Morpho-Syntactic Study of Errors from Speech Recognition System

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Abstract
The study provides an original standpoint of the speech transcription errors by focusing on the morpho-syntactic features of the erroneous chunks and of the surrounding left and right context. The typology concerns the forms, the lemmas and the POS involved in erroneous chunks, and in the surrounding contexts. Comparison with error free contexts are also provided. The study is conducted on French. Morpho-syntactic analysis underlines that three main classes are particularly represented in the erroneous chunks: (i) grammatical words (to, of, the), (ii) auxiliary verbs (has, is), and (iii) modal verbs (should, must). Such items are widely encountered in the ASR outputs as frequent candidates to transcription errors. The analysis of the context points out that some left 3-grams contexts (e.g., repetitions, that is disfluences, bracketing formulas such as “c’est”, etc.) may be better predictors than others. Finally, the surface analysis conducted through a Levenshtein distance analysis, highlighted that the most common distance is of 2 characters and mainly involves differences between inflected forms of a unique item.

Keywords: Automatic Speech Recognition; Error Analysis; Morpho-Syntactic Analysis

1. Introduction
Automatic speech recognition (ASR) systems take as input oral signal and produce as output a text version of the signal: the transcription of the signal in natural language. They make use of a speech model composed of acoustic, pronunciation and lexical n-gram models to decode the incoming speech stream. However the transcription process entails a number of errors, the speech model being able to handle at various level the ambiguity characterizing the spoken signal. Such ambiguity is due to various factors:

- Quality of the signal: low quality acquired from the telephone vs. high quality from radio news,
- Type of speech: prepared speech vs. spontaneous speech,
- Quality of speech: overlaps, fast speech due to stress or emotions, etc.,
- Out-Of-Vocabulary (OOV) items—especially foreign names—, etc.

In-depth description of the observing ASR errors are essential to characterize the variability intrinsic to the spoken language and to consider improved speech models (Adda-Decker and Lamel, 1999; Adda-Decker, 2006). Herein, instead of studying ASR errors causes, the current study focuses on the surface features of the errors so as to produce classes of errors. Our long run objective is to anticipate the impact of error classes on further NLP processes. The study described here is based on the work hypothesis that both speech transcription errors and their surrounding contexts are predictable of the regions likely to be problematic for ASR. An in-depth characterization of such regions may help to efficiently adapt language models. Whereas most of the studies on ASR errors considered the phenomenon from lexical or phonetic standpoints, we focus here on the morpho-syntactic structure of the erroneous regions. In this purpose, we provide an original morpho-syntactic taxonomy of the ASR speech errors, so as to categorize the unrecognized chunks as well as their larger contexts. Comparisons with error free contexts are also provided for an in-depth comprehension of local conditions inducing speech ambiguity and penalizing the ASR system. The following taxonomy would be also of valuable for various domains linked to automatic speech recognition such as speech understanding, named-entity recognition, question/answering systems, etc.

2. Related work
ASR transcription errors highlight speech regions which are problematic with respect to the ASR system’s decoding capacities. ASR errors have been mainly investigated in the framework of comparisons between automatic vs. human decoding of speech (Scharenborg, 2007; Lippmann, 1997). They pointed out that although today best ASR speech models are quite efficient, they have not yet reached the status of being able to perfectly take into account all observed acoustic variation, human listeners still outperforming them 5 to 6 times better (Vasilescu et al., 2012). The taxonomy of errors pointed out that some words are frequently subjects to ASR errors: in particular short, acoustically poor and frequent items lead to local ambiguity (Adda-Decker, 2006).

The homophony is particularly challenging for ASR systems, as underlined in (Vasilescu et al., 2012): such lexical items are both problematic for ASR systems and human listeners. Although a rich literature analyzed errors from the perspective of the ASR vs. human (in)capacities in decoding spoken signal, there is a lack of studies which consider the morpho-syntactic patterns of erroneous contexts. In the next sections, we propose a preliminary analysis of the morpho-syntactic characteristics of the errors in French compared with the error free contexts. Most largely we aim at investigating the global morpho-syntactic characteristics of a corpus of spoken data used in the French ANR ETAPE project (Gravier et al., 2012) and of the ambiguous regions which lead to erroneous ASR transcriptions.
3. Material and methods

3.1. Corpora

The study is based on a textual corpus in French consisting of manual and automatic transcriptions. The data were gathered in the framework of the ETAPE project (Gravier et al., 2012) and correspond to different audio sources manually and automatically transcribed by an ASR system (Bougares et al., 2013). A general description of the corpus is given in Table 1.

| Genre            | Source | # words | # distinct words | # Error spans |
|------------------|--------|---------|-----------------|---------------|
| TV News          | BS     | 64318   | 6946            | 3851          |
|                  | TQ     | 21896   | 3644            | 834           |
| TV Debates       | CVR    | 49033   | 5187            | 4374          |
|                  | ELL    | 54267   | 5670            | 4081          |
|                  | PF     | 43990   | 4481            | 2302          |
| TV Amusement     | PDV    | 2049    | 2645            | 3489          |
| Radio shows      | FrDeb  | 142417  | 12508           | 13752         |

Table 1: General description of the corpus depending on the source: BS (“BFM Story”), TQ (“Top Question”), CVR (“Ça Vous Regarde”), ELL (“Entre les Lignes”), PF (“Pile ou Face”), PDV (“La Place du Village”), French Debate (FrDeb)

Each sentence from each transcription has been aligned with the manual reference. The alignment highlights the error spans (Luzzati et al., 2014). An error span is defined as all the consecutive words in the hypothesis which are different from the reference. The error span level has been adopted in the current study (e.g., in contrast to the word level).

