs(w_i, w_j)$ is the length of the longest common subsequence in words w_i and w_j , $len(w_i)$ is the length of word w_i , and $edist(w_i, w_j)$ is the edit distance between words w_i and w_j .

280 *Edit Distance:* The edit distance allows insertion, deletion and substitution operations. We obtain the cost of edit distance operations in two ways:

Manually Defined – In a naive approach, we consider the cost of every operation to be equal and set them to 1. We refer to this edit distance cost as edist_{man} . This technique has a downside of considering all operations equally necessary which is an erroneous assumption. For example, the substitution cost of a Roman character 'a' to 'e' should be less than the cost of 'a' to 'z' because both 'a' and 'e' have related sounds in some contexts. It is possible to use these characters alternatively when transliterating from Perso-Arabic script to Roman Script.

290 **Automatically Learning Edit Distance Cost** – In this approach, we automatically learn the edit distance cost from the data. Consider a list of word pairs where one word is a lexical variation of another word. One can automatically learn the character alignments between them using an EM algorithm. The inverse character alignment probability serves as cost for the edit distance operations.

In our case, we do not have a cleaned list of word pairs to learn character alignments automatically. Instead, we try to learn these character alignments from the noisy training data. To do this, we build a list of candidate word pairs by aligning every word in the corpus to every other word in the corpus as a possible lexical variation. We split the words into characters and run the word-aligner GIZA++ (Och and Ney, 2003). Here, the word-aligner considers every character as a word and every word as a sentence. We use the learned character alignments with one minus their probability as the cost for the edit distance function. We refer to this edit distance cost as edist_{giza} .

Since the model learns the cost from the noisy data, it is likely that it is not a good representative of the accurate edit distance cost that would be learned from the cleaned data. In our alternative method, we automatically refine the list of candidate pairs and learn character alignments from it. In this approach, we consider the problem of lexical variations as a **transliteration mining** problem (Sajjad et al., 2011), where, given a list of candidate word pairs, the algorithm automatically extracts word pairs that are transliterations of each other. For this purpose, we use the unsupervised transliteration mining model of (Sajjad et al., 2017), who define the model³ as a mixture of a transliteration sub-model and a non-transliteration sub-model. The transliteration sub-model generates the source and target character sequences jointly and is able to model the dependencies between them. The non-transliteration model consists of two monolingual character sequence models that generate source and target strings independently of each other. The parameters of the transliteration sub-model are uniformly initialized and then learned during EM training of the complete interpolated model. During the training process, the model penalizes character alignments that are less likely to be part of a transliteration pair and favors character alignments that are likely to be part of a transliteration pair.

³ https://github.com/hsajjad/transliteration_mining

320 Similar to GIZA++ training, we train the unsupervised transliteration miner on our candidate list of word pairs and learn character alignments. We then use these character alignments with one minus their probability as cost for the edit distance metric. We refer to this cost as $\text{edist}_{\text{miner}}$.

3.3.3 Context Information

325 We observe that non-standard variants of a standard word have similar contexts. For example, *truck* and *truk* will be used in similar contexts, which might be very different from *cat*. We used this idea to define a contextual similarity measure between two words. We compare the top-k frequently occurring preceding (previous) and following (next) words' features of the two words in the corpus. The previous and next word's features can be each word's ID, UrduPhone ID, or cluster/group ID (based on initial clustering of the words).

330 Let $a_1^i, a_2^i, \dots, a_5^i$ and $a_1^j, a_2^j, \dots, a_5^j$ be the features (word IDs, UrduPhone IDs, or cluster IDs) for the top-5 frequently occurring words preceding word w_i and w_j , respectively. We use the similarity between the two words based on this context as defined by (Hassan et al., 2009):

$$\sigma_{ij}^C = \frac{\sum_{k=1}^5 \rho_k}{\sum_{k=1}^5 k} \quad (4)$$

340 Here, ρ_k is zero for any a_k^i (i.e., the k th word in the context of w_i) when there exists no match in a_k^j (i.e., in the context of word w_j). Otherwise, $\rho_k = 5 - \max[k, l] - 1$ where $a_k^i = a_l^j$ and l is the highest rank (smallest integer) at which a previous match has not occurred. In other words, this measure is the normalized sum of rank-based weights for matches in the two sequences, with more importance given to those occurring in higher ranks. Note that contextual similarity can be computed even if the context sizes of the two words are different, an essential step as a word may not have 5 distinct words preceding it in the corpus.

345 We combine all the features using our similarity measure from Eq. 1. The code for combining a set of features is mentioned in Algorithm 3.

3.4 Parameter Optimization

The feature weights $\alpha^{(f)}$ used to measure word similarity in Eq. 1 can be tuned to optimize prediction accuracy. For example, by changing the weights in our clustering framework (see Eq. 1), we can make contextual similarity more prominent (by increasing the weight α^C) so that words with the same UrduPhone encoding but different contexts are placed in separate clusters (see discussion in Section 4.4). But, we also test with other weight combinations and features, including using both word IDs and UrduPhone IDs to represent the top-5 most frequently occurring previous and next words (rather than just one representation as used in other experiments).

350 We identify corresponding weights for contexts based on word IDs and UrduPhone IDs as α^{C_1} and α^{C_2} , respectively. The weights for phonetic and string features are α^P and α^S , respectively.

Algorithm 3: Similarity measure with weighted feature combination

Input: w_i, w_j (input words), F (set of features used), α (set of feature weights)
Output: sim (similarity between w_i & w_j)

```

1  $total\_weight = 0$ ;
2  $sum = 0$ ;
3 if  $phonetic \in F$  then
4    $encoded_i = urduphone(w_i)$ ;
5    $encoded_j = urduphone(w_j)$ ;
6    $\sigma_{ij}^P = phonetic\_sim(encoded_i, encoded_j)$ ; // see Eq. 2
7    $sum = sum + \alpha^P \times \sigma_{ij}^P$ ;
8    $total\_weight = total\_weight + \alpha^P$ ;
9 end
10 if  $string \in F$  then
11    $\sigma_{ij}^S = string\_sim(w_i, w_j)$ ; // see Eq. 3
12    $sum = sum + \alpha^S \times \sigma_{ij}^S$ ;
13    $total\_weight = total\_weight + \alpha^S$ ;
14 end
15 if  $context \in F$  then
16    $prev_i = top5prev(w_i)$ ;
17    $prev_j = top5prev(w_j)$ ;
18    $\sigma_{ij}^{C1} = context\_sim(prev_i, prev_j)$ ; // see Eq. 4
19    $sum = sum + \alpha^{C1} \times \sigma_{ij}^{C1}$ ;
20    $total\_weight = total\_weight + \alpha^{C1}$ ;
21    $next_i = top5next(w_i)$ ;
22    $next_j = top5next(w_j)$ ;
23    $\sigma_{ij}^{C2} = context\_sim(next_i, next_j)$ ; // see Eq. 4
24    $sum = sum + \alpha^{C2} \times \sigma_{ij}^{C2}$ ;
25    $total\_weight = total\_weight + \alpha^{C2}$ ;
26 end
27 if  $word2vec \in F$  then
28    $vec_i = word\_vector(w_i)$ ; // see Section 4.3.5
29    $vec_j = word\_vector(w_j)$ ;
30    $\sigma_{ij}^W = cosine(vec_i, vec_j)$ ;
31    $sum = sum + \alpha^W \times \sigma_{ij}^W$ ;
32    $total\_weight = total\_weight + \alpha^W$ ;
33 end
34 if  $2skip1gram \in F$  then
35    $sigma_{ij}^G = 2skip1gram(w_i, w_j)$ ; // see Algorithm 5
36    $sum = sum + \alpha^G \times \sigma_{ij}^G$ ;
37    $total\_weight = total\_weight + \alpha^G$ ;
38 end
39  $sim = \frac{sum}{total\_weight}$ ;

```

We also optimize n variables to maximize an objective function using the Nelder-Mead method (Nelder and Mead, 1965). We use the Nelder-Mead method to maximize the F-measure by optimizing the feature weights of our Similarity function in Eq. 1, as well as **the hyperparameter, threshold t** , mentioned in Line 21 of Algorithm 1. We apply 10-fold cross-validation on the SMS (small) dataset (Table 9). We will describe the results in Section 4.3.4.

