A New Approach to Semantic Parsing of Metonymic Phrases by a Business Intelligence System

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Abstract **- The functioning of numerous business intelligence systems (BIS) substantially depends of the content of databases. In many thematic domains, this content is highly dynamic, e.g., in case of the prices for oil, aluminum, wheat, etc. It is the reason for the birth of a BIS project aimed at updating the content of relational databases by means of extracting actual values of data from the texts in natural language (NL). The principal subject of the paper is theoretical foundations of building semantic representations (SRs) of the metonymic phrases. In linguistics, a metonymic construction is a linguistic construction in which an entity is referred to by the name of something closely associated with that thing or situation. The main scientific results set forth in the paper are as follows: (a) a logical structure of a minimalist terminological knowledge base helping to fulfil semantic parsing of metonymical phrases, it is motivated by the theory of K-representations; (b) an original algorithm of finding a semantic interpretation of metonymic phrases of some kinds.**

Keywords - metonymy; logical structure of terminological knowledge base; natural language processing; semantic parsing of metonymical phrases; theory of K-representations; SK-languages

I. INTRODUCTION

The history of computer intelligent systems called natural language processing systems (NLPSs) is over five decades long. During several initial decades, the main attention of the researchers was attracted to developing computational methods of processing regular phrases and short discourses. It means that the meaning of such texts is determined by their syntactic structure and the correspondence between their lexical units and their meanings, taking into account that one lexical unit may be associated with several meanings, as, e.g., in case of the words “mouse”, “cloud”, “battery”, “green”.

However, the specialists in numerous fields very often encounter the so called irregular texts, first of all, the texts with metaphors, metonymic constructions, and with idiomatic constructions. The focus of the present paper is the processing of metonymical phrases. One says in theoretical and computational linguistics about a metonymical sentence in case a sentence *Expr* mentions an object *X* but uses with this aim a designation of an object *Y* associated in any way (through a knowledge base) with the object *X*. For instance, the phrase S1 = “The winners in this hockey match were the maple leaves” means that the winner in this match was the combined team of Canada.

The problem of developing computational algorithms for analyzing metonymical texts has attracted the attention of many researchers since the 1990s, see, in particular, [1-4]. For the authors of [1], semantic parsing of metonymic texts is a particular kind of abduction, i.e., an inference to the best explanation. The interpretation of a text is considered as the minimal explanation of why the text would be true. In [1], first order logic is used as a formal tool for theoretical considerations. No algorithm of metonymic texts’ semantic parsing is suggested.

Markert and Hahn set forth in [2] deep theoretical foundations of constructing semantic representations of sentences and discourses. With this aim, they use a version of KL-ONE terminological knowledge representation language. The paper [2] provides a methodological basis for developing computer systems being able to analyze metonymic texts. However, for designing a system of the kind, a group of programmers should have a rather high background in descriptive logics’ formalisms. The paper [2] contains no algorithm of metonymic texts’ parsing being clear for the programmers of average qualification.

The paper [3] suggests to use associative relations between the words for discovering and interpreting metonymic phrases. E.g., the stated method uses the information about the triples of the form (A, B, C), where A is a stimulus word (a verb, e.g., “to convey”), B is a deep case (in other terms, a semantic role, a conceptual case), and C is the information about associated nouns and pronouns connected with certain distances.

The subject of the paper [4] is detecting implicit metonymic relations regarding the organizations and locations presented in WordNet.

The common feature of the listed papers is that the stated approaches don’t suggest a domain-independent logical structure of a terminological knowledge base and of objects database helping to find a semantic interpretation of metonymic phrase.

The analysis shows that today there is a need of formal models and algorithms being quite clear for the programmers and being able to become a starting point for the creation of effective computational systems "understanding" the texts with metonymy.

The main scientific results set forth in the paper are as follows: (a) a logical structure of a minimalist terminological knowledge base helping to fulfil semantic parsing of metonymical phrases, it is motivated by the theory of K-representations; (knowledge representations); (b) an original algorithm of finding a semantic interpretation of metonymic phrases of some kinds.