Figure 1 illustrates an extract from the data. For a given sentence, three levels of information are provided and considered in the analysis: the reference transcription (REF), the automatic transcription made by the system (HYP) and the description of the types of errors within each span (that is D=deletion, I=insertion, S= substrate).

Table 2 underlines the frequencies inside an error span in comparison with the frequencies in the whole corpus for some of the most frequent forms found in an error span.

![Figure 1: Extract from the aligned corpus](image)

Global statistics on the corpus show that 21% of tokens are involved in an error span. The errors consist either in a substitution (49%), a deletion (35%) or an insertion (16%).

3.2. Methods

3.2.1. Presentation

This study is based on the hypothesis that erroneous spoken regions and their surrounding contexts convey some salient and predictive information about potentially ambiguous chunks for ASR. To gather as much as possible information about such chunks we are conducting an in-depth morpho-syntactic analysis. Three levels are then considered: (i) basic morpho-syntactic analysis (token, lemma, POS), (ii) contextual analysis (within the error span, on the left or on the right of the error span), and (iii) analysis based upon the edition distance of characters (distance frequency and POS involved).

The morpho-syntactic tagging has been made with the Tree Tagger (Schmid, 1994). This tool is known to be poorly adapted to process speech transcriptions which may involve repetitions and erroneous solutions. Nevertheless, for this preliminary study we make use of tagged data without a post-processing phase, in order to avoid potential new errors.

3.2.2. Issues

Morpho-syntactic analysis. The morpho-syntactic analysis is aimed to provide insights about the forms, lemmas and POS occurring in an erroneous chunk. The following questions have been addressed.

- Which forms, lemmas and POS are the most frequent in error spans?
- Which forms, lemmas and POS obtain the higher error percentage out of the whole corpus?
- Does the most frequent POS in the error spans represent the most frequent lemmas and forms?
- Does the form that achieve the highest error percentage belongs to the POS and the lemma that also achieve the highest error percentage?

Contextual analysis. Alongside with the error span analysis a contextual similar investigation have been also conducted to answer to the following points:

- Which n-gram and POS sequences are the most frequent on the left and right context of the error spans?
- Does the most frequent n-gram sequences correspond to the most frequent POS?
- Which kind of sequence precedes/follows an error span?
- Which kind of semantic information can we infer from an error span?

Surface analysis. At last, the edition distance is conducted to estimate the mean number of modifications to process from an erroneous string to a correct string, and the most frequent POS concerned with high distance editions.

4. Results

4.1. Error span analysis

In this section an overview of the main results is provided. Table 2 underlines the frequencies inside an error span in comparison with the frequencies in the whole corpus for some of the most frequent forms found in an error span.
4.2. Contextual analysis

4.2.1. Left context of an error span

Sequences of forms. In this sections we focus on the contextual analysis. The context is viewed here as the forms, lemmas and POS at left and right sides of an erroneous span. It is analyzed increasingly (from one item left/right to 3 items left/right) as to evaluate the impact of the increasing surrounding information in erroneous chunks prediction. Table 4 provides the frequencies of sequences of one, two or three forms in the whole corpus and in the left context of an error span.

Sequences of POS. Table 5 underlines the frequencies of sequences of one, two or three Part-of-Speech in the whole corpus and in the left context of an error span.

4.2.2. Right context of an error span

Sequences of forms. Table 6 underlines the frequencies of sequences of one, two or three forms in the whole corpus and in the right context of an error span.

Sequences of POS. Table 7 underlines the frequencies of sequences of one, two or three Part-of-Speech in the whole corpus and in the right context of an error span.

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1 We used the following POS abbreviations: Adj (adjective), Adv (adverb), Conj (conjunction), Det:art (article), Name (proper name), Pro:dem (demonstrative pronoun), Pro:per (personal pronoun), Pro:rel (relative pronoun), Subst (substantive), Ver:info (verb at infinitive), Ver:pres (verb at present tense).
Table 7: Frequencies of sequences of 1, 2 or 3 POS in the whole corpus and in the right context of an error span

| Sequence (1, 2, 3 POS) | Corpus | Context | Ratio |
|------------------------|--------|---------|-------|
| ... Prep               | 37,089 | 2,860   | 7.7%  |
| ... Prep Prep          | 1,169  | 138     | 11.8% |
| ... Pro:per Pro:per    | 6,021  | 564     | 9.4%  |
| ... Pro:dem Pro:rel    | 1,884  | 177     | 9.4%  |
| ... Pro:dem Pro:rel Pro:per | 921   | 97      | 10.5% |
| ... Prep Det:art Subst| 7,716  | 597     | 7.7%  |
| ... Pro:rel Pro:per Ver:pres | 1,960 | 112  | 5.7%  |

4.3. Surface analysis

Figure 2 shows the edition distance according to Levenshtein’s algorithm (Levenshtein, 1965), in terms of characters between the correct and the erroneous forms in an error span.