4 Experiments

In this section, we first describe our evaluation setup and the datasets used for the experiments. Later, we present the results.

4.1 Evaluation Criteria

Since the lexical normalization of Roman Urdu is equivalent to a clustering task, we can adopt measures for evaluating clustering performance. We need a gold standard database defining the correct groupings of words for evaluation. This database contains groups of words such that all words in a given group are considered lexical variations of a lexical entry. In clustering terminology, all words in a cluster are considered more similar to each other than to words in other clusters. On the other hand, accuracy (i.e., the proportion of OOV words that correctly match to IV words) is typically used to evaluate lexical normalization of a standardized language like English. This measure is appropriate because we know the IV words and can be compared to every OOV word.

Bagga and Baldwin (Vilain et al., 1995) discussed measures for evaluating clustering performance and recommend the use of BCubed precision, recall, and F-measure. These measures possess all four desirable characteristics for clustering evaluation (homogeneity, completeness, rag bag, and cluster size vs. number of clusters – see (Vilain et al., 1995) for details). In the context of lexical normalization of non-standard languages, they provide the additional benefit that they are computed for each word separately, and then averaged for all words. For example, if a cluster contains all variants of a word and nothing else, then it is considered homogeneous and complete, and this is reflected in its performance measures. These measures are robust in the sense that incorporating small impurities in an otherwise pure cluster impacts the measures significantly (rag bag characteristic), and trade-off between cluster size and number of clusters is reflected appropriately. Other clustering evaluation measures do not possess all these characteristics and, in particular, commonly-used measures like entropy and purity are not based on individual words.

Let $\mathcal{L} = \{\ell_1, \dots, \ell_K\}$ be the set of output clusters and $\mathcal{L}' = \{\ell'_1, \dots, \ell'_K\}$ be the set of actual or correct clusters in the gold standard. Then we define correctness for word pair w_i and w_j as

$$C(w_i, w_j) = \begin{cases} 1 & \text{iff } (\exists \ell_m \in \mathcal{L} \ \& \ \ell'_n \in \mathcal{L}' \ \text{such that } w_i \ \& \ w_j \in \ell_m \ \& \ \ell'_n) \\ 0 & \text{otherwise} \end{cases} \quad (5)$$

In other words, $C(w_i, w_j) = 1$ when words w_i and w_j appear in the same cluster (ℓ_m) of the clustering and the same cluster (ℓ'_n) of the gold standard; otherwise, $C(w_i, w_j) = 0$. By definition, $C(w_i, w_i) = 1$.

The following expressions give the BCubed precision $P(w_i)$ and recall $R(w_i)$ for a word w_i :

$$P(w_i) = \frac{\sum_{j=1}^N C(w_i, w_j)}{|\ell_m|} \quad (6)$$

$$R(w_i) = \frac{\sum_{j=1}^N C(w_i, w_j)}{|\ell'_m|} \quad (7)$$

Here, ℓ_m and ℓ'_m identify the cluster in the clustering and gold standard, respectively, that contain word w_i . The summation for Eq. 6 & Eq. 7 is over all the words j . Finally, we define the BCubed F-measure $F(w_i)$ of word w_i in the usual manner as:

$$F(w_i) = 2 \times \frac{P(w_i) \times R(w_i)}{P(w_i) + R(w_i)} \quad (8)$$

405 We compute the overall BCubed precision, recall, and F-measure of the clustering as the average of the respective values for each word. For example, we calculate the F-measure of the clustering as $\frac{\sum_{i=1}^N F(w_i)}{N}$.

4.2 Datasets

We utilize four datasets in our experimental evaluation. The first and second 410 datasets, SMS (small) and SMS (large), are obtained from Chopaal, an internet-based group SMS service.⁴ These two versions are from two different time periods and do not overlap. The third dataset, Citizen Feedback Monitoring Program (CFMP) dataset, is a collection of SMS messages sent by citizens as feedback on the quality of government services (e.g., healthcare facilities, property registration).⁵ 415 The fourth dataset, Web dataset, is scraped from Roman Urdu websites on news,⁶ poetry,⁷ SMS,⁸ and blogs.⁹ Unless mentioned otherwise, the SMS (small) dataset is used for the experiment. All four datasets are preprocessed with the following steps: (1) Remove single-word sentences; (2) add tags to URLs, email addresses, time, year, and numbers with at least 4 digits; (3) Collapse more than two repeating 420 groups to only two (e.g., *hahahaha* to *haha*); (4) Replace punctuations with space; (5) Replace multiple spaces with single space. For the SMS (small) and SMS (large) datasets, we carry out an additional step of removing group messaging commands.

We evaluate the performance of our framework against a manually annotated database of Roman Urdu variations developed by Khan and Karim (2012). This 425 database, which we refer to as the ‘gold standard’, is developed from a sample of the SMS (small) dataset. It maps each word to a unique ID representing its standard or normal form. There are 61,000 distinct variations in the database, which map onto 22,700 unique IDs. The number of variations differs widely for different unique IDs. For example, *mahabbat* [love] has over 70 variations such as *muhabaat*, *muhabbat*, 430 and *mhbtt*. The gold standard database also includes variations of English language words that are present in the dataset.

Table 3 shows statistics of the datasets in comparison with the evaluation gold standard database. The overlap of a dataset with the gold standard gives the number of words in the dataset that also appear in the standard database. The table

⁴ <http://chopaal.org>

⁵ <http://cfmp.punjab.gov.pk/>

⁶ <http://www.shashca.com>, <http://stepforwardpak.com/>

⁷ <https://hadi763.wordpress.com/>

⁸ <http://www.replysms.com/>

⁹ <http://roman.urdu.co/>

Table 3. *Datasets and gold standard database statistics*

Dataset	SMS (small)	SMS (large)	CFMP	Web
Message Count	159,158	1,994,136	183,083	5,423
Unique words	89,692	366,583	101,395	21,800
Overlap with Gold Standard (OGS)	57,699	51,477	23,112	12,634
OGS and context information ≥ 1	51,133	49,272	18,516	9,773
UrduPhone IDs Previous Case	11,146	9,738	4,683	6,171
OGS and context information ≥ 5	12,852	30,856	1,414	2,479
UrduPhone IDs for Previous Case	4,218	6,681	1,305	2,175

435 also gives the number of words that appear in the gold standard *and* have at least (1) one preceding and at least one following word (context size ≥ 1), and (2) five distinct preceding and following words in the dataset (context size ≥ 5). We evaluate these numbers of words for the respective datasets. The UrduPhone IDs of a dataset give the number of distinct encodings of the evaluation words in the dataset
440 (corresponding to the number of initial clusters).

