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Information technology for Ukrainian Sign Language translation based on ontologies

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Abstract. The article discusses an information technology for Ukrainian Sign Language translation based on ontologies. The components of the technology that are based on grammatically augmented ontology are described. New methods and tools for Ukrainian Sign Language translation were developed. These tools can be used for the development of a machine translation system from spoken to sign language and vice versa to facilitate communication between deaf people and those who do not speak sign language.

The experiments for Ukrainian Sign Language translation were conducted. The increase of the percentage of correctly parsed sentences shows the feasibility of using the information technology for Ukrainian Sign Language translation.

Key words: sign language translation, grammatical analysis, grammatically augmented ontology.

INTRODUCTION

Ukrainian Sign Language (USL) is a natural way of communication that is used by people with impaired hearing. Thus a necessity of obtaining information in the form of sign language for this category of people is important. Today there are about 400,000 people with impaired hearing who live in Ukraine. For this category of citizens there are 59 specialized schools, 20 universities (including the National Technical University of Ukraine "Kyiv Polytechnic Institute").

There are educational materials available for deaf people that include video dictionaries of USL, tutoring software, online courses, etc. However, there are no effective tools for machine translation of sign language. The development of information technology for Ukrainian sign language translation is a relevant task. This information technology can be in great social demand; in particular it will provide persons with hearing disabilities with the opportunity to actively engage in communication with people who do not speak sign language.

Sign Language (SL) is a natural language, which is based on a combination of signs [1]. Every sign is performed with one or both hands, combined with facial expressions and body posture. Ukrainian Sign Language is an independent visual-spatial language and has its own grammar that is different from Ukrainian Spoken Language grammar (USpL) [2]. Some features of USL allow parallel transfer of information by performing signs with both hands, using facial expressions and articulations. It is impossible in Ukrainian Spoken Language, where information transfer is linear (word by word).

THE ANALYSIS OF RECENT RESEARCH AND PUBLICATIONS

There are several approaches to sign language translation. The most studied among them are approaches based on statistical models [3, 4], rule-based models [5, 6], data-driven models [7], and ontologies [8 – 10].

Scientists J. Bungeroth and H. Ney studied the statistical approach for German Sign Language (DGS) translation [11]. The translation process consists of gesture recognition, statistical translation, and rendering of a visual avatar.

In [12] a method of statistical machine translation from English text to American Sign Language is described. The components of the method are: a parallel corpus, a decoder for statistical machine translation of English and ASL, and a method for improvement of translation results.

Indian scientists T. Dasgupta et al. [13] have presented a prototype of Text-To-Indian Sign Language (ISL) rule-based translation system. The process of translation consists of five modules: input text preprocessor and parser, LFG f-structure converter, translator based on grammar rules, ISL sentence generator, and ISL synthesizer.

The information technology of rule-based machine translation for Spanish Sign Language was described in [14] (R. San Segundo et al.) The translation system is composed of a speech recognizer (for decoding the spoken utterance into a word sequence), a natural language translator (for converting a word sequence into a sequence of sign language gestures), and a 3D avatar animation module (for playing gestures). The translation process is carried out by using a database of grammar rules of Spanish spoken and sign languages.

Information technology of Polish Sign Language translation based on rules was studied in [15]. The translation process includes syntactic and semantic analysis of the input text, transformation of predicate-argument structure of Polish sentence into predicate-argument structure of SL sentence, and gesture animation.

In [8] an ontology-based machine translation system from Arabic text to Arabic SignWriting in the jurisprudence of prayer domain was developed. The translation process consists of the following modules:

morphological analysis, grammatical transformation and semantic translation using domain ontology. The system produces SignWriting symbols as a result.

Ukrainian scientists Iu. Krak, O. Barmak and Iu. Kryvonos [16] have developed an information technology for bidirectional Ukrainian Sign Language translation. This technology is based on the following processes: calculation of inflection parameters for each word in an input sentence, search and replacement of USpL grammatical constructions with appropriate USL grammatical constructions and replacement of words with appropriate gestures.

The study of known approaches to sign language translation showed that rule-based and ontology-based approaches are the most applicable to Ukrainian Sign Language translation because of lack of big parallel corpora for statistical translation. In order to increase the translation quality an alternative approach based on grammatically augmented ontology was studied.

OBJECTIVES

The article focuses on the development of an information technology for Ukrainian Sign Language translation. The information technology is based on grammatically augmented ontology (GAO) that was introduced in [17]. Methods and tools for Ukrainian Sign Language translation were created. They can be used for the development of machine translation from one language to another, which will facilitate communication between deaf people and people who do not speak sign language.

The process of Ukrainian Sign Language translation is a complex problem, which consists of word sense disambiguation (WSD), parsing sentences in Ukrainian Spoken Language and Ukrainian Sign Language, and applying translation rules.

For the development of the information technology of Ukrainian Sign Language translation the following problems were solved:

1) grammatical analysis of Ukrainian Sign Language,
2) task decomposition of Ukrainian Sign Language translation system,
3) building a system of GAO-based rules for Ukrainian Sign Language translation,
4) development of USL translation methods using GAO,
5) experimental studies and evaluation of results.

THE MAIN RESULTS OF THE RESEARCH

Information technology of Ukrainian Sign Language translation consists of the following processes:

• filling grammatically augmented ontology [18];
• rule-based translation [19, 20] and translation based on grammatically augmented ontology [17];
• testing translation system.

The processes of information technology using a use case diagram is shown in Fig. 1.

A domain specific language (DSL) was developed for filling grammatically augmented ontology of Ukrainian Spoken and Sign Languages. The DSL named GAODL was created to facilitate uniform editing and processing of grammatically augmented ontologies. These ontologies could be created for specific subject areas and lately merged to obtain upper ontologies. The GAODL language contains means for definition of new grammatical attributes, synsets, relations on synsets, predicates and expressions.

Grammatically augmented ontology for "Education", "Nature", "Journey", "State", "Family", "Production", "Profession", "Army", "Theatre", "Culture", and "Hospital" subject areas were built. For this purpose, 1200 words were collected from these subject areas and the meaning of each word was verified using the Ukrainian glossary [21]. The meaning of USL signs was clarified with teachers of Lviv Maria Pokrova Secondary Residential School for Deaf Children because there are no glossaries for USL yet. GAO description was built using the collected words as synsets. Expressions in USpL and USL were added for all verb synsets.

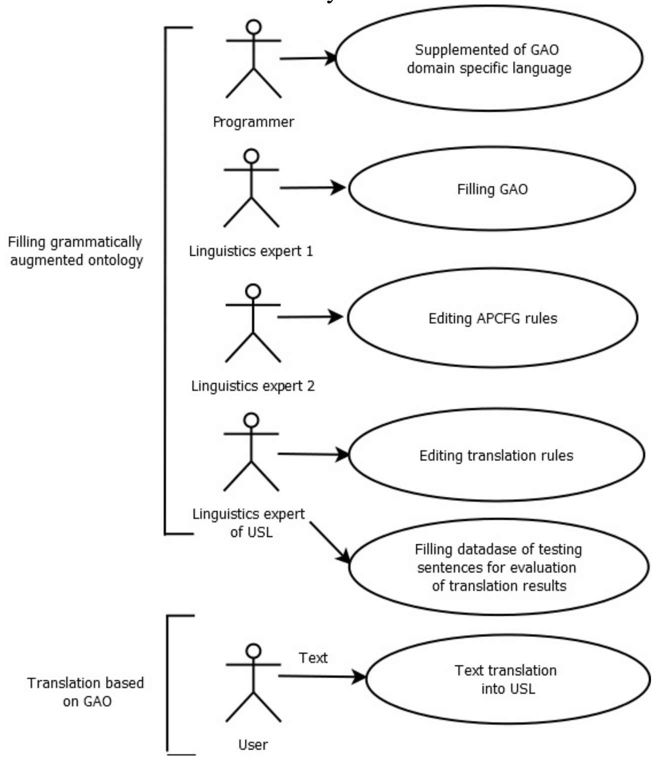

Fig. 1. Use case diagram of information technology of USL translation

Linguistics experts, programmers and experts in Ukrainian Sign Language are involved in the process of filling grammatically augmented ontology.

