Translation of natural language queries to structured data sources

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***Abstract*—Nowadays most of people of developed economy countries interact with software every day. As a result of computer systems expansion to all scope of people's activity the problem of transition from visual and command interfaces to natural language user interfaces is thrown into the sharp relief. Computational linguistics and natural language processing methods are described in this article. Methods of natural language manipulation are applied in machine translation software systems, systems of search and exchange the data, text annotation and expert systems. Prototype of natural language user interface to structured data source is developed. As a result it is convert natural language user's query to SQL query to database. Natural language user interface is created to predefined subject field. User interface interacts to database that contain information about existent program libraries and frameworks. Consequently, using natural language processing methods it is possible to develop user natural language user interface providing capability to interact with machine.**

***Index Terms*—Natural language processing, database.**

I. Introduction

There are many computer software systems in the world. Each of them has a different principle of interaction. As a result it leads to some problems of their free using.

Using natural language to communicate with computer software systems is a way to solve the problem. Natural language user interface may help people to interact with computer systems. And this method has such advantages as

- Minimal user preparation for working with computer system
- Simple and fast way to put an arbitrary question to software system.

Simplicity of natural language interface interaction is achieved by everyday using natural language.

Limited set of vocabulary and grammar units can be used for natural language user interface of software systems. It doesn't lead to deep functionality degrading of question-answering system.

Limited language is a subset of natural language. A native speaker easily understands the text in a limited language.

There is no need to lengthy learning skills of limited language text composition because it has a limited set of vocabulary and grammar.

It allows avoiding linguistic uncertainty and decreases natural language elements processing time [1].

II. Workflow

Natural language user interface is considered to be a specific intelligence system providing a dialogue between the user and the software system within a definite subject field.

Intelligence system of natural language user interface consists of:

- User interface whereby the user inputs the message and gets an answer from the system.
- Translator of natural language requests to internal language of queries.
- Translator of internal language units to natural language.

The operation cycle of natural language user interfaces starts with the message input in natural language by entering the text. The next step is creating a formal description of the text. All previous analysis results are used to analyse the following queries. It makes it possible to resolve the issues connected with using the same terms in different subject fields.

All components of natural language user interface knowledge machine may be classified into translators and analyzers. Translators translate knowledge from one language to another. For example, they translate the descriptive knowledge of some subject field to a natural language text.

The analyzers analyze knowledge units and develop previously unknown facts. For example, it can be the analysis of a user's question to find an answer.

III. Markov decision process

Translation system is the part of dialogue system. This section represents dialogue system as a Markov decision process. It will be illustrated by the example of dialogue where the goal of the system is to get the list of libraries to user through the shortest possible interaction. In this example user should make queries using values of "programming language" and "license type" as a filter.

Markov decision process is described in terms of a state space, an action set and a strategy. Dialogue system's state represents all resources it interacts with. For our example, the state includes two entries: libraries list filter by "programming language" and libraries list filter by "license type". The total number of states including one initial state, different combinations of libraries list depends on input values and filter, and a special final empty state.

The action set of the dialogue system includes all possible actions it can perform, such as interactions with the user (e.g. asking the user for input, providing a user some output, confirmations, etc.), interactions with other external resources (e.g. querying a database), and internal processing.

For our example, the action set include such actions as:

1) A question where user asking libraries list for specific programming language.

2) A question where user asking libraries list with specific license type.

3) Step-by-step questions where user asking libraries list with specific programming language and license type or vice versa.

4) A final action, closing the dialogue.

When an action a is taken at state s, the system's state changes to be s'. The state transitions are modeled by transition probabilities as in Eq. 1.

$$P_T(s(t+l) = s' \mid s(t) = s,\ a(t) = a) \tag{1}$$

Path from initial to final state is a dialogue session. A dialogue strategy shows what is the next action will be invoked for each reached state.

It is possible to measure the system performance by an objective function C, where the costs C_i measure the distance to the achievement of the application goal, and the efficiency of the interactions as in Eq. 2.

$$C = \sum C_i \tag{2}$$

In general, the costs in Markov decision process are described by the conditional distributions as in Eq. 3.

$$P_C(c(t) = c \mid s(t) = s,\ a(t) = a) \tag{3}$$

Quadruple of state space, action set, transition probabilities, and cost distributions defines a Markov decision process.

For our example the objective function includes three terms as:

$$C = W_i \times \langle\#\ interactions\rangle + W_e \times \langle\#\ errors\rangle + W_f \times \langle\#\ incomplete\ values\rangle$$

The first term is the expected duration of the dialogue; the second corresponds to the expected number of errors in the obtained values; and the third measures the expected distance from achieving our application.