Figure 2: Edition distance in characters between erroneous and correct forms

5. Discussion

5.1. Forms in error spans

In this section some trends highlighted by the morpho-syntactic analysis are mentioned. As shown in Table 2, the most frequent forms in the error spans correspond to grammatical words that is short, acoustically poor and subject to homophony items, which are good candidates to recognition errors as underlined in (Adda-Decker, 2006).

While the most frequent POS category in the corpus is substantives (20.74% of all categories\(^3\)), followed by personal pronouns (9.15%) and prepositions (9.06%), three main classes are particularly represented in the erroneous chunks: (i) grammatical words (to, of, the), (ii) auxiliary verbs (has, is), and (iii) modal verbs (should, must).

The table confirms the trends highlighted by the analysis of word frequencies (see Table 2) and by previous studies both in ASR output analysis and comparison with humans (Vasilescu et al., 2012).

However, it is worth noticing that some word classes occur more frequently in an error span than others: for instance, the category of the proper names is frequently unrecognized by the system (9.3% of proper names are within an error span).

Paronyms are also good candidates to ASR errors:

- “if” [il] (he) / “y” [i] (there)
- “et” [e] (and) / “est” [e] (is)
- “a” [a] (has) / “à” [a] (to)
- “un” [ü] (a, one) / “en” [ë] (in) / “on” [o] (one)

5.2. Contexts

One may notice that the salient information is provided by (at least) two items in particular at the left side of the error span. The left 3-grams suggest that some contexts (e.g. repetitions, that is disfluencies, bracketing formulas such as “c’est” etc.) may be better predictors than others (see Table 4). Among the most frequent sequences at the left side of an error span, several syntagms have a bracketing role, that is they introduce information (c’est/’est pas, it is/it is not, est à dire, to say). Speech disfluencies and in particular repetitions may also occur (les les, the the). Such phenomena are spontaneous speech proper.

At last, the contexts also involved (more frequent) substantives and proper names (départements, departments, Roche sur Foron\(^4\)).

The analysis of the left and right contexts points out that grammatical words are the most frequent neighbors of an erroneous span (Table 5 and 7). They also occur within disfluent regions suggesting that speakers’ difficulties in building the verbal message may involve less accurate pronunciations and then errors.

The same contextual analysis conducted in terms of POS (Table 5 and 7) underline the high frequency of short words, potential candidates to transcription errors.

Finally, one may notice the similarity between erroneous and error free regions close to the erroneous spans: the most frequent items present in erroneous span are also present as surrounding context suggesting that a “fragile” chunk in terms of morpho-syntactic characteristics may anticipate an error.

5.3. Surface analysis

Finally, concerning the surface analysis conducted through a Levenstein distance analysis, the maximum distance is of 256 characters, which corresponds to a deletion of a whole sequence. The most common distance is a distance of 2 characters, which mainly involves inflection differences between an infinitive and a past participle in French or between singular and plural of names and adjectives. This finding suggest that the most frequent errors in French do not necessarily affect the content of the message.

\(^{3}\)This percentage corresponds to the 84,873 substantives found in the corpus out of the total number of 409,185 tokens.

\(^{4}\)La Roche-sur-Foron is the name of a town in Savoie, France.
6. Conclusion
Nowadays ASR systems reached high levels of accuracy, however speech transcription errors still occur. Several studies on the speech transcription errors have been conducted during the last decade, mainly focusing on the frequency of the lexical items concerned and on the acoustic patterns of the items likely to be unrecognized. In our paper we provide an original standpoint of the phenomenon by focusing on the morpho-syntactic features of the erroneous chunks and of the surrounding left and right contexts. The typology concerns the forms, the lemmas and the POS involved in erroneous chunks, and in the surrounding contexts. Comparison with error free contexts are also provided. The study is conducted on French. Findings comfort previous observations about the presence of grammatical words among the most frequent missrecognized items. Results also underline the presence of such items before and after an erroneous span as well as the presence of “fragile” contexts (e.g., disfluences) as predictors of erroneous regions. However, the analysis of surface forms (Levenshtein analysis) points out the high frequency of errors of level 2 (2 characters difference) which correspond to inflection differences. The long run aim is to make use of such investigation as to improve language models. Similar work will also be conducted on different corpora and languages as to lead to an in-depth comprehension of the speech transcription errors.

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