The possibility of introducing new concepts is implemented by a programmer using a grammatically augmented ontology domain specific language toolchain.

The GAO is filled with the assistance of a linguistics expert. It involves the choice of topics, words, signs, and grammatical constructions. To editing of the APCFG rules involves a linguistics expert as well.

A Ukrainian Sign Language expert is involved in editing database of USL translation rules and filling the corpus of testing sentences for the evaluation of translation results. Users use the translation system for the translation of USpL sentences into USL and vice versa. The evaluation of translation performance is performed by comparing translated sentences with the known translations from the testing sentences database.

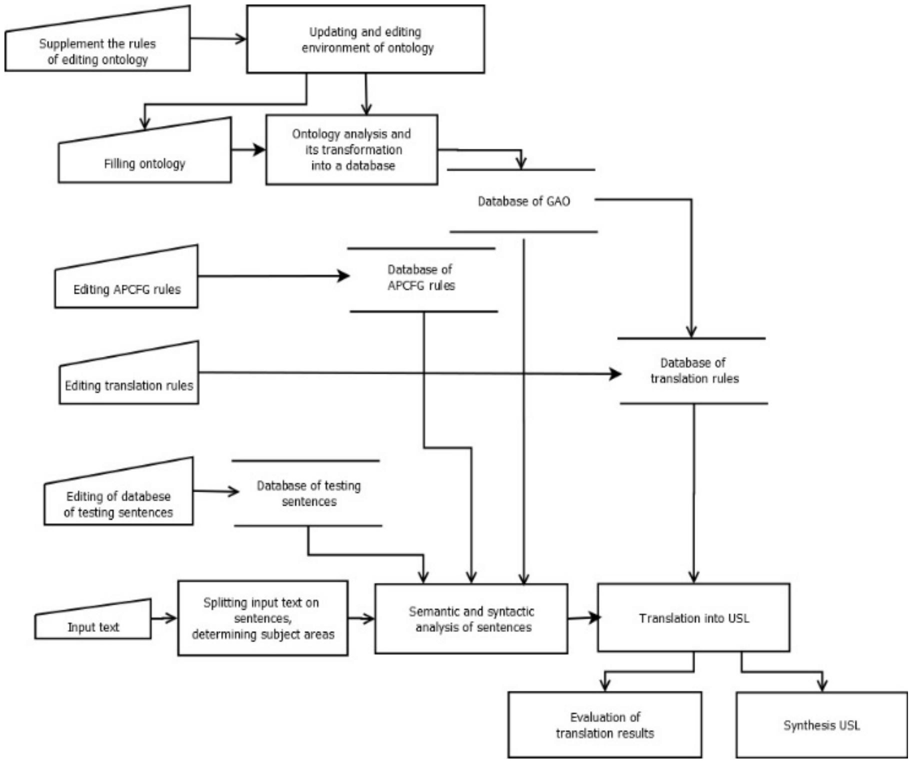

Fig. 2. The scheme of information technology of Ukrainian Sign Language translation based on grammatically augmented ontology

The scheme of the developed information technology for USL translation is shown in Fig. 2. The technology is based on rules that are extracted from grammatically augmented ontology. Then a semantic-syntactic analysis of sentences is performed. The use of grammatically augmented ontology in the first stage of translation enables further semantic-syntactic analysis of sentences and avoids the problem of ambiguous parsing.

The main difference from the known ontology-based approaches is that expressions are stored with ontology using a new domain-specific language GAODL (Grammatically Augmented Ontology Description Language). The use of GAODL facilitates uniform editing and processing of grammatically augmented ontologies. These ontologies could be created for specific subject areas and lately merged to obtain upper ontologies. The GAODL language contains constructions for the definition of new grammatical attributes, synsets, relations on synsets, predicates and expressions. USL signs were represented by glosses for the purpose of translation.

The grammatically augmented ontology is defined in [17] as a tuple:

$$O_G = O,P,E,T,R_p \tag{1}$$

where: O is an ontology, defined as a tuple $O = \langle L,C,F,R_c \rangle$, where $L = \{w_i\}$ is a vocabulary of a subject area, $C = \{c_i\}$ is a set of the subject area concepts, $F \subset L \times C$ – a relation between appropriate terms and concepts, R_c is a set of relations on concepts (hyponymy, hyperonymy, meronymy, holonymy, etc);

$P = \{p_i\}$ is a set of predicates;

$E = \{e_i\}$ is a set of expressions, where each expression $e_i = ((w_1, g_1), (w_2, g_2), \ldots, (w_n, g_n))$ is a tuple of grammatically augmented ontology terms (w_i, g_i);

$T = \{t_j\}$ is a set of parametrized expressions, where $t_j = (e_j, f_j, p_j)$ is a triple of expression e_j, argument positioning function $f_j : \{1,2,\ldots,Len(e_j)\} \to \{0,1,\ldots,N(p_j)\}$, and a related predicate p_j. $Len(e_j)$ denotes the length of tuple e_j, $N(p_j)$ is the number of places of predicate p_j;

R_p is a relation that matches predicates to verb concepts.

For some predicate p_j and some expression e_j argument positioning function $f_j(k)$ was defined to be 0 for the term in position k of the expression e_j that can't be changed without breaking the expression relation to predicate p_j. The value $f(k) > 0$ means that appropriate term in position k represents an argument of the predicate with ordinal number $f(k)$, and it can be replaced with another term from the set of hyponyms of term w_k. If the related predicate has n places and for each $i \in \{1,2,\ldots,n\}$ exists $k \in \{1,2,\ldots,Len(e_j)\}$ such that $f(k)=i$ then expression e_j completely defines predicate p_j. Otherwise, some arguments of the predicate are considered to be undefined in the sentence. They can be either completely unknown or can be devised from the context of speech or from a situation.

The definition of grammatically augmented ontology provided the possibility to express links between concepts, predicates and means of their expression in the form of language constructions.

For example, the predicate $PLAY(a,b,c)$, where a is someone who plays, b is something that is played and c is a musical instrument, can be expressed using expressions e_1 = "(somebody) (play) (something) (on something/musical_instrument)".

In spoken languages the grammatical forms of subject, object, predicate, and complement comply to certain grammatical rules. These rules in the grammatically augmented ontology are defined by grammatical attributes of the expression terms.

These grammatical attributes were divided into 3 groups:

1) attributes that can't be modified (for example, preposition and casus of a complement),

2) attributes that can be freely modified (usually, number and gender of an object),

3) attributes that should be matched (like person and number of a subject or predicate).

Process of translation based on GAO use Affix probabilistic context free grammar (APCFG) [18] parser for parsing sentences and transformation of sentence according to the grammar rules. Fig. 3 shows a block diagram of the translation algorithm based on grammatically augmented ontology.

All experiments were conducted for Ukrainian language and examples below are English equivalents of them. The algorithm for parsing a sentence comprises the following steps:

1. Look up all possible meanings of every word from the sentence.
2. Add base forms for every word and detect its grammatical attributes.
3. Add hypernyms for every meaning of the words.
4. Add all expressions for every verb in the sentence.
5. Parse the sentence using UrkParser.

Consider parsing sentences "The boy plays sonata on the piano" and "The boy plays sonata on a book". The parsing starts by adding all possible meanings of all words from the sentences, their base forms and all possible hyperonyms (steps 1-3 of the algorithm). GAO relation "hyperonym" is not limited to be a simple tree structure. It can be used to define different groups of words that share some common property. For example:

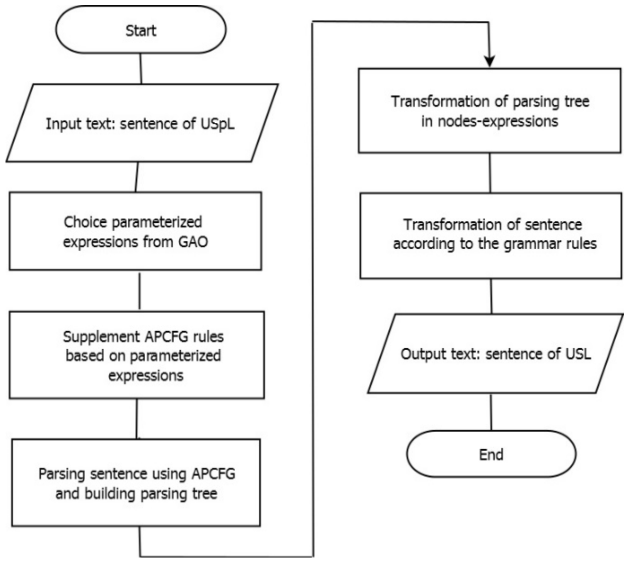

Fig. 3. Algorithm of Ukrainian Sign Language translation based on grammatically augmented ontology

- **Boy** (a youthful male person). Hypernyms: male, male person → person, individual, someone, some body, mortal, soul → organism, being → living thing, animate thing → whole, unit → object, physical object → physical entity → entity.
- **Play** (play on an instrument). Hypernyms: perform → re-create → make, create.
- **Play** (participate in games or sport). Hypernyms: compete, vie, contend.
- **Act, play, represent** (play a role or part). Hypernyms: re-create → make, create.
- **Play** (be at play; be engaged in playful activity; amuse oneself in a way characteristic of children). Hypernyms: act.
- **Play, spiel** (replay (as a melody)) Hypernyms: re-create → make, create.
- **Play** (bet or wager (money)). Hypernyms: play → compete, vie, contend.
- **Play** (pretend to be somebody in the framework of a game or playful activity). Hypernyms: simulate, assume, sham, feign → diss emble, pretend, act.
- **Play** (emit recorded sound). Hypernyms: sound.
- **Play** (put (a card or piece) into play during a game, or act strategically as if in a card game). Hypernyms: deploy → position → put, set, place, pose, position, lay → move, displace.
- **Play, toy** (engage in an activity as if it were a game rather than take it seriously). Hypernyms: act, behave, do.
- **Play** (use to one's advantage) Hypernyms: exploit, work → use, utilize, utilise, apply, employ.
- **Sonata** (a musical composition of 3 or 4 movements of contrasting forms). Hypernyms: classical music, classical, serious music → music genre, musical genre, genre, musical style → expressive style, style → communication → abstraction, abstract entity → entity

- **Piano, pianoforte, forte-piano** (a keyboard instrument that is played by depressing keys that cause hammers to strike tuned strings and produce sounds). Hypernyms: keyboard instrument → musi cal instrument, instrument → device → instrument ality, instrumentation → artifact, artefact → whole, unit → object, physical object → physical entity → entity
- **Book** (a written work or composition that has been published (printed on pages bound together)). Hypernyms: work, piece of work → product, production → creation →artifact, artefact → whole, unit → object, physical object → physical entity → entity.

The next step is to add expressions for these words. Only verb "play" contains an associated expressions, so it is added to the set of APCFG rules:

VP → play <musical_composition>[NP] on <musical_instrument>[NP] (1.1),

VP → play <sport_game >[NP] (1.1),

VP → play_act <actor_role>[NP] in < theatrical performance>[NP] (1.1),

VP → play_with <game >[NP] (1.1),

VP → play_replay <something >[NP] (1.1),

VP → play <wager_money >[NP] (1.1),

VP → play_pretend < playful_activity >[NP] (1.1),

VP → play_emit < recorded_sound >[NP] (1.1),

VP → play_behave < certain_way >[NP] (1.1),

VP → play_manipulate < something >[NP] (1.1),

VP → play_advantage on <somebody_interests> [NP] (1.1),

VP → play on < specific_position> [NP] (1.1).

where: VP means verb phrase, NP means noun phrase and the numbers in braces mean multiplicative weight of the rules. In the conducted experiment all grammatical rules were weighted 1.0 and the weight of all expression rules was set to 1.1. This helped the parser to prefer expressions over the grammatical rules where it was possible.

The results of the experiment with parsing 200 test sentences in USL and USpL language are given in table 1. The percentage of correctly parsed sentences was low when only the grammatical rules were used. This percentage is small especially for spoken language. It was due to the fact that Ukrainian spoken language grammar has flexible word order and word order in sign language is fixed in most expressions.

Table 1. Percentage of correctly parsed USL and USpL sentences

Rule set	Ukrainian Sign Language	Ukrainian Spoken Language
Grammatical rules only	72%	65%
Grammatical rules + rules generated from GAO	91%	90%

The result of parsing the sample sentences is shown in Fig. 4. An expression "play" was used when the first sentence was parsed, thus the weight of the result is 1.1. In the second sentence the expression "play" could not be used because "a book" does not belong to the group of entities "musical_instrument". Thus, the second sentence was parsed using only grammatical rules.

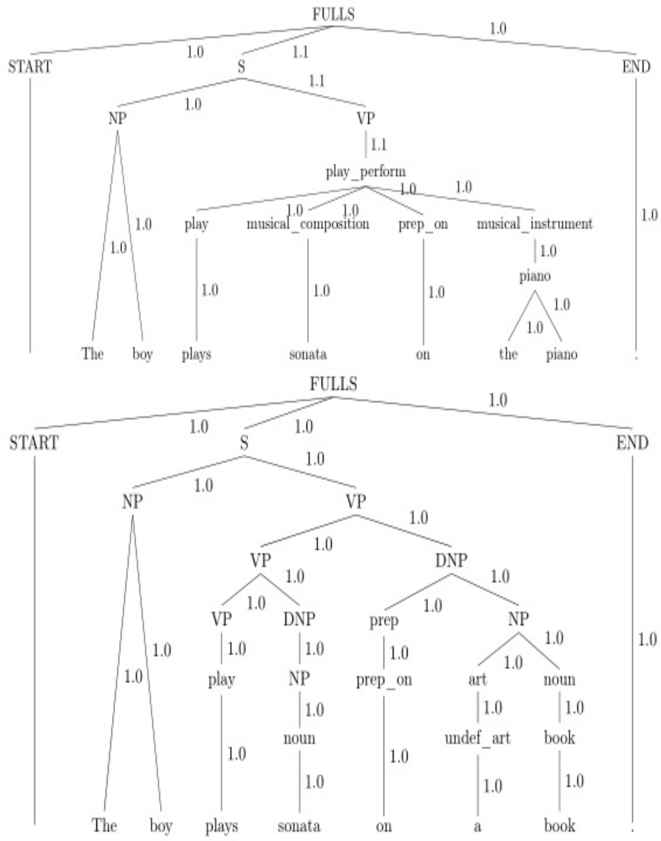

Fig. 4. The result of parsing sentences "The boy plays sonata on the piano" and "The boy plays sonata on a book". FULLS stands for "full sentence", S – a part with major clause, VP – verb phrase, NP – noun phrase, DNP – object or complement.

CONCLUSIONS

Experimental results have confirmed that the information technology for Ukrainian Sign Language translation based on grammatically augmented ontology performed better translation than other information technologies. The use of the developed grammatically augmented ontology for parsing sentences in Ukrainian Spoken and Ukrainian Sign Languages improved the performance of APCFG parser. The major increase in percentage of correctly parsed sentences was achieved for Ukrainian Sign Language. The work is a part of a larger project conducted by authors to tackle the bidirectional Ukrainian Sign Language translation problem.

However, we faced challenges of verification ontology files from different sources, the automation of the process of building GAO ontologies from other known ontologies and large text corpora. Besides, optimal weights for rules generated from GAO expressions and grammatical rules should be determined to achieve better performance of APCFG parser. These challenges will be the subject of further research.

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