4.3 Experimental Results and Analysis

We conduct different experiments to evaluate the performance of our clustering framework for lexical normalization of Roman Urdu. We test different combinations of features (UrduPhone, string, and/or, context) and different representations of contextual information (UrduPhone IDs or word IDs). We also establish
445 two baseline methods for comparisons.

Table 4 gives the details of each experiment’s setting. Exp. 1 and 2 are baselines corresponding to segmentation using UrduPhone encoding and string similarity-based clustering (with initial random clusters equal to the number of UrduPhone segments), respectively. The remaining experiments utilize different combinations of features (string, phonetic, and context) in our clustering framework. Here, for string-based features, we used manually defined edit distance rules.¹⁰ The initial clustering in these experiments is given by segmentation via UrduPhone encoding. In Exp. 3 no contextual information is utilized, while in Exp. 4 and Exp. 5 the context is defined
455 by the top-5 most frequently occurring previous and next words (context size ≥ 5) represented by their UrduPhone IDs and word IDs, respectively. In Exp. 2 to 5, we select the similarity threshold t such that the number of discovered clusters

¹⁰ Section 3.3.2 presents a comparison of using automatically learned edit distance rules with manually defined rules.

Table 4. Details of experiments' settings

Exp.	Initial clusters	String	Phonetic	Context
1	UrduPhone	✗	✗	–
2	Random	✓	✗	–
3	UrduPhone	✓	✓	–
4	UrduPhone	✓	✓	UrduPhone ID
5	UrduPhone	✓	✓	Word ID

is as close as possible to the number of actual clusters in the gold standard for each dataset. This is done to make the results comparable across different settings. During our experiments we observed that a threshold within a range of 0.25 – 0.3 was optimal for smaller datasets, including Web & CFMP, and 0.4 – 0.45 gave the best performance for larger datasets, including SMS (small) & SMS (large). However, we also tried to find the optimum threshold value using the Nelder-Mead method (see Table 9), which maximizes the F-Measure.

Figures 4a, 4b, 4c, and 4d show performance results on SMS (small), SMS (large), CFMP, and Web datasets, respectively. The x-axes in these figures show the experiment IDs from Table 4, while the left y-axes give the BCubed precision, recall, and F-measure, and the right y-axes describe the difference between the number of predicted and actual clusters.

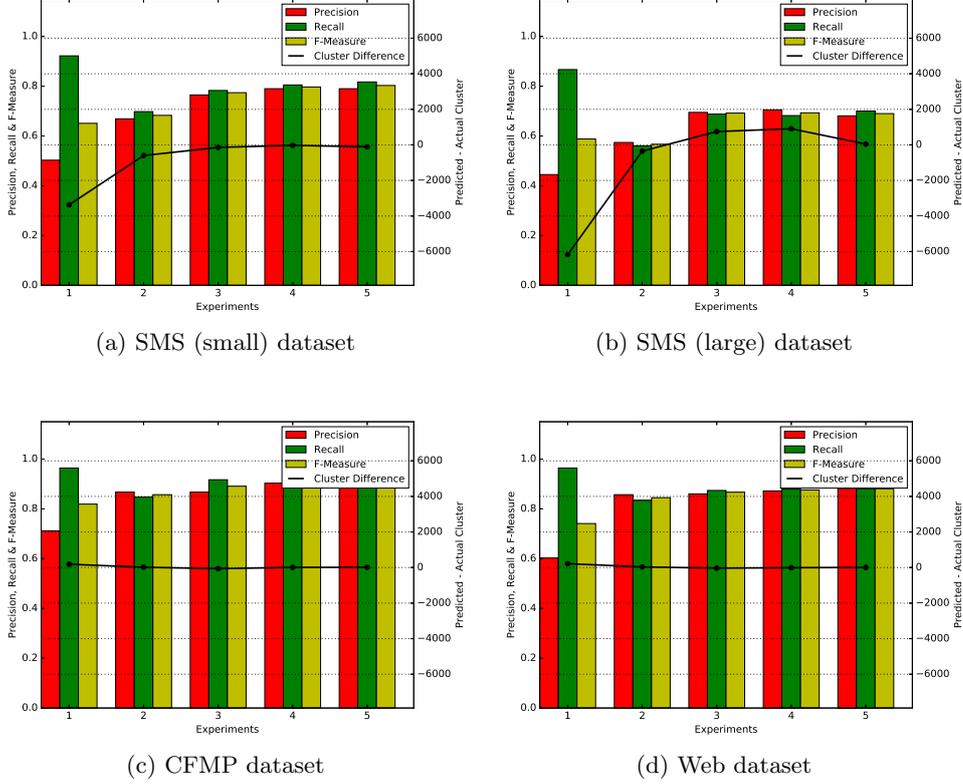
The baseline experiment of segmentation via UrduPhone encoding (Exp. 1) produces a high recall and a low precision value. This is because UrduPhone tends to group more words in a single cluster, which decreases the total number of clusters and results in an overall low F-measure. The second baseline of string-based clustering (Exp. 2) gives similar values for precision and recall since the average number of clusters is closer to that of the gold standard. Although the F-measure increases over Exp. 1, string-based similarity alone does not result in sound clustering.

Combining string and phonetic features in our clustering framework (Exp. 3) results in an increase in precision and recall values as well as a marked increase in F-measure from the baselines (e.g., there is an increase of 9% for the SMS (small) dataset, see Fig. 4a). When contextual information is added (via UrduPhone IDs in Exp. 4 and word IDs in Exp. 5), precision, recall, and F-measure values increase further. For example, for the SMS (small) dataset, the F-measure increases from 77.4% to 79.7% (2% gain) and from 77.4% to 80.3% (3% gain) from Exp. 3 to Exp. 4 and Exp. 5, respectively.

The higher performance values obtained for the CFMP and Web datasets (Fig. 4c and Fig. 4d) are due to fewer variations in these datasets, as evidenced by their fewer numbers of unique words in comparison to the SMS datasets.

Overall, our clustering framework using string, phonetic, and contextual features shows a significant F-measure gain when compared to baselines Exp. 1 and Exp. 2. We obtain the best performances when we use UrduPhone and string similarity, and when the context is defined using Word IDs (Exp. 5).

Fig. 3. Performance results for experiments in Table 4



4.3.1 UrduPhone

We compare UrduPhone with Soundex and its variants¹¹ for lexical normalization of Roman Urdu. All the phonetic encoding algorithms are used to group/segment words based on their encoding and then evaluated against the gold standard. Table 5 shows the results of this experiment on the SMS (small) dataset.

We observe that UrduPhone outperforms Soundex, Caverphone, and Metaphone while NYSIIS's F-measure is comparable to that of UrduPhone. NYSIIS produces a large number of single-word clusters (4,376 have only one word out of 6,550 groups), which negatively impacts its recall. UrduPhone produces fewer clusters (and fewer one-word clusters) giving high recall. This property of UrduPhone is desirable for initial clustering in our clustering framework, as Lex-Var can split them but cannot collapse them.

We also test our clustering framework by replacing UrduPhone with NYSIIS as the phonetic algorithm. In Exp. 5 on the SMS (small) dataset, we find that the

¹¹ We use Apache Commons Codec for DoubleMetaphone (<http://bit.ly/2fHTUBB>) & NLTK-Trainer's phonetic library (<http://bit.ly/10JGL9Q>) for the remaining

Table 5. Comparison of UrduPhone with other algorithms on the SMS (small) dataset. Single clusters are clusters with one word only. Actual clusters = 7,589

Algorithm	Precision	Recall	F-measure	Clusters	Single Clusters
Soundex	0.216	0.960	0.353	1,647	525
Metaphone	0.468	0.871	0.601	3,906	2,061
Double Metaphone Primary Encoding	0.295	0.931	0.448	2388	1008
Double Metaphone Alternative Encoding	0.280	0.927	0.430	2291	964
Caverphone	0.286	0.885	0.433	2,498	1,315
NYSIIS	0.584	0.668	0.623	6,550	4,376
UrduPhone	0.508	0.923	0.655	4,272	2,399

F-measure increases by only 5% over the NYSIIS baseline (Table 5), which is lower than the F-measure achieved with UrduPhone (Fig. 4a).

In another experiment, we analyze the effect of encoding length on the performance of the algorithm. We use the SMS (small) dataset to generate UrduPhone encodings of different sizes and cluster the words accordingly. Fig. 4 summarizes the results. We see an increase in F-measure with an increase in encoding length until length seven and eight where we achieve similar performance.

Fig. 4. Effect of varying UrduPhone encoding length on SMS (small) dataset (Exp 5)

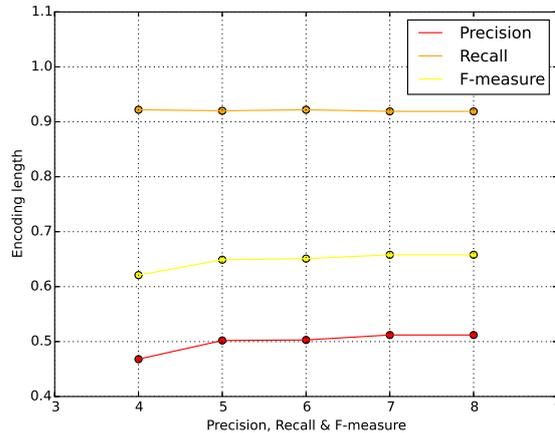


Table 2 defines the UrduPhone rules based on well known techniques used for phonetic encoding schemes (dropping vowels) and on common knowledge of how people write Roman Urdu. As an additional experiment, we try to learn these rules from some dataset and use them to define our encoding scheme. We call this

Table 6. *Experiments using UrduPhone, learning rules from Urdu-Roman Urdu transliteration corpus*

Features	Precision	Recall	F-measure
UrduPhone (Exp. 1)	0.508	0.923	0.655
UrduPhone + String + Context (Exp. 5)	0.790	0.817	0.803
UrduPhone _{prob}	0.503	0.922	0.651
UrduPhone _{prob} + String + Context	0.512	0.919	0.658

approach UrduPhone_{prob}. Jiampojarn et al. (2007) propose an alignment tool¹² based on the initial work of Ristad and Yianilos (1998). Instead of mapping each grapheme to a single phoneme, their method creates a many-to-many mapping. We use an Urdu script and Roman Urdu transliteration parallel corpus scraped from the internet.¹³ Unlike the Roman Urdu words in our experiment dataset, these have more standardized spellings. We use maximum length 2 as a parameter for training the model. Our output is probabilities of Roman Urdu characters mapping to Urdu script characters or to null.

We use the maximum probability mapping rules to define our UrduPhone_{prob} encodings. We experimented with using UrduPhone_{prob} as the feature in our system and also in combination with other string and context features. Table 6 shows the results.

4.3.2 String-similarity

In section 3.3.2, using the SMS (small) dataset, we compare the performance of three methods used to calculate edit distance cost – manually defined (edist_{man}), automatically learned using GIZA++ (edist_{giza}), and automatically learned using unsupervised transliteration mining (edist_{miner}).¹⁴

For each word in our vocabulary, we found 100 closest pairs, where closeness here is defined by our similarity function as described in Eq. 1 using UrduPhone, edist_{man} for the string similarity, and context of previous and next Word IDs as the feature set. We created a list of candidate word pairs by pairing every word with every other word in the cluster of 100 closest words. We use the candidate word list as input to the EM-based character alignment tools, GIZA++, and unsupervised transliteration mining. Here, GIZA++ considers every word pair in the list of candidate pairs as a correct word pair to learn character alignments, whereas the transliteration mining tool penalizes the pairs that are less likely to be transliterations of each other during the training process. Since our list of candidate pairs is a mix of correct and incorrect pairs, the character alignments learned by the transliteration miner

¹² <https://github.com/letter-to-phoneme/m2m-aligner>

¹³ <http://www.ijunoon.com/transliteration/>

¹⁴ The experiment reported in previous sections used the manually defined edit distance cost which associates cost of 1 for each insertion, deletion and substitution operation.

Table 7. Varying edit distance cost for SMS (small) dataset. Learning character pair alignment probabilities

String feature	Precision	Recall	F-measure
edist _{man} (Exp. 5)	0.790	0.817	0.803
edist _{giza}	0.786	0.817	0.802
edist _{miner}	0.794	0.813	0.803

are likely to be better. The edit distance cost for each pair of characters can be computed from character alignments as $cost(char_i, char_j) = |1 - P(char_i, char_j)|$. Our string similarity function uses these edit distance costs instead of manually defined costs. Table 7 reports the results for both of these experiments using the SMS (small) dataset. The F-measure of the cost learned by the miner and GIZA++ are competitive with the manually defined cost. edist_{giza} is affected by the noise in the data, which can be seen in its low precision compared to other methods. edist_{miner} achieved the highest precision, though it has the lowest recall.

4.3.3 Context Size

The experiments presented in the previous section used a context of top-5 frequently occurring previous and next words. Here, we study the effect of varying context size on the performance of our clustering framework. Table 8 shows the F-measure for all experiments with two different context sizes on the SMS (small) dataset. Decreasing the minimum context list size to one increases the number of words to evaluate; therefore, results are reported for all experiments with context size between 1 and 5, even though Exp. 1 to 3 do not use contextual information. Decreasing the minimum context list size to one also explains the lower performance values for these experiments as compared to those with context size of at least 5.

We see that context size of 1 to 5 (including words with contexts defined by at least 1 to 5 top previous/next words) is less effective in lexical normalization and sometimes even negatively impacts performance. For example, for the SMS (small) and CFMP datasets, Exp. 3 (no contextual information) performs better than Exp. 4 and Exp. 5 due to the noisy nature of shorter contexts.

For further analysis, we carried out experiments where we changed the context length from 1 to 5; an approach that differs from the previous experiments in which we used context size = 5 & ≥ 1 . Fig. 5 describes the results of the tests carried out on the SMS (small) dataset. We see a significant increase in performance when context size changes from 2 to 3. After 3, there is a slight performance increase. The best F-measure is from context size of 4 and 5.

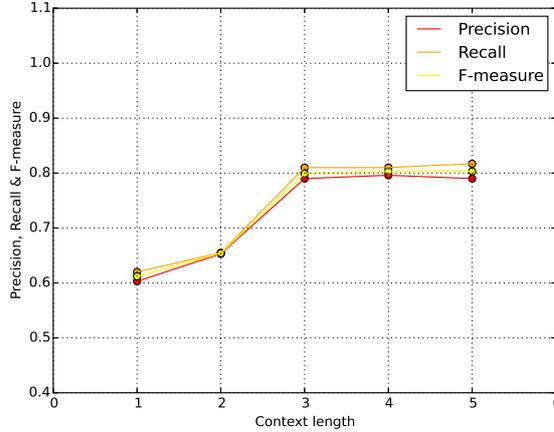
4.3.4 Parameters: Feature Weights and Clustering Threshold

Feature Weights As discussed in Section 3.4, we test the impact of changing the weights in our clustering framework (see Eq. 1). We assumed that all features have

Table 8. Performance (*F*-measure) with two different context sizes. Details of the experiments are given in Table 4.

Exp.	SMS (small)	SMS (large)	CFMP	Web
Context Size = 5				
1	0.651	0.588	0.852	0.831
2	0.683	0.567	0.857	0.845
3	0.774	0.692	0.891	0.867
4	0.797	0.693	0.900	0.876
5	0.803	0.690	0.917	0.881
Context Size = 1 to 5				
1	0.593	0.576	0.616	0.641
2	0.542	0.537	0.598	0.756
3	0.658	0.645	0.712	0.785
4	0.617	0.642	0.692	0.778
5	0.637	0.640	0.695	0.794

Fig. 5. Effect of varying context size on SMS (small) dataset (Exp 5)



equal weights in experiments presented in Section 4.3. Then, we change the feature weights to emphasize different features. The increased weights caused words to break their initial UrduPhone clusters in favor of better contextual similarity, but the overall performance did not change. We tried several combinations, including using both the contexts (i.e., word IDs and UrduPhone IDs).

Table 9 shows the performance of our clustering framework on the SMS (small) dataset with different feature weight combinations. As a comparison, we show results for Exp. 5 (context represented by word IDs only) and have the following observations with respect to F-Measure. (1) F-measure does not improve when using both word IDs and UrduPhone IDs to represent context. (2) F-measure degrades

Table 9. Performance with different weights for features (Exp. 5 on SMS (small) dataset). α^P = Weight of phonetic feature, α^S = Weight of string feature, α^{C_1} = Weight of context using Word ID, α^{C_2} = Weight of context using UrduPhone ID.

Experiment	Precision	Recall	F-measure
Exp. 5	0.790	0.817	0.803
Nelder-Mead method	0.797	0.843	0.819
$\alpha^P = 1.0, \alpha^S = 1.0, \alpha^{C_1} = 1.0, \alpha^{C_2} = 1.0$	0.777	0.814	0.795
$\alpha^P = 1.0, \alpha^S = 1.0, \alpha^{C_1} = 2.0, \alpha^{C_2} = 0.0$	0.784	0.810	0.797
$\alpha^P = 1.0, \alpha^S = 1.5, \alpha^{C_1} = 2.0, \alpha^{C_2} = 0.0$	0.801	0.812	0.807
$\alpha^P = 1.0, \alpha^S = 1.0, \alpha^{C_1} = 1.5, \alpha^{C_2} = 0.0$	0.801	0.811	0.806
$\alpha^P = 1.5, \alpha^S = 1.0, \alpha^{C_1} = 2.0, \alpha^{C_2} = 0.0$	0.701	0.819	0.805
$\alpha^P = 1.0, \alpha^S = 1.0, \alpha^{C_1} = 0.0, \alpha^{C_2} = 2.0$	0.768	0.781	0.774
$\alpha^P = 1.0, \alpha^S = 1.0, \alpha^{C_1} = 2.0, \alpha^{C_2} = 1.5$	0.736	0.763	0.749
$\alpha^P = 1.0, \alpha^S = 1.0, \alpha^{C_1} = 1.5, \alpha^{C_2} = 0.5$	0.793	0.809	0.801
$\alpha^P = 0.0, \alpha^S = 1.0, \alpha^{C_1} = 1.0, \alpha^{C_2} = 0.0$	0.754	0.758	0.756
$\alpha^P = 0.0, \alpha^S = 1.0, \alpha^{C_1} = 1.5, \alpha^{C_2} = 0.0$	0.710	0.726	0.717
$\alpha^P = 1.5, \alpha^S = 1.0, \alpha^{C_1} = 1.0, \alpha^{C_2} = 0.0$	0.802	0.811	0.807
$\alpha^P = 1.5, \alpha^S = 1.0, \alpha^{C_1} = 1.5, \alpha^{C_2} = 0.0$	0.804	0.813	0.808
$\alpha^P = 2.0, \alpha^S = 1.0, \alpha^{C_1} = 2.0, \alpha^{C_2} = 0.0$	0.813	0.809	0.811
$\alpha^P = 2.0, \alpha^S = 1.5, \alpha^{C_1} = 2.0, \alpha^{C_2} = 0.0$	0.791	0.815	0.803

when removing the phonetic similarity feature. (3) F-measure achieves the highest value when we set a higher weight to phonetic and contextual similarity than to string similarity.

590 We also use the Nelder-Mead method to maximize the F-measure by optimizing the feature weights of our similarity function in Eq. 1, as well as the threshold mentioned in line 21 of Algorithm 1 on cross-validation set (see Section 3.4). The average F-measure is slightly better than what we observed with manual selection of weights in Exp. 5 (described in Table 4).

595 *Clustering Threshold* We analyze the performance of Exp. 5 (best setting) for the SMS (small) dataset with varying threshold t (Fig. 6). The value of t controls the number of clusters smoothly, and precision increases with this number while F-measure reaches a peak when the number of predicted groups is close to that of the gold standard.

600 4.3.5 Comparison with Other Clustering Methods and Variations

In addition to our k-medoids based Lex-Var clustering method, we propose using agglomerative hierarchical clustering (Hierarchical Lex-Var) as our clustering framework for lexical normalization. To reduce the search complexity at each merge decision, we form (once) and search within the 10 most similar words for each word
605 (neighborhood). At each merge decision, we merge the two most similar words

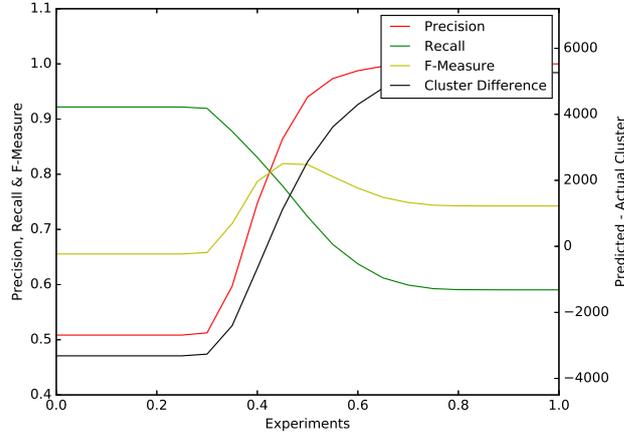
Fig. 6. Effect of varying threshold t on SMS (small) dataset (Exp 5)

Table 10. Performance of Hierarchical Lex-Var on SMS (small) dataset.

Experiment	Precision	Recall	F-measure
Exp. 5	0.790	0.817	0.803
Nelder-Mead method	0.797	0.843	0.819
Neighborhood= 10	0.793	0.837	0.815
Neighborhood= 100	0.771	0.849	0.808

and/or groups (if either word is part of a group) in their respective neighborhoods. Algorithm 4 describes the Hierarchical Lex-Var Clustering algorithm. We tested with a neighborhood size of 10 and 100. The results are mentioned in Table 10.

610 Hierarchical Lex-Var, when used instead of Lex-Var, results in slightly better performance, however, it is significantly slower than Lex-Var. Even with our neighborhood-based optimization, hierarchical clustering takes hours to converge, while our Lex-Var algorithm converges in minutes when processing the SMS (small) dataset.

615 Additionally, we compare our clustering framework with other clustering methods as independent approaches. We also test with variations in similarity features of our clustering framework. We report the following experiments:

- 620 1. Rule-based transliteration: Each word in the vocabulary was transliterated based on method by (Ahmed, 2009). The final words were mapped to an Urdu word dictionary of around 150,000 words¹⁵. Each Urdu word acted as a cluster label.
2. Brown clustering: Brown clustering is a hierarchical clustering method for grouping words based on their contextual usage in a corpus (Brown et al.,

¹⁵ <https://raw.githubusercontent.com/urduhack/urdu-words/master/words.txt>

Algorithm 4: Hierarchical Lex-Var

```

Input:  $\mathcal{W} = \{w_1, w_2, \dots, w_N\}$  (words),  $t$  (similarity threshold),  $K$  (neighborhood size)
Output:  $\mathcal{L} = \{\ell_1, \ell_2, \dots, \ell_K\}$  (predicted clusters)
1  $\mathcal{L} = \mathcal{W}$ ;
   /* Create a similarity matrix */
2 for  $\forall w_i \in \mathcal{W}$  do
3   | for  $\forall w_j \in \mathcal{W} \setminus w_i$  do
4   |   |  $Sim\_matrix_{i,j} = S(w_i, w_j)$ ;
5   |   end
6 end
   /* Create  $K$  sized neighborhoods for each word */
7  $\mathcal{N} = \{\}$ ;
8 for  $\forall w_i \in \mathcal{W}$  do
9   |  $n_i = get\_max\_k(Sim\_matrix_i, K)$ ; // Get  $K$  most similar words to  $w_i$ 
10  |  $\mathcal{N} = \mathcal{N} \cup \{n_i\}$ ;
11 end
12 repeat
13   | /* Assign word to clusters */
14   | for  $\forall w_i \in \mathcal{W}$  do
15   |   |  $closest = null$ ;
16   |   |  $maxSim = 0$ ;
17   |   | for  $\forall w_j \in \mathcal{N}_i$  do
18   |   |   | if  $S(w_i, n_j) > t$  and  $S(w_i, n_j) > maxSim$  then
19   |   |   |   |  $maxSim = S(w_i, n_j)$ ;
20   |   |   |   |  $closest = n_j$ ;
21   |   |   | end
22   |   | end
23   |   | if  $closest \neq null$  then // Move word  $w_i$  to cluster  $\ell_j$ 
24   |   |   |  $\ell_j = \ell_j \cup \{w_i\}$  |  $closest \in \ell_j$ ;
25   |   | end
26 until stop condition Satisfied;

```

1992). We use this as an independent approach for lexical normalization of Roman Urdu.

- 625 3. Word2Vec clustering: Word2Vec represents words appearing in a corpus by fixed length vectors that capture their contextual usage in the corpus (Mikolov et al., 2013). The Word2Vec model is generated using the gensim¹⁶ python package to learn vectors for each Roman word. For learning the word vectors, we used the minimum count of 5, dimension size of 100, and 10 iterations.
- 630 Words are clustered using K-Means clustering on word vectors and we report the performance for lexical normalization of Roman Urdu.
4. 2-skip-1-grams: In our clustering framework for lexical normalization, we use the 2-skip-1-gram approach with Jaccard coefficient (Jin, 2015) to compute string similarity (rather than our string similarity function (Eq. 3)). Algorithm
- 635 5 shows the 2-skip-1-gram algorithm.
5. 2-skip-1-gram + String feature: We use both 2-skip-1-gram and our string similarity functions for computing string similarity in our clustering framework for lexical normalization.
- 640 6. ‘h’ omitted UrduPhone: We use a modified version of UrduPhone in our clustering framework for lexical normalization. The modified version discards aspirated characters in the encoding. For example, encoding for *mujhay* [me] becomes identical to that for *mujay* [me] to handle ‘h’ omission.

¹⁶ <https://github.com/RaRe-Technologies/gensim>

7. Word2Vec Vectors (50): We generate Word2Vec vectors of size 50. We use the cosine similarity of these vectors instead of the contextual similarity described in Eq. 4.
8. Word2Vec Vectors (100): We increase the size of Word2Vec vectors to 100.
9. Word2Vec Words: Word2Vec vectors are used to find the 10 most similar words for each word. These neighboring words define the context of each word, and contextual similarity is computed using Eq. 4. We use our clustering framework for lexical normalization.
10. Word IDs + Word2Vec Words: We use two contextual features: top-5 frequently occurring previous/next words represented by word IDs (like in Exp. 5) and top-10 most-similar words according to Word2Vec (as above).

Table 11 summarizes the results. Experiment 1 is a rule-based lexical normalization method. Experiments 2 and 3 are independent clustering methods for lexical normalization. We also modify string feature (experiments 4 and 5), phonetic feature (experiment 6), and contextual feature (experiments 7, 8, 9, and 10), respectively, in our clustering framework.

Algorithm 5: 2-skip-1-gram

Input: w_i, w_j (pair of words)
Output: σ_{ij}^G (2-skip-1-gram similarity)

```

1  $m = \text{length}(\text{word}_i)$ ;
2  $A = \phi$ ;
3 for  $k \in 1, m - 2$  do
4    $X = \{\text{word}_i[k], \{\text{word}_i[k + 2]\}$ ;
5    $A = A \cup X$ ;
6 end
7  $n = \text{length}(\text{word}_j)$ ;
8  $B = \phi$ ;
9 for  $l \in \{1 \dots n - 2\}$  do
10   $Y = \{\text{word}_j[l], \{\text{word}_j[l + 2]\}$ ;
11   $B = B \cup Y$ ;
12 end
13  $\sigma_{ij}^G = \frac{|A \cap B|}{|A \cup B|}$ ;

```

We can make the following observations from these experiments. (1) Rule-based transliteration performs slightly lower than our clustering method (2) Brown clustering and Word2Vec clustering are unsuitable for lexical normalization as evidenced by their poor performance. (3) Word2Vec-based context (either Word2Vec vectors or similar words) and 2-skip-1-gram-based string feature do not outperform our context and string features. One possible reason for the low performance of Brown clustering and Word2Vec could be the small size of the training data. These algorithms require a huge amount of data to learn.

4.3.6 Lexical Normalization of English Text

To test the robustness of our dataset for other languages, we experimented with an English dataset provided by Derczynski et al. (2013) and used in the W-NUT 2015

Table 11. Performance of other clustering methods and variations in our framework on SMS (small) dataset.

	Experiment	Precision	Recall	F-measure
Other methods	Rule-based (Ahmed (2009))	0.833	0.765	0.797
	Brown clustering	0.024	0.447	0.046
	Word2Vec clustering	0.350	0.221	0.271
Additional features	2-skip-1-gram	0.782	0.810	0.796
	2-skip-1-gram + String feature	0.791	0.799	0.795
	'h' omitted UrduPhone	0.796	0.808	0.802
	Word2Vec Vectors (50)	0.782	0.802	0.792
	Word2Vec Vectors (100)	0.795	0.803	0.799
	Word2Vec Words	0.777	0.779	0.778
	Word IDs + Word2Vec Words	0.780	0.808	0.793

Table 12. Performance of Lex-Var on English dataset. We used Soundex & UrduPhone encodings as phonetic features

Language	Phonetic Encoding	Precision	Recall	F-measure
Roman Urdu (Exp. 5)	UrduPhone	0.790	0.817	0.803
English	Soundex	0.950	0.948	0.949
English	UrduPhone	0.967	0.961	0.965

670 task.¹⁷ The gold standard we used is the lexical normalization dictionary provided
 by the University of Melbourne.¹⁸ The dataset has more than 160,000 messages
 containing 60,000 unique words. After pre-processing (the same pre-processing steps
 as for the Roman Urdu datasets) we get a 2,700 word overlap with the gold standard.
 For the phonetic encoding, we tested with Soundex and UrduPhone.

675 Table 12 summarizes the results along with the best results for the Roman Urdu
 dataset from Table 4. We observe an F-measure of more than 90% with both en-
 coding schemes, with UrduPhone performing better than Soundex. This difference
 in performance is presumably due to the extended encoding size in UrduPhone,
 which makes it possible to keep more information about the original word.

680 4.4 Error Analysis

To gain a better understanding of our clustering framework, we analyze the output
 of different experiments with examples of correct and incorrect lexical normaliza-
 tion. While lexical normalization based on UrduPhone mappings (Exp. 1) is a good
 starting point for finding word variations, it produces some erroneous groupings.
 685 We summarize these groupings as follows:

¹⁷ <https://noisy-text.github.io/norm-shared-task.html>

¹⁸ available on the W-NUT 2015 website

1. Words that differ only in their vowels are in the same cluster:

- *takiya* [pillow], *tikka* [grilled meat], *take*
- *khalish* [pain], *khuloos* [sincerity]
- *baatain* [conversations], *button*
- 690 • *doosra* [another], *desire*
- *separate*, *spirit*, *support*

2. Same words having different consonants map to different groups:

- *mujhse*, *mujse* meaning [from me]
- *kuto*, *kuton* meaning [dogs]
- 695 • *whose*, *whoze*
- *skool*, *school*

3. Words whose abbreviations or short forms do not have the same UrduPhone mapping:

- *government*, *govt*
- 700 • *private*, *pvt*
- *because*, *coz*
- *forward*, *fwd*

Exp. 4 and Exp. 5 can separate words initially clustered incorrectly (group 1.) (e.g., *baatain* [conversations] and *button*, *spirit* and *support*) due to contextual information and similarity differentiating the variations. Despite using phonetic variations in combination with contextual feature we see incorrect clusterings in the two experiments. We can divide these inaccuracies into several groups.

1. Words that have different UrduPhone mappings but are in fact the same. These are not clustered in the final outcome.

- 710 • [*mujy*] and [*mujhy*] meaning [me]
- [*oper*] and [*uper*] meaning [up]
- [*prob*] and [*problem*]
- [*mornin*] and [*mornng*]
- [*number*] and [*numbers*]
- 715 • [*please*] and [*plx,plz*]

2. Words that have the same UrduPhone mapping and are lexical variants but are not clustered in the same group:

- [*tareeka*] and [*tareka*] meaning [way]
- [*zamaane*] and [*zamany*] meaning [times]
- 720 • [*msg*] and [*message*]
- [*mornng*] and [*morning*]
- [*complete,complet,complete*] and [*cmplt*]

3. Words that are different but have the same UrduPhone mapping and are clustered together:

- 725 • *maalik* [owner], *malika* [queen], *malaika* [angels]
- *nishaan* [vestige], *nishana* [target]
- *tareka* [way], *tariq* [a common name meaning 'a night visitor']

- *what, white*
- *waiter, water*

730 A closer look at the examples reveals that some words that have the same Urdu-Phone mapping and should cluster together are found in separate groups (group 2.). This result is due to low context similarity between the words, which causes them not to group (e.g., *tareeka* and *tareka* meaning [way] have a contextual similarity of 0.23, even though they have the same UrduPhone mapping).

735 Another prominent issue is that words in separate clusters in UrduPhone remain separated in the output of Exp. 4 and Exp. 5 (groups 2. and 3.). This observation highlights the point that our experiments do not perform well at handling abbreviations (e.g., *prob* and *problem*), plurals (e.g., *number* and *numbers*), and some phonetic substitutes (e.g., *please* and *plx*). Our framework separates Roman Urdu
740 words that can be written with an additional consonant (e.g., *mujy* and *mujhy* meaning [me]). It also maps words that start with a different vowel (e.g., *oper* and *uper* meaning [up]).

To tackle the issue of low contextual similarity not overcoming the difference in UrduPhone mapping, we doubled the weight assigned to the context feature. This
745 adjustment produces almost no change in overall performance when compared to standard (Exp. 4 and Exp. 5). However, this adjustment causes more words with different UrduPhone mappings to be clustered together, usually incorrectly:

- *acha* [okay], *nahaya* [bathe], *sucha* [truthful]
- *maalom* [know], *manzor* [approve]
- 750 • *chalang* [jump], *thapar* [slap]
- *darzi* [tailor], *pathar* [stone]
- *azmaya* [to try], *sharminda* [ashamed]

Furthermore, as the same UrduPhone mappings do not restrict the clusters, this variation produces interesting combinations. The words in the groups below, al-
755 though not lexical variants of each other, have strong contextual similarity and sometimes can even be replaced (for the other) in the sentence.

- *admi* [man], *larkay* [boys], *larki* [girl]
- *kufr* [to unbelieve in God], *shirk* [to associate partners with God]
- *shak* [suspicion], *yaqeen* [certainty]
- 760 • *loves, likes*
- *private, pvt*
- *could, may, would*
- *tue, tuesday, wed*
- *blocked, kicked*
- 765 • *gov, government*

5 Previous Work

Normalization of informal text messages and tweets has been a research topic of interest (Sproat et al., 2001; Kaufmann and Kalita, 2010; Clark and Araki, 2011;

Wei et al., 2011; Pinto et al., 2012; Ling et al., 2013; Sidarenka et al., 2013; Roy
770 et al., 2013; Chrupała, 2014; Desai and Narvekar, 2015), with the vast majority of
the work limited to English and other resource-rich languages. Our work focuses
on Roman Urdu, an under-resourced language, that does not have a gold standard
corpus with standard word forms. We restrict our task to finding lexical variations
775 of every other word in the corpus. Additionally, the spelling variation problem of
Roman Urdu inherits inconsistencies that occur due to the transliteration of Urdu
words from Perso-Arabic script to Roman script. In our work, we model these
inconsistencies separately and in combination with other features.

Researchers have used phonetic, string, and contextual knowledge to find lexical
780 variations in informal text.¹⁹ Pinto et al. (2012); Han et al. (2012); Zhang et al.
(2015) used phonetic-based methods to find lexical variations.

Contractor et al. (2010) used string edit distance based on longest common sub-
sequence ratio and edit distance of Consonant Skeletons (Prochasson et al., 2007)
of the IV-OOV words. Gouws et al. (2011) used a sizable English corpus to ex-
785 tract candidate lexical variations and re-score them based on lexical similarity. We
also use lexical similarity as a feature in our clustering framework but do not have
a reference to a Roman Urdu corpus with standard word forms. Jin (2015) also
generated an OOV-IV list by using the Jaccard Index (Levandowsky and Winter,
1971) between k -skip- n -grams of string s and standard word forms. As we do not
790 have these in Roman Urdu, we consider every word as a possible lexical variation
of every other word in the corpus. Similar to Jin (2015), we use k -skip- n -grams in
our additional experiments and find that they perform slightly worse than our al-
gorithm. Chrupała (2014) used Conditional Random Field (Lafferty, 2001) to learn
the sequence of edits from labeled data.

795 Han et al. (2012) used word similarity and word context to enhance performance
by initially extracting OOV (out-of-vocabulary) – IV (in-vocabulary) pairs using
contextual similarity and then re-ranking them based on string and phonetic dis-
tances. In contrast, we define a similarity function that considers all three features
together to find lexical variations of a word. Unlike previous approaches, we have a
800 small corpus from which to extract contextually similar word pairs. Also, there is no
standard Roman Urdu dictionary that can be used to annotate words as either IV
or OOV. Li and Liu (2014) defined similarity measure as a combination of longest
common subsequence, term frequency, and inner product of word embeddings. We
use longest common subsequence as part of the string similarity feature. In our
805 additional experiments, we test with cosine similarity of word embeddings (Table
11). Li and Liu (2014) used a combination of string similarity and vector-based
similarity to generate a candidate list, which was re-ranked using a character-level
machine translation model (Pennell and Liu, 2011) and Jazzy Spell Checker,²⁰ etc.

¹⁹ Spelling correction is also considered as a variant of text normalization (Damerou, 1964; Tahira, 2004; Fossati and Di Eugenio, 2007). Here, we limit ourselves to the previous work on short text normalization.

²⁰ <http://jazzy.sourceforge.net/>

Yang and Eisenstein (2013) used an unsupervised approach that learns string edit distance, lexical, and contextual features using a log-linear model and sequential Monte Carlo approximation.

(Singh et al., 2018; Bertaglia and Nunes, 2017) used word embeddings to find similar standard and non-standard words for text normalization. Chrupała (2014) used character-level neural text embeddings (Chrupała, 2013) as added information from unlabeled data for better performance. Rangarajan Sridhar et al. (2014) used deep neural networks to learn distributed word representations. We experimented with word embeddings as a feature in our similarity measure in the supplementary experiments Table 11.

Hany Hassan (2013) used a 5-gram language model to create a contextual similarity lattice and applied Markov random walk for lexicon generation. Their approach uses a linear combination of contextual feature and string similarity (longest common subsequence ratio and edit distance), which is very similar to our approach. However, unlike Hany Hassan (2013), we assume that every Roman Urdu word is a noisy word and thus can not separate nodes of the graph into standard and non-standard forms. Sproat and Jaitly (2017) used a recurrent neural network to normalize text. Pennell and Liu (2011); Li and Liu (2014) used a character-level machine translation system for the normalization task. Luseti et al. (2018) used an encoder-decoder architecture where different levels of granularity were used for the target-side language model, e.g. characters and words. Wang and Ng (2013) used a beam-search decoder with integrated normalization operations such as missing word recovery and punctuation correction to normalize non-standard words. Our work, however, is limited to grouping the lexical variations of Roman Urdu words. However, we do not have any labeled data or parallel data available to build such a translation system. Our proposed method is robust since it learns from user data and groups abbreviations and their complete forms together in one cluster.

Almeida et al. (2016) used a standard English dictionary and an informal English dictionary to normalize words to their root forms. In our case, we do not use a standard dictionary as one does not exist for Roman Urdu words. Ling et al. (2013) automatically learned normalization rules using a parallel corpus of informal text. Irvine et al. (2012) used manually prepared training data to build an automatic normalization system for Roman Urdu script. Unlike Irvine et al. (2012), we propose an unsupervised approach, which does not require labeled data. Additionally, our approach to the Roman Urdu normalization problem does not require us to have a corresponding Urdu script form for each Roman word.

Phonetic encoding schemes There have been several sound-based encoding schemes used in the literature to group similar sounding words together. Here, we summarized a few of the schemes in the context of lexical normalization.

The Soundex algorithm (Knuth, 1973; Hall and Dowling, 1980) encodes the first letter and the following three consonants of a word with consonants having the similar place of articulation sharing the same code. The NYSIIS method (Taft, 1970), designed by the New York Police for American names, employ more sophisticated encoding rules based on multi-character n-grams and relative vowel positioning.

The Metaphone algorithm (Philips, 1990), developed in 1990 as a Soundex variant, incorporates English pronunciation rules for phonetic encoding of words. Other, more-recent variations include Caverphone (Wang, 2009) and Double Metaphone;²¹ they include complex grammatical rules for phonetic encoding of words. The Double Metaphone algorithm also differs from others in that it generates up to two encodings for each word – one reflects the basic version of the word’s pronunciation, and the other reflects an alternative pronunciation based on other languages. This is particularly useful when comparing foreign names with their anglicized versions. For example, the names *Catherine* and *Katrina* have a common code *KTRN*. Previous algorithms like Metaphone and Soundex do not provide such a capability.

Most of these schemes are designed for English and European languages and are not sufficiently expressive, especially for lexical normalization or when applied to another family of languages.

We propose a method to find lexical variations in Roman Urdu that uses string edit distance like Contractor et al. (2010), sound-based encoding like Pinto et al. (2012), and contextual information like Han et al. (2012) combined in a discriminative framework. In contrast to previous work, our method does not use a resource of standard word forms to find lexical variations.

6 Conclusion and future work

Roman Urdu is a transliterated form of the Urdu language written in Roman script, used in informal communication in social media and SMS texts. It does not have a standard lexicon, which results in extensive use of lexical variations that hamper automatic processing. Our framework for lexical normalization of Roman Urdu is an unsupervised model meant to address this important issue. Our clustering framework incorporates customized phonetic encoding, string-based matching, and contextual similarity. Following an extensive evaluation of the framework on four real-world datasets and evaluations using a manually created database of lexical variations in Roman Urdu, we find that our framework effectively discovers lexical variations in Roman Urdu corpora with significantly better performance than baseline methods.

Our work brings us one step closer to automatically generating a normalized Roman Urdu corpus. We can cluster spelling variations of a word and then map them to the most frequent form, and can use this corpus to develop NLP applications. In the future, we would like to extrinsically evaluate our normalization procedure on several NLP tasks, such as POS tagging and machine translation.

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