In order to reflect this objective function in our dialogue model, we associate a cost c to the taken action a in a state s. The cost incurred with any of the first three actions in dialogue system is $W_i + W_e \times$ *number of errors*. If we assume that the concept error rate for recognition of filter values separately (for questions 1 and 2) is p_1 , and together (for question 3) is p_2, $p_2 > p_1$, then the expected cost accumulated when actions 1 or 2 are taken is $W_i + W_e \times p1$, while for question 3 is $W_i + 2 \times W_e \times p_2$. For action 4 (closing the dialogue) the cost depends deterministically on the state in which this action is taken and is $W_i + 2 \times W_f$ for an initial state, $W_i + W_f$ for states in which one of the filter values isn't used, and W_i for the states in which both filter values are used.

Fig. 1 shows three different strategies and their costs for the example system. Optimal strategy minimizes the objective function. In this case $C_1 = W_i + 2 \times W_f$. For example, in strategy 1 (where the system close the dialogue as the first action) is optimal when the recognition error rate is too high: $p_1 > (W_f - W_i) / W_e$.

In strategy 2, a user asking libraries list for one of the disposable filter values, and closes the session. In this case $C_2 = 2 \times W_i + 2 \times p_2 \times W_e$.

In strategy 3, a user asking library list with specific programming language and license type, and then closes the session. In this case $C_3 = 3 \times W_i + 2 \times p_1 \times W_e$. Strategy 3 is optimal when the difference in error rates justifies a longer interaction: $p_2 - p_1 > W_i / 2 \times W_e$.

There exist in literature several techniques for computing the optimal strategy given the correct model parameters (the transition probabilities and the cost distributions), including value iteration, policy iteration, etc. These techniques are based on dynamic programming that can be used due to the Markovian nature of this model. They rely on the following definition:

Optimal value $V(s)$ of a state s is the lowest expected cost incurred after the system left state s and until it reached the final state. The optimal value function is unique and can be defined as the solution to the simultaneous equations as in Eq. 4.

$$V(s) = \min_a \Big(\langle C(s,a) \rangle + \textstyle\sum_{s'} P_T(s' \mid s,a)\, V(s') \Big), \tag{4}$$

where $\langle C(s,a) \rangle$ is the expected cost for action a in state s [2].

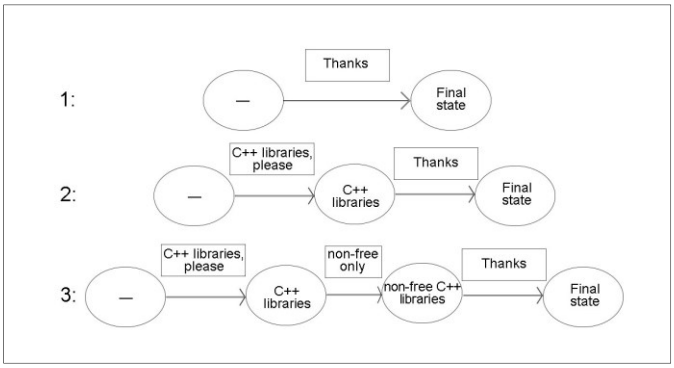

Fig 1. Different strategies of Markov decision process.

IV. Natural language processing

Natural language processing of a text consists of three phases:

- Morphological analysis.
- Syntactic analysis.
- Semantic analysis.

The first step is morphological analysis. For each allolog relations for grammatical categories like gender, case, declension and so on are formally extracted from the sentence.

The next step is syntactic analysis. Syntactic relations between words are created in the sentence, main and subordinate parts of sentence are extracted, sentence type is specified, and so on.

Syntactic analysis is executed phase-by-phase using the data obtained at the previous step. This phase uses lexical and syntactic rules for analyzing the language.

Semantic analysis phase is the most difficult phase of natural language processing. Semantic analysis is based on knowledge machine for a specific subject field and the information received within previous phases. At this stage a linguistic construction is compared with the construction stored in system memory.

Creating word semantic model is referred to as polysemanticism. Word sense is a set of possible values, each of them may be implemented in a specific subject field.

V. Translation natural language query to SQL

Prototype of natural language user interface to database was developed in this research. Source data is relational database MySQL that contains information about existent program libraries and frameworks. Test database contains table that consists of such fields as:

- Unique identifier
- Name
- URL to official website or repository
- Creation date
- Author
- License
- Type: library or framework
- Size
- Dependencies
- Programming language
- Active community occurrence

Output data of natural language user interface is SQL query to database. One of the necessary conditions is occurrence of data structure describing the database. In particular, information about table's and their fields names should be occurred.

Complex natural language sentence in user's query to database didn't used in natural language user interface. Though, it needs to create linguistic analyser as converter that consists of two text abstraction levels — morphological and syