An Open and Extensible Platform for Machine Translation of Spoken Languages into Sign Languages

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Abstract. The purpose of this paper is to investigate the feasibility of offering a multilingual platform for text-to-sign translation, i.e., a solution where a machine translates digital contents in several spoken languages to several sign languages in scenarios such as Digital TV, Web and Cinema. This solution called **OpenSigns**, is an open platform that has several common components for generic functionalities, initially originated from the **Suíte VLibras**, including the creation and manipulation of 3D animation models, and interchangeable mechanisms specific for each sign language, such as a text-to-gloss machine translation engine, a sign dictionary for each sign language, among others. Our motivation is that the concentration of efforts and resources around a single solution could provide some state-of-the-art improvement, such as a standard solution for the industry and a greater functional flexibility for common components. In addition, we could also share techniques and heuristics between the translation mechanisms, reducing the effort to make a new sign language available on the platform, which may further enhance digital inclusion and accessibility, especially for poorest countries.

Keywords: Digital video · Online video · Accessibility · Sign language Machine translation

1 Introduction

In Brazil, according to the 2010 census of the Brazilian Institute of Geography and Statistics (IBGE), there are approximately 9.7 million Brazilians with some type of hearing loss, representing 5.1% of its population [9]. The World Health Organization estimates that approximately 360 million people worldwide have some level of hearing loss [13].

This relevant part of the population faces several challenges in accessing information, usually made available through written or spoken language. The main problem is that most deaf people spend several years in school, but are not proficiency in reading and writing the spoken language of their country. One of the possible explanations is the fact that these languages are based on sounds [16].

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A study carried out in 2005 with 7 to 20 years old Dutch deaf persons found that only 25% of them had a reading capacity equal or greater than a 9-year-old child without disability [18].

One of the reasons for this difficulty is that the deaf communicate naturally through sign languages (SL), and spoken languages are only a "second language". Each SL is a natural language, with its own lexicon and grammar, developed by each deaf community over time, just as each hearing community developed its spoken language. Thus, there is no unique SL. Although there are many similarities between all these languages, each country usually has its own, some even more than one - by 2013, there were already over 135 sign languages cataloged around the world [1].

In order to allow adequate access, one solution is to translate/interpret spoken contents into the associated SL. However, considering the volume and dynamism of information in some environments and platforms, such as on the Web, performing this task using human interpreters is not viable, considering the high volume of content that is added daily on the Internet. In the context of Digital TV, the support for sign languages is generally limited to a window with a human sign language interpreter, which is displayed overlaying the video program. This solution has high operational costs for generation and production of the contents (cameras, studio, staff, among others), needs full-time human interpreters, which ends up restricting its use to a small portion of the programming. To address this question pragmatically, one of the most promising approaches today is the use of tools for machine translation of a spoken language into a SL.

Proportionately to the number of SL, there are also numerous parallel initiatives to build machine translation tools for these SLs, usually focused on the scope of a single language/country, some even competing with each other. Most of these text-to-sign machine translation tools, although conducted completely independently in their respective countries, have similarities in approach, scope, and architecture. In general, the basic functionalities are present in some form in most of them. Steps such as extraction of the text to be translated from audio and subtitles, generation of the sign language video, incorporation of the sign language videos into the original videos (e.g., on Digital TV), spelling and rendering of glosses by plugins and mobile applications, etc. There are also similarities in the structure and behavior of components, such as APIs and backends of communication, translation and control, etc.

The main points of variation are usually the specific mechanism of translation and the dictionary of signs of the language (visual representation of signs). For the latter and considering the use of avatars, the modeling process of visual represention is similar (e.g., a set of animations) and usually depends on the allocation of financial and human resources, regardless of the technology used.

To reduce this problem, the objective of this paper is to propose an open, comprehensive and extensible platform for *text-to-sign* translation in various usage scenarios and countries, including Digital TV. In the proposed platform, the common components share generic functionalities, including the creation and manipulation of the dictionaries.

Only the translation mechanism and the dictionary itself are interchangeable, being specific to each SL. To accelerate the development, we used the Suíte VLibras[1] as a basis.

Our motivation is the concentration of efforts and resources around an unique solution that can be able to provide cutting edge gains, such as the definition of patterns for the industry standard and greater functional flexibility for the common components, and also allow advances in the state-of-the-art, such as sharing techniques and heuristics among translation mechanisms.

A single standardized platform with centralized processing of multiple sign languages can also serve as a catalyst for more advanced translation services, such as incorporating text-to-text conversion. In this sense, available translation mechanisms between spoken languages can be integrated to allow Deaf in Brazil or Spain to understand, in Brazilian Sign Language (LIBRAS) or Spanish Sign Language (LSE), respectively, a text in English, for example.

Another contribution is to leverage the emergence of a common core rulebased translator that can be extended/adapted to meet new languages and regionalisms. Reducing the effort to make a new SL available may further enhance digital inclusion and accessibility, in technologies such as Digital TV, Web and Cinema, especially in the poorest countries.

The remainder of the paper is organized as follows. Section 2 lists some of the machine translation tools available in the scientific literature. Section 3 presents the proposal generic platform for machine translation of spoken language to sign language. Section 4 presents a prototype of the proposed platform as proof of concept. This prototype accepts input texts in any spoken language and translates into three target sign languages. Section 5 finally brings our conclusion and final remarks.

2 Machine Translation Platforms for Sign Languages

Machine translation systems for sign language are generally divided into three main classes: Rule-Based Machine Translation (RBMT), Statistical Machine Translation (SMT) and Example-Based Machine Translation (EBMT) [17]. One important challenges of such systems is to ensure that the content available to Deaf has the same consistency and quality of the original content, allowing the adequate understanding of the message.

Considering these systems may be a viable alternative to minimize the marginalization of Deaf, especially through digital inclusion, several researches have been developed around the world focusing on the development and offering of operational platforms for machine translation of spoken languages into SL [2, 4].

[1] The **Suíte VLIBRAS** is the result of a partnership between – removed for blind review, and consists of a set of tools (text, audio and video) for the Brazilian Sign Language (LIBRAS), making TVs, computers, mobile devices and Web platforms accessible to deaf. Currently, VLibras is used in several governmental and private sites, among them the main sites of the Brazilian government (brasil.gov.br), Chamber of Deputies (camara.leg.br) and the Federal Senate (senado.leg.br). Further information can be obtained from http://www.vlibras.gov.br.

In Brazil there are at least four platforms available for machine translation of Brazilian Portuguese digital contents into LIBRAS: **Suíte VLibras** [7, 8], **HandTalk** [3], **ProDeaf** [5] e **Rybená** [6].

The **Suíte VLibras** consists of a set of open source computational tools, responsible for machine translating digital content into Brazilian Portuguese for LIBRAS, making the information available on computers, TVs, mobile devices and Internet portals accessible to Deaf. The VLibras main components are:

- *VLibras-Plugin*: a browser extension that allows the translation of any selected text to LIBRAS;
- *VLibras-Mobile*: VLibras clients for mobile devices (both iOS and Android);
- *VLibras-Desktop*: is a Tool used to translate into sign language any marked text taken from applications running on personal computers;
- *VLibras-Video*: is a portal that allows translation to LIBRAS of audio tracks or subtitles associated with videos;
- *LibrasTV:* an adaption of VLibras for the Brazilian Digital TV system.

3 OpenSigns: A Proposal of a Multilingual Machine Translation Platform

It is a consensus that machine translation does not match the quality of a human interpreter in capturing and transmitting all the nuances of a message. However, the use of glosses and animation can be a complementary and practical solution, especially when human interpreters are not available or are not feasible.

In this sense, the main contribution of our work was the transformation of a complete platform of automatic translation from Brazilian Portuguese (written or spoken) to LIBRAS, called VLibras, into an extensible platform, called OpenSigns.

The new platform can be expanded with the addition of new text-to-gloss translators with support for other pairs of spoken languages and sign languages. In the restructuring of the platform, an additional step of automatic text-to-text translation was also included in order to extend the scope of each specific text-to-gloss translator to other input languages.

During our study, we identified that a number of features of the original platform (VLibras) were agnostic regarding input and output languages and possibly applicable to other contexts directly. Thus, among the technological tools already available in the generic platform (OpenSigns), we can mention:

- **Plug-ins** for many popular browsers that allow texts on web pages to be captured, submitted to a remote text-to-gloss translator and the resulting glosses rendered by an avatar (Fig. 1).
- **TV applications** for the most popular platforms that allow the presentation of sign language contexts available on Digital TV signal.
- **Mobile applications** for the two most popular platforms that allow the translation and rendering of signals from an input text, also using a remote text-to-gloss translator (Fig. 2).

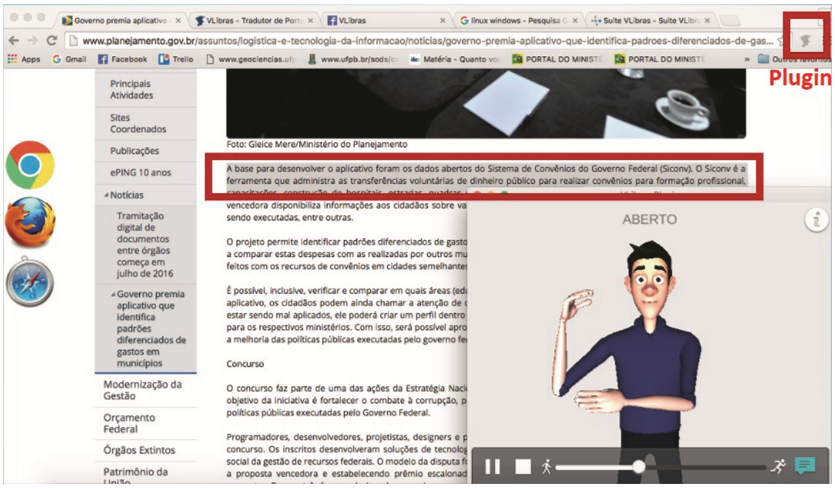

Fig. 1. VLibras Plugin

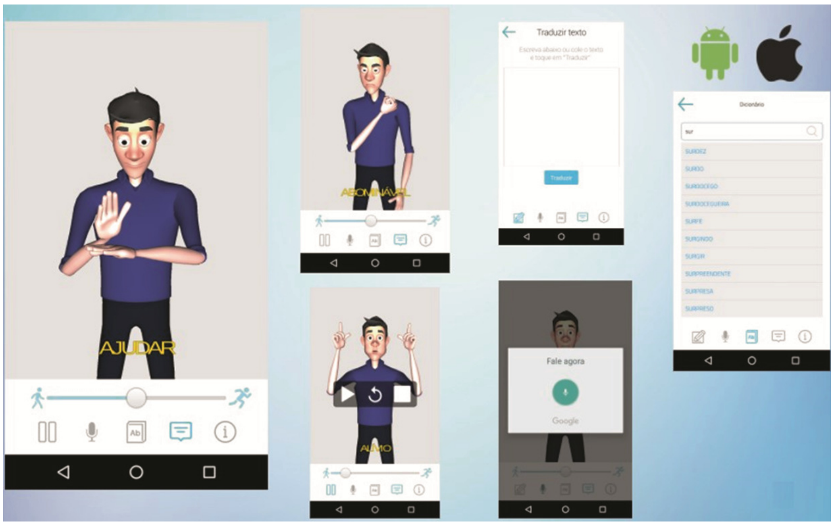

Fig. 2. VLibras Mobile

– **Desktop applications** for major operating systems that allow content from multiple sources on the user's computer to be translated and rendered offline (Fig. 3).
– **Extraction mechanisms** of texts from audio and videos for later translation text-to-gloss.
– A **web portal** for on-demand text translation, performed by an internal text-to-gloss translator.
– A **web portal** for video translation resulting in a new video with a signal language window synchronized with the original audio (Fig. 4).

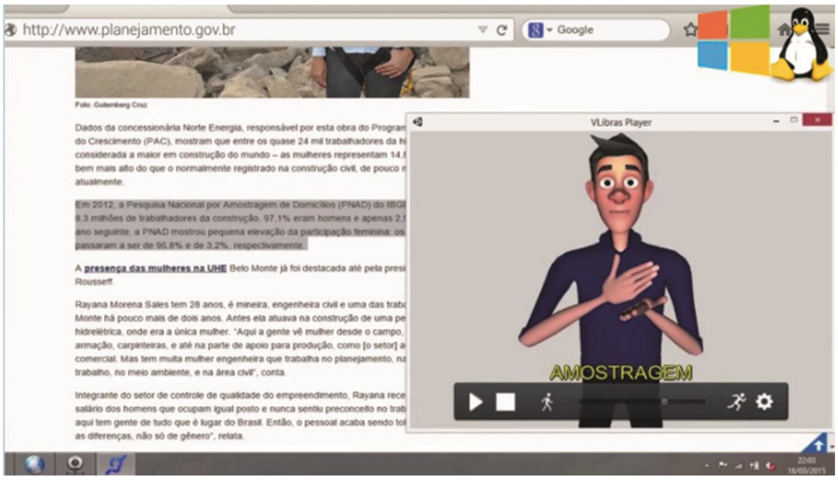

Fig. 3. VLibras Desktop

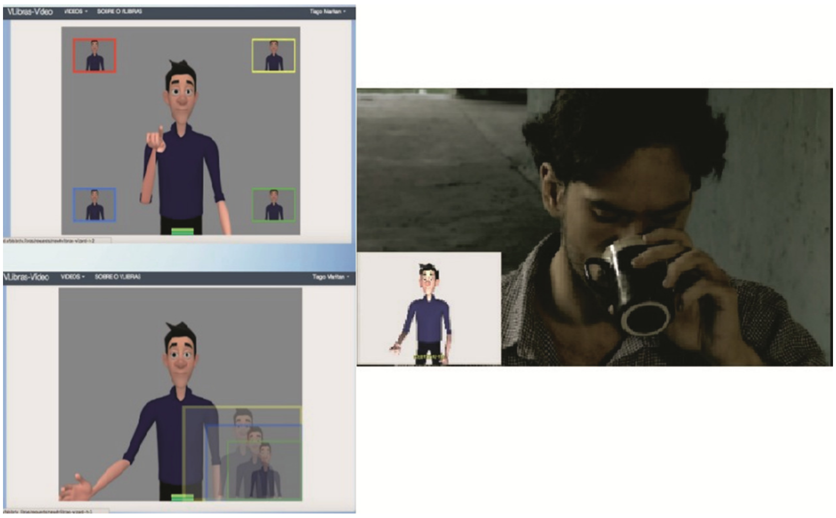

Fig. 4. VLibras Video

An integrated set of tools like this for machine translation using avatars is not easy to build and we believe that few initiatives in the world have such reach and penetration, with a dictionary with more than 13,500 LIBRAS 3D modeled signs. With the effort of generalization practiced in this work, this framework is available to be extended and used in other countries and languages.

The main effort to include the treatment of a new sign language is the creation of the 3D sign language dictionary and the addition of the associated text-to-gloss translator. The text-to-gloss translation components have been carefully isolated on the new platform so they can be easily retrofitted and/or replaced.

In this sense, the focus of this research was to validate previously three aspects of the new platform:

– If the new text-to-text translation step, which converts any spoken language into the reference spoken language of the desired sign language, inserts too much noise into the quality of the generated gloss;
– If the process of incorporating new text-to-gloss translators is feasible and simplified;
– If the process of setting up a new text-to-gloss translator (for example, ASL) using the generic internal translator with morphological, semantic and syntactic treatment is feasible.

The experiments and comparison of the obtained results were concentrated in the result of the gloss obtained automatically with respect to the glosses produced by human interpreters. They considered results in previous works, including validated in real experiments done with users.

4 Proof of Concept: Text Translation in Any Language for LIBRAS, LSE or ASL

4.1 Prototype Architecture

We started with an initial assessment that good part of the **Suíte VLibras** components had generic features that could be shared among several sign languages with minor changes. The main changes needed were aimed at making the components that access the translation services "agnostic", ie, independent of the input and output languages. In addition, we also focused on enabling the solution to support multiple machine translation engines and multiple sign dictionaries.

Figure 5 illustrates the architecture of the *VLibras Suite* [8]. Initially, it only translated content from Brazilian Portuguese to Libras.

Figure 6 presents an adapted version of the original architecture, which includes support for multiple source and target languages. In the new architecture shown, the components highlighted in orange and red represent the points of variance and have been rebuilt to support multiple input and output languages.

The components in blue had their basic behavior maintained. The minor adjustments required are related to the generalization and internationalization of their interface.

4.2 Prototype Implementation

To develop a proof of concept of the proposal platform, initially, we developed a translator prototype able to translate texts into any spoken language of source into three target SLs: LIBRAS, LSE and ASL.

The text-to-text pre-translation module was created using the Google Cloud Translation API[2], to convert texts in any spoken language into Portuguese, Spanish or English depending on the target sign language.

[2] This API is able to identify the input language of a sentence and translate it automatically into a target spoken language (www.google.com/translate).

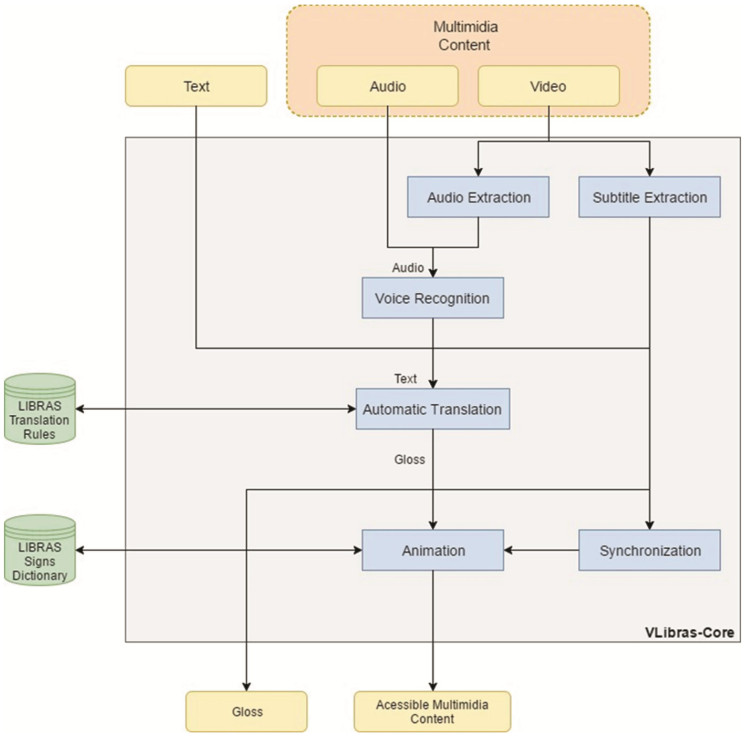

Fig. 5. Internal architecture of *VLibras*

Then, the text-to-gloss translation module was adapted to support the translation of sentences in Brazilian Portuguese (BP), English or Spanish for a sequence of glosses

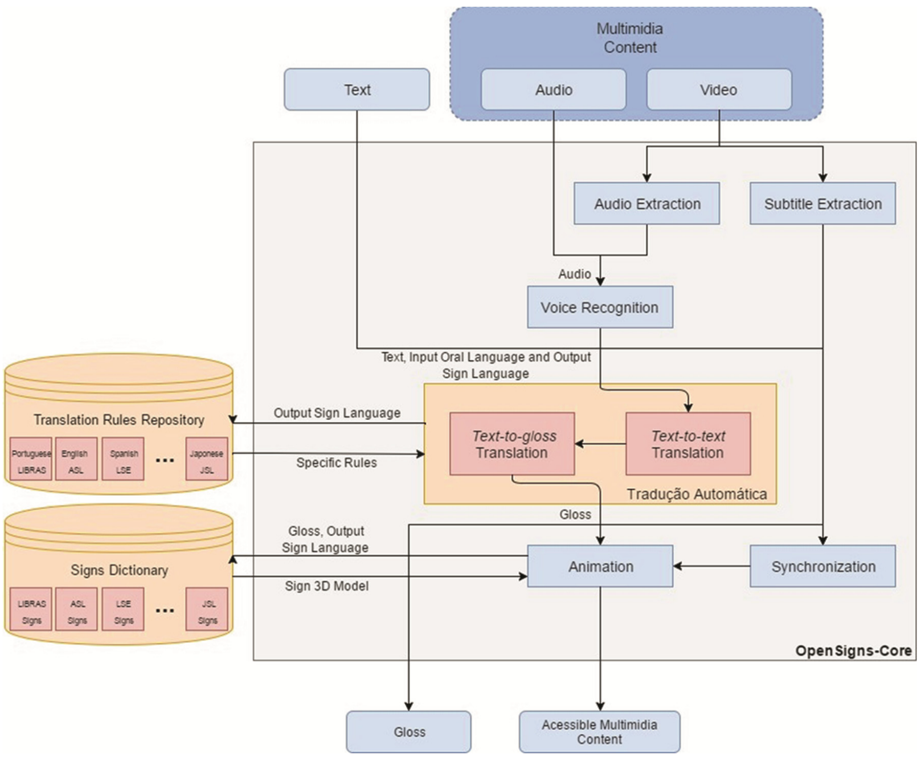

Fig. 6. Internal architecture of *OpenSigns* (Color figure online)

into LIBRAS, ASL or LSE respectively. The tokenization (i.e., the separation of words from each sentence) in English or Spanish languages was made specifically for each of them, taking into account their own structural characteristics.

We also adapted the process of generation of sentence syntax trees for English and Spanish new translation modules. Figure 7 bring one example of syntactic trees for the same sentence in BP, English and Spanish, respectively.

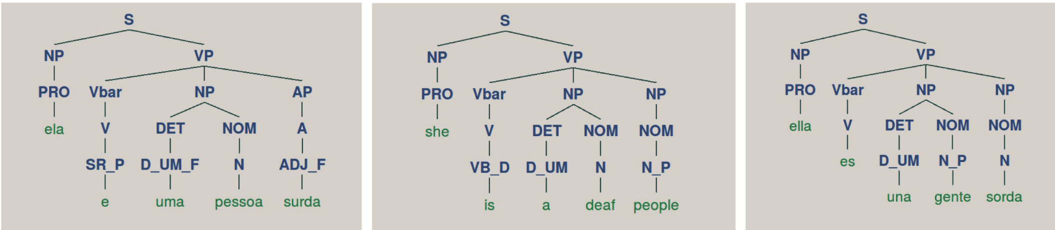

Fig. 7. Example of a sentence syntactic tree in BP, English and Spanish

We also have to make a mapping between the tags of the languages treated in the prototype and apply the syntactic description of the BP language. An excerpt from the crosstab that was created is illustrated in Fig. 8.

Grammatical Class	Portuguese (Aelius)	English (NLTK)	Spanish (Conll 2007)
PROPER NOUN	NPR	NNP	NP
PERSONAL PRONOUN	PRO	PRP	PP
POSSESSIVE PRONOUN	PRO$	PRO$	DP
INTERROGATIVE PRONOUN	-	-	PI
DEMONSTRATIVE PRONOUN	D	-	PD
PREPOSITION	P	IN	SP
VERB	VB	VB	V
MAIN VERB	-	-	VM
IMPERATIVE VERB	VB-I	-	-
PRESENT VERB	VB-P	VBP	-
PAST VERB	VB-D	VBD	-
CONDITIONAL FUTURE VERB	VB-R	-	-
DEFINITE ARTICLE	D	DT	DA
INDEFINITE ARTICLE	D-UM	DT	DI
DEMONSTRATIVE DETERMINE	DEM	-	DD
ADJECTIVE	ADJ	JJ	A
SUPERLATIVE ADJECTIVE	ADJ-S	JJS	-
ADVERB	ADV	RB	-
COORDINATING CONJUNCTION	CONJ	CC	CC
NUMERAL	NUM	CD	Z (digit) / DN (in words)

Fig. 8. Grammatical tags mapping between the source spoken languages

Thus, before the generation of the syntactic tree, the proper labels of English and Spanish are replaced by their grammatical equivalents in BP, if any. Such a temporary artifice used in the prototype may have some impacts on the generation of the syntactic tree of some sentences but does not make the translation process unfeasible.

The text-to-gloss translation is based on a set of grammatical rules specific to each language treated in the prototype. Such rules are aimed at the adequacy of the morphosyntactic divergences between the spoken language and the associated target sign language.

All rules, whether morphological or syntactic, are modeled in XML files. Basically, each rule contains information from which grammar class it is intended for and the action should be taken whether the rule applies to the sentence. The application of syntactic rules implies the updating of the syntactic tree in order to keep it consistent with the modifications made. Below we have an example of rule applied in prepositions (P) of BP:

```
<rule name = "P"><!-- remove specific preposition -->
    <active>true</active>
    <count>1</count>
    <class>
        <title>P</title>
            <specific>x</specific>
          <action>remove</action>
    </class>
</rule>
```

where

- *active* indicates that the rule is active, if its application is required;
- *count* is used for the next iteration with the sentence. In the case of BP prepositions, for example, only the current token will be evaluated. The next iteration should only advance one sentence token;
- *specific* is a specific action given to the need for translation into a target sign language. In the case presented, this action verifies whether the token is actually one of the prepositions of the spoken language;
- *action* is a generic action in case the outcome of the specific action is affirmative. The absence of a *specific* results in the execution of *action*. In the example, the prepositions are removed.

In this other example of treatment of verbs in the past, *newprop* specifies that the new token tag will be after the rule is applied. In that case, the part of the tag representing the verb tense (-D) will be removed, since the action made in this type of verb for the translation to LIBRAS is the conversion of the verb to the infinitive and the addition of a new tuple to the sentence containing the verb tense of the verb treated.

```
            <rule name = "VB-D"><!-- verb tense - past with advt-->
      <active>true</active>
      <count>1</count>
      <class>
          <title>VB-D</title>
             <specific>advt</specific>
            <action>change_vb</action>
          <newprop>VB</newprop>
      </class>
  </rule>
```

The two examples presented are morphological rules, but the syntactic rules follow the same pattern.

The adaptations made from BP to LIBRAS also use auxiliary dictionaries and algorithms for treatments of special plurals. In the morphological adaptations to English, auxiliary dictionaries are also used for the verification of some specific, as well as exclusive modules for verbal treatment and treatment of plurals, in both cases using algorithms based on WordNet[3]. In this first version of the prototype, in the translation from English to ASL and Spanish to LSE, only morphological adequacy is being done.

The post-processing step implemented in the *OpenSigns* prototype refines the translation in a specific way for each of the three SL. Some examples of steps performed in this step are: substitution of words or part of the sentence by a synonym, the substitution of numbers by numerals and identification of compound words, among others.

4.3 Experiments and Results

A set of tests was carried out to verify the feasibility of the proposal in the translation of sentences for ASL and LIBRAS.

The tests were performed using objective metrics WER (*Word Error Rate*) and BLEU (*Bilingual Evaluation Understudy*) [14], which are generally used to evaluate machine translation strategies [11, 15, 17]. According to Melo et al. [12], this type of computational test has the “purpose of evaluating machine translation systems with greater economy, speed and independence of languages than evaluations performed manually”.

Initially, we performed a set of tests to evaluate the machine translation of sentences in English to LIBRAS. To perform this task, we used the same sentences of the corpus “Bosque” [10] used by Lima et al. [11] to evaluate the Suíte VLibras translation[4].

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[3] https://wordnet.princeton.edu/wordnet/citing-wordnet/.

[4] In this test, the authors randomly selected 69 sentences and two LS interpreters generated a sequence of glosses in LIBRAS for each one. Then the VLibras translator was used to automatically generate a sequence of glosses of these same sentences and the values of the WER and BLEU metrics were calculated for the two scenarios.

In the tests with our prototype, these 69 sentences were initially translated from BP into English by an English specialist. Then, the OpenSigns prototype was used to machine translate these sentences in English for glosses in LIBRAS. Then, the WER and BLEU metrics, considering the precision in 1-grams (unigrams), 2-grams (bigrams), 3-grams (trigrams) and 4-grams, were recalculated for this sequence of glosses. The results can be seen in Table 1.

Table 1. BLEU and WER values for the 69 sentences of corpus Bosque

	VLibras [11]	OpenSigns
BLEU 1-grams	73.50%	56.80%
2-grams	61.20%	39.00%
3-grams	51.20%	27.70%
4-grams	43.00%	20.30%
WER	31.70%	55.00%

According to Table 1, the BLEU and WER values of VLibras were better than those of OpenSigns in all cases. This result was expected, since the sentences were translated using a single step of machine translation from BP to LIBRAS in VLibras. In the case of OpenSigns, on the other hand, the sentences were translated using two stages of translation (one from English to BP and the other from BP to LIBRAS), which explain the difference in the results.

However, we can observe that this difference of values was not so significant, considering that a new stage of translation was included. This difference was around 20% for all metrics. For the WER metric, VLibras obtained a value of 33%, whereas OpenSigns had a value of 55%, an average difference of 22%. In the BLEU metric, the difference was also in the range of 20%, for all n-grams.

It is also important to consider that despite having slightly lower values in translation metrics, OpenSigns has a great positive difference on VLibras: the possibility of a deaf user translating a text in a foreign language (possibly unknown to him) into his own sign language (e.g., LIBRAS), increasing the scope of inclusion of these users, allowing them to access texts in other spoken languages.

Table 2. BLEU and WER values for VLibras, OpenSigns and direct translation

	English-LIBRAS (OpenSigns)	BP-LIBRAS (VLibras) [11]	BP-LIBRAS (Direct Translation)
BLEU 1-grams	56.80%	73.50%	40.70%
2-grams	39.00%	61.20%	22.20%
3-grams	27.70%	51.20%	11.40%
4-grams	20.30%	43.00%	5.50%
WER	55.00%	31.70%	87.70%

In addition, the sentences in BP were also translated using a direct approach to gloss in LIBRAS, and WER and BLEU values were also calculated. Direct translation, as its name implies, involves the literal translation of each term of the sentence to a correspondent in gloss, i.e. without processing, interpretation or analysis of the context. With this, it is expected to contrast the translation made using VLibras, OpenSigns and direct translation. Table 2 lists the BLEU and WER values for the three scenarios.

According to Table 2, we can observe there was a reduction in BLEU values, and an increase in WER value, when the translation using the prototype is compared with the translation generated by VLibras. As mentioned before, we expected a worse result in OpenSigns due to the intermediate machine translation process text-to-text, which is an inherent bias that can be reflected in the final result of the translation. The reduction in BLEU values averaged 20% to 30%, which can in principle be considered an acceptable noise considering that there are two translation processes involved. However, it is part of our future roadmap to conduct an experiment with deaf users to verify the level of intelligibility of the translations obtained.

In any case, when we compare the machine translation of English to LIBRAS generated by the prototype with a direct translation strategy (from words in Portuguese for glosses in LIBRAS), we can observe that there was an improvement in the results of the BLEU and WER. This is an indication that the translation of sentences from English to LIBRAS using the proposed approach has the potential to produce better results than a direct translator of words to glosses. In other words, this result may point out that, even containing an intermediate stage of translation from English to BP, the noise generated in this process is not so high that it will not allow machine translation, since it had better results than a direct translation from BP words to LIBRAS glosses.

Continuing the validation of the approach, we carried out a second set of tests with the objective of evaluating the use of an additional translation stage between sign languages, rather than a stage of intermediate translation between spoken languages. For example, to translate English contents to LIBRAS, instead of translating from English to Portuguese, and then translating to LIBRAS, we performed two step of translations: translation from English into ASL glosses, followed by a translation from ASL to LIBRAS.

In this test, some English sentences (and their respective glosses in ASL) were randomly selected from the *American Sign Language University* (ASLU)[5] site. After the selection, a LIBRAS specialist with advanced knowledge in the English language, translated all the sentences to a sequence of LIBRAS glosses.

The sentences in English were then submitted to the prototype and translated into LIBRAS glosses. Then, the ASL glosses of these sentences were submitted to the prototype and translated into BP, and then to LIBRAS. The BLEU and WER values were generated for the two scenarios based on the reference translation produced by the LIBRAS specialist. The values of WER and BLEU obtained are shown in Table 3.

Analyzing the results, we can observe that the BLEU values are higher and the WER value is lower in the first scenario, where the translation was made directly from the sentences in LIBRAS. This result indicates that the translation of the sentence in a given spoken language directly to the target SL, can offer better results than translation from the gloss in another SL.

[5] www.lifeprint.com/asl101/index/sign-language-phrases.htm.

Table 3. BLEU and WER values for ASLU ASL sentences

	English-LIBRAS	ASL-LIBRAS
BLEU 1-grams	65.20%	47.80%
2-grams	42.60%	18.90%
3-grams	25.60%	0.00%
4-grams	14.20%	0.00%
WER	19.3%	28.0%

Afterwards, the sentences translated by the specialist were converted to a sequence of glosses in LIBRAS, where the VLibras and the prototype were again used to generate the sequence of glosses in LIBRAS from phrases and glosses randomly selected from the ASLU database[6]. With this, we can calculate the BLEU and WER values of the glosses in LIBRAS generated from the text in English and the glosses in ASL in order to analyze the best approach: direct translation of the sentence or translation from the gloss. Table 4 contains the percentage values of the two approaches.

Table 4. BLEU and WER values for the two approaches to translation

	Direct from English	Glosses in ASL
BLEU 1-grams	65.18%	47.80%
2-grams	42.58%	18.89%
3-grams	25.60%	0.00%
4-grams	14.18%	0.00%
WER	19.32%	28.02%

According to Table 4, we verified that the BLEU values are larger and the WER value is lower in the first approach, where the translation was performed directly from English to gloss in LIBRAS using the prototype. On the other hand, the second approach presented lower values in the BLEU and higher in the WER. In a first analysis, the direct translation of the sentence of a given language offered better result than from the gloss of another language.

5 Final Remarks

In this work, we present the results of a research whose objective is the development of a multilingual platform for ”text-to-sign” machine translation, ie, a unique ecosystem that accepts several spoken languages as input and performs a machine translation for several output sign languages. The proposed platform is based on several common existing components, derivated from the **Suíte VLibras**, in which components supporting specific mechanisms of different sign languages have been added.

[6] http://www.lifeprint.com/asl101/index/sign-language-phrases.htm.

A prototype, based on an extension of **Suíte VLibras** was developed with the aim of verify that the basic concepts of the proposed platform are feasible. In this prototype, additional components have been implemented to support the translation of texts in any language for Libras and ASL.

In our conception, it is fundamental to stimulate the community of researchers and developers who work with translation support systems for sign language to collaborate. As we are distinct groups, in some cases with commercial interests and competing in the market for accessibility products, cooperation is only possible with the definition of standards for architecture and some system components. One of the components that is critical for the evolution of the results in the area is the dictionary. For us, the dictionary must be a resource shared by the different translation systems. This would imply in a more accelerated increase in the number of signs, quality and convergence in the use of signs. It is therefore vital to accelerate the definition and expansion of the sign languages themselves.

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