II. THE CENTRAL IDEA OF THE APPROACH

Example. Let T1 = "On April 12, a match between the football teams "Zenith" and "Spartak Moscow" took place in Saint-Petersburg". It was the victory of the red-whites with the score 2:1". Let's consider a scheme of understanding by a fan what team has achieved the victory. The noun-like construction "the red-whites" denotes an unknown physical object associated with the semantic unit "a value of colour". The text T1 mentions the entities associated with the notions "a match", "a football team", "a city", "a victory". Let Set1 be the set of all characteristics of the listed concepts. Then Set1 includes the characteristic Symbolics associated with the concept "a football team", and its semantic restriction is the concept "emblem". Suppose that this concept has the characteristic Colour with the semantic restriction "a value of colour", and the characteristic Drawn-object with the semantic restriction "a physical object".

Then the information about the emblems of the teams participated in the match is looked for in the objects database. The result of this search is that the emblem of the team "Zenith" combines the colours white and blue, and the emblem of the team "Spartak Moscow" combines the colours red and white. Then the conclusion is drawn that the team "Spartak" (Moscow) is the winner in the match.

Below an algorithm of processing metonymical phrases is introduced. The essence of this algorithm is processing of two relations called terminological knowledge base (TKB) and objects database (ODB). The originality of TKB is, in particular, the lack of fixed semantic interpretation of the most part of this relation's attributes. It is because the considered structure of TKB aims at reflecting the structure of a K-string representing a piece of knowledge (a semantic frame) associated with a concept.

III. SHORTLY ABOUT THE THEORY OF K-REPRESENTATIONS

The methodological basis of the present paper is the theory of K-representations (knowledge representations). It is an original theory of designing semantic-syntactic parsers of natural language (NL) with a broad usage of formal means for representing input, intermediary, and output data. The theory of K-representations (TKR) is presented in numerous papers both in English and Russian written by V. A. Fomichov and his colleagues [5-15].

The *first constituent* of TKR is the theory of SK-languages (standard knowledge languages), stated, in particular, in [10, 14]. The kernel of the theory of SK-languages is a mathematical model describing a system of such 10 partial operations on structured meanings (SMs) of natural language texts (NL-texts) that, using primitive conceptual units as "blocks", we are able to build formal representations of SMs of arbitrary NL-texts (including articles, textbooks, etc.) and of arbitrary pieces of knowledge about the world [10].

The initial version of the theory of SK-languages is called the theory of K-calculuses and K-languages [5-8].

The *second constituent* of TKR is a broadly applicable mathematical model of a linguistic database, it is described in Chapter 7 of [10]. The model describes the frames expressing the necessary conditions of the existence of semantic relations, in particular, in the word combinations of the following kinds: "Verbal form (verb, participle, gerund) + Preposition + Noun", "Verbal form + Noun", "Noun1 + Preposition + Noun2", "Noun1+ Noun2", "Number designation + Noun", "Attribute + Noun", "Interrogative word + Verb".

The *third basic constituent* of TKR is formed by a family of complex, strongly structured algorithms carrying out semantic-syntactic analysis of texts from some practically interesting sublanguages of NL. These algorithms transform NL-texts into their semantic representations being K-representations, i.e., the expressions of some SK-languages. The algorithm *SemSynt1* is presented in the second part of the monograph [10]. The input texts can be from the English, German, and Russian languages. That is why the algorithm *SemSynt1* is multilingual.

An important feature of the algorithm *SemSynt1* is that it doesn't construct any syntactic representation of the inputted NL-text but directly finds semantic relations between text units. The other distinguished feature is that a complex algorithm is completely described with the help of formal means, that is why it is problem independent and doesn't depend on a programming system.

The *fourth constituent* of TKR is a collection of scientific results expanding theoretical foundations of advanced ontologies, cross-lingual conceptual information access, multilingual semantic web, the design of agent communication languages in multi-agent systems] and recording the content of e-negotiations [6-15].

The main output of the algorithm *SemSynt1* is a semantic representation (SR) of the input text being its K-representation. The expressions of SK-languages are constructed from the basic conceptual units and several service symbols by means of certain partial operations Op[1] - Op[10]. Let's see (without mathematical details) how these partial operations do work.

The operation Op[1] allows us to join intensional quantifiers and designations (simple or compound) of notions, in particular, for constructing the formulas *certain airplane1*, *certain airplane1 * (Manufacturer, Boeing), all airplane1 * (Manufacturer, Boeing).*

The operation Op[2] is used for constructing the expressions of the form $f(t_1, \ldots, t_n)$, and Op[3] enables us to build the expressions of the form $(c \equiv d)$. Example: *(Age(S.Nosov) ≡ 27/year).*

One uses the operation Op[4] for building the expressions of the form *rel*(t_1 ,..., t_n), where *rel* is the name of a relation with *n* attributes (example: *Earlier (Creation-date(certain file1), #yesterday)*). The operation Op[5] provides the possibility to mark a formula or its part by means of a variable. Example: *all car1 * (Manufacturer, BMW) : S1.*

The operation Op[6] allows us to join the negation connective ¬ to a formula (example: ¬*airplane1*). The operation Op[7] governs the use of the logical connectives ∧ (and) and ∨ (or). Example: *car1 * (Manufacturer, (BMW ∨ Opel)).*

Using the operation Op[8] at the last step of an inference, it is possible to construct compound designations of notions. Example: *file1 * (Extension1, ("doc" ∨ "docx"))(Location, certain desktop).*

The partial operation Op[9] enables us to use universal quantifier and existential quantifier for building the formulas. The operation Op[10] helps to construct the designations of the *n*-tuples of the form $<c_1 ,..., c_n >$, where $n \geq 1$.

IV. DEVELOPING LOGICAL STRUCTURE OF TERMINOLOGICAL KNOWLEDGE BASE AND OBJECTS DATABASE

In the middle of the 1970s, professor M. Minsky from MIT suggested the notion of frame as a structure for representing stereotype knowledge [15]. This notion acquired a broad popularity in the 1970s – 1980s. In particular, a new generation of knowledge representation languages was born, they were called the frame-like knowledge representation languages. A frame of a concept distinguishes the main components of the objects qualified by this concept and indicates the semantic restrictions for each component.

Using broad expressive possibilities of SK-languages introduced in the theory of K-representations, let's consider a formal model of a terminological knowledge base in the form of a finite set *Set-Concepts-Frames,* consisting of the expressions of the form

*<concept1, concept2 * (rel*$_1$*, value*$_1$*)…(rel*$_n$*, value*$_n$)>, (1)

where *concept1* is the focus concept (i.e., the concept to be explained), *concept2* – the concept-stereotype, that is, the known concept used for explaining the meaning of *concept1*; $n \geq 1$, for each $k = 1,..., n$, rel_k is the name of a binary relation or the name of a function with one argument; $value_k$ is ether the second attribute of the relation or the value of the function depending on the kind of rel_k.

Let's demand that the expression of the form (1) be a K-string, that is, be an expression of the SK-language *Ls(B)* in certain conceptual basis *B*. Then it is seen from the structure of the form (1) that the partial operation Op[10] was used during last step of its inference, and the operation Op[8] was applied during the preceding step of inference.

Example. The set *Set-Concepts-Frames* may contain the expression

*<football-team, sport-team * (Called, certain string)(Sport-kind, football)(Symbolics, certain emblem)(Country-relation, certain country1)(City-relation, certain city1)(Senior-coach-relation, certain person)(Captain-relation, certain person)>.*

It is suggested to implement the finite set *Set-Concepts-Frames* as a relation *ConceptsFrames* of a relational database. The structure of this relation is original, in particular, due to the lack of fixed semantic interpretation of the most part of this relation's attributes. It is because the considered structure of TKB aims at reflecting the structure of a K-string representing a piece of knowledge (a semantic frame) associated with a concept.

Only the first – fourth attributes of the relation *ConceptsFrames* have a fixed semantic interpretation. The attribute No. 1 with the index Row contains the ordered numbers of the relation's rows. The attribute No. 2 with the index Focus contains the concepts characterized by the values of other attributes of the same row. For instance, in case of the considered text T1, the column 2 of the relation *ConceptsFrames* may contain the elements *match1, football-team, city1, emblem1.* For arbitrary row p, the element on the intersection of this row and the column 3 is the basic concept for the focus concept on the intersection of the same line and column No. 2. E.g., it may be that ConceptsFrames[p, 2] = football-team, and ConceptsFrames[p, 3] = sport-team.

The column No. 4 has the index Numb. For arbitrary row p, the element Concepts-frames[p, 4] is a positive integer interpreted as the number of the so called *search attributes.* Let numb-search-attr1 = ConceptsFrames[p, 4]. The elements of the columns with ordered numbers 4+1, 4+3, …, 4+2numb-search-attr1 – 1 will be called *search attributes.* The attributes and their values will be (with some exclusions) used for semantic processing of metonymic phrases.

The elements of the columns with ordered numbers 4+2, 4+4, …, 4+2*numb-search-attr1 will be called *semantic restrictions of the search attributes.*

Due to technical reasons, the relations ConceptsFrames and ObjectsBase (the latter is described below and contains the data about various entities from the considered application domain) are represented below not by the tables (as usual) but as the sequences of linear records of their rows. For instance, the table 1

A	B	C
U_1	U_2	U_3
W_1	W_2	W_3

Table 1. A table for constructing a linear record of the matrix. Here A. B. C are the indices of the columns 1. 2, 3, the values U_1 U_2 , U_3 are the elements of the first row, and W_1 W_2 , W_3 are the elements of the second row.

will be represented by the expressions

A/ U_1 , B/ U_2 , C/ U_3 ,

A/W_1 , B/W_2 , C/W_3.

Let the columns of the relation ConceptsFrames with the numbers 4+1, 4+3, 4+5 have the indices Attr1, Attr2, Attr3,…, and the columns of the relation ConceptsFrames with the numbers 4+2, 4+4, 4+6 have the indices Restr1, Restr2, Restr3,….

Example 1. Taking into account these agreements, let's consider the following linear record of the relation ConceptsFrames containing semantic frames of the concepts *contry1*, *city1*, *football-team*, and *emblem1*:

Row/1, Focus/country1, Base/space-object, Numb/3, Attr1/Called, Restr1/string, Attr2/World-part, Resrt2/space-object, Attr3/capital, Restr3/city1,
Row/2, Focus/city1, Base/space-object, Numb/3, Attr1/Called, Restr1/string, Attr2/Country-part, Restr2/country1, Attr3/Population, Resrt3/integer*,
Row/3, Focus/football-team, Base/sport-team, Numb/3, Attr1/Called, Restr1/string, Attr2/Sport-kind, Restr2/football, Attr3/Symbolics, Resrt3/emblem1,
Row/4, Focus/emblem1, Base/picture1, Numb/2, Attr1/Colours-combination, Restr1/colour-value*, Attr2/Drawn-object, Restr2/phys-object.

It is important for us that, according to TKR, *the constructs have no semantic frames*. This fact is used below in the description of the suggested algorithm.

In order to "understand" metonymic phrases, an intelligent computer system is to use not only a terminological knowledge base but also a database containing the information about the objects of external world and coordinated with TKB.

Example 2. With respect to this purpose, let's consider (continuing the example 1) the following logical structure of the relation ObjectsBase:

Row/1, Identifier/Voronezh-city, Concept/city1, Numb/3, Attr1/Called, Restr1/ "Voronezh", Attr2/Country-part, Restr2/Russian-Federation, Attr3/Population, Restr3/1.05#mln,
Row/2, Identifier/Moscow-city, Concept/city1, Numb/3, Attr1/Called, Restr1/ "Moscow", Attr2/Country-part, Restr2/Russian-Federation, Attr3/Population, Restr3/13#mln,
Row/3, Identifier/emblem73, Concept/emblem1, Numb/2, Attr1/Colours-combination, Restr1/(*red* $\wedge$ *white*), Attr2/Drawn-object, Restr2/sport-ball,
Row/4, Identifier/Spartak (Moscow), Concept/football-team, Numb/3, Attr1/Called, Restr1/ "Spartak Moscow", Attr2/Sport-kind, Restr2/football, Attr3/Symbolics, Restr3/emblem73.

The meaning of the first column in the relations ConceptsFrames and ObjectsBase is the same: the elements of these columns are the ordered numbers of the rows. The second column of the relation ObjecstBase has the index Identifier, the elements are the unique identifiers of various entities. The column No. 3 has the index Concept, the elements of this column are conceptual characteristics of the entities represented in the corresponding rows. The columns with the numbers ≥ 4 have the meanings similar to the meanings of the columns with the numbers ≥ 5 of the relation ConceptsFrames. The difference is as follows: instead of formulating a semantic restriction for a search attribute, an exact value of this attribute is indicated (for instance, compare Restr1/string and Restr1/"Moscow").

V. THE CENTRAL IDEA OF THE FIRST EXTERNAL CYCLE ACROSS SEARCH ATTRIBUTES OF THE RELATION CONCEPTSFRAMES

Suppose that the algorithm to be introduced below is processing the notion in the position *j* of the array *MentionedConcepts*, where j≥1, and the array contains the concept *football-team* in the position *.j* Let *row1* be the minimal integer ≥1 such that *ConceptsFrames*[*row1*, 2] = *football-team*. This situation means that the input text T1 mentions an entity A, and it is a football team.

The goal of our current step is to be as follows: to verify that the concept *current-sema* qualifies an entity A, and A is associated with such entity B that the value of one of the properties of B is the *sort-value*. In our example, B is an emblem, the sort-value = *colours-combination*, and the focus-value = (*red* $\wedge$ *white*).

We assume that a connection between the entities A and B may be realized only with the help of any of search attributes of the concept *current-sema*. We should consider not all search attributes of *current-sema* but only the search attributes with semantic restriction satisfying two conditions:

(a) It is not a sort, i.e., it doesn't belong to the set of sorts determined by the considered conceptual basis B (see [14]); in particular, it means that semantic restriction is not the concept *string*;

(b) It is not a sort of a construct, i.e., its semantic restriction doesn't have the final symbol * (for example, the semantic restriction of the search attribute *Population* has the semantic restriction *integer**).

The variable numb-sem-attr1 receives the value ConceptsFrames[row1, 4], it denotes the number of search attributes in the line row1. Then we consider the columns with ordered numbers of the form 4+2k-1 (k=1, 2,..), and for each fixed k fulfill the following actions;

Attribute:= ConceptsFrames[row1, 4+2k-1],

Current-value:=ConceptsFrames[row1, 4+2k].

If *current-value* is either a construct or belongs to the set of sorts St(B) (in particular, it is the sort *string*), then we do nothing and fulfil the same step after executing the assignment operator k:=k+1.

Example 3. Let j=2, then MentionedConcepts[j] = football-team, and row1:=3. Firstly, k:=1, then

ConceptsFrames[row1, 4+2-1] :=Called,

Current-value:=ConceptsFrames[row1, 4+2], hence *current-value*:=*string*. Since string is a sort, we go to the next value of k (by means of the assignment k:=k+1).

VI. A DESCRIPTION OF THE ALGORITHM OF PROCESSING METONYMIC PHRASES

An algorithm called AlgMetonymyProcessing1 is introduced below. The condition of calling it by a computer program has some small peculiarities depending on the considered input language. For English language, this condition is the occurrence in the processed text of the artificial noun attribute constructed from an attribute or several attributes. We say here “artificial noun” in the sense that the dictionaries contain no such expression with the mark that it is a noun. The expression “the red-whites” gives us an example of such construction. In case of Russian language, the condition of calling the algorithm described below is that the considered text contains an attribute or a bunch of attributes relating to no noun (an example: “krasno-belye”).

In a situation of the kind, the main module of computer program forms a construct as the value of the string variable *focus-value*. For instance, for the text T1 = “On April 12, a match between the football teams “Zenith” and “Spartak Moscow” took place in Saint-Petersburg. It was the victory of the red-whites with the score 2:1”, the variable *focus-value* will have the value (*red* $\wedge$ *white*).

The initial version of the algorithm AlgMetonymyProcessing1 is realized in an intelligent computer system updating the content of relational databases by means of semantic processing of the resources from a full-text database [16]. This initial version is developed by the author of the present paper and is not published anywhere. The algorithm’s initial version looks rather similar to a method description, it is not a clear pseudocode. The pseudocode given below is original, and it is a contribution to theoretical foundations of algorithms fulfilling semantic processing of metonymic texts.

External specification of the algorithm

Input:

One-dimensional array **MentionedConcepts** (listing the concepts qualifying the entities mentioned in the input text);

things-number – integer – the number of filled in positions of the array MentionedConcepts;

Sorts – a finite set of symbols called sorts and denoting the most general concepts from the considered thematic domains;

The relations (two-dimensional arrays) **ConceptsFrames, ObjectsBase**;

focus-value – a construct being a unique characteristic of an object to be found;

sort-value – the sort of the construct focus-value.

Auxiliary function First-row. Its argument is any concept *semunit*. The value is such minimal $n \geq 1$ that ConceptsFrames[n, 2] = *semunit* or the value is 0.

Example 4. For the considered text T1, MentionedConcepts[2] = football-team, MentionedConcepts[3] = city1; Things-number = 4; the structure of the relations ConceptsFrames and ObjectsBase is illustrated above in the examples 1 and 2 respectively. Focus-value is the compound construct (*red* $\wedge$ *white*); sort-value is the sort *colour-value.*

Output:

posfound – integer – the number of a row of the relation ObjectsBase indicating a unique entity in the world.

Algorithm AlgMetonymyProcessing1

Begin An one-dimensional array MentionedConcepts is constructed, and the value of the integer variable Things-number is calculated.

var-go-out1 := false; var-go-out2 := false; var-go-out3 := false; j:=0

Cycle 1 with conditional exit (until-cycle) on the parameter j

Begin j:= j+1

Current-sema := MentionedConcepts[j]

{Comment: if j = 2, then current-sema := football-team}

row1 := First-row(current-sema, ConceptsFrames)

{Example: if j=2 then row1:=3 for the input text T1, see Example 1 in Section IV}

Numb-search-attr1 := ConceptsFrames[raw1, 4]

K := 0

Cycle 2 with conditional exit (until-cycle) on search attributes of the concept current-sema

{Comment: exit condition is ((var-go-out 1= true) OR (k = Numb-search-attr1))}

Begin k:= k+1

Current-value:= ConceptFrames[row1, 4+2k]

{Comment: It is semantic restriction of the k-th search attribute}

{Example. If j =2, row1= 3, k=1 then current-value:= string}

If ((current-value doesn’t belong to the set of sorts) AND (current-value is not a construct))

then begin looked-concept := current-value;

row2 := First-row(looked-concept, ConceptFrames)

numb-search-attr2 := ConceptsFrames[raw2, 4]

if row2 > 0

then begin m := 0

Cycle 3 with conditional exit (until-cycle) on search attributes of the concept *looked-concept*

{Comment: exit condition is ((var-go-out 2= true) OR (m = numb-search-attr2))}

Begin m := m+1

second-search-value := ConceptsFrames[row2, 4+2m]

if second-search-value = focus-value

then var-go-out2 := true

{Comment: end-if}

until ((var-go-out2 = true) OR (m=numb-search-attr2)

{Comment: end-cycle on m}

end

until ((var-go-out1 = true) OR (k=numb-search-attr1))

{Comment: end-cycle on k}

end

until (((var-go-out1 = true) AND (var-go-out2 = true)) OR (j=ThingsNumber(MentionedConcepts)))

{Comment: end-cycle on j}

End

{Comment: Now go to processing the relation ObjectsBase}

var-go-out3= false

thing-row:= 0

Cycle with conditional exit (until-cycle) on the rows of the relation ObjectsBase

{Comment: exit condition is ((var-go-out3= true) OR (thing-row is the last row of the relation ObjectsBase))}

thing-row := thing-row + 1

current-thing:= ObjectsBase[thing-row, 4+2m]

if current-thing = focus-value

then var-go-out 3 ;= true, posfound:=thing-row

until ((var-go-out 3= true) OR (thing-row is the last row of the relation ObjectsBase))

{Comment: end-cycle on thing-row}

Output(k, m, posfound)

End End

Example 5. Taking into account the examples 1 and 2 in section IV, the successful result for the considered text T1 will be achieved for the following values of the variables: k=3 (according to the example 1, k is the ordered number of the search attribute *Symbolics* of the concept *football-team*), m = 1 (according to the example 1, m is the ordered number of the search attribute *Colours-combination* of the concept *emblem1*), posfound = 4 (according to the example 2, it is the number of the row containing information about the football-team "Spartak Moscow').

That is why the winner in the match is the football team "Spartak Moscow". This information will be inscribed into a corresponding sportive relational database.

VII. CONCLUSION

The purpose of the introduced algorithm is to process metonymical phrases. It seems that it would be easy to implement it with the help of arbitrary programming environment. The content of the next stage of the research would be the expansion of the algorithm in order to process several different kinds of metonymical phrases. In particular, to process the phrases of the kind "The winners in this hockey match were the maple leaves" with the meaning "The combined hockey team of Canada became the winner in this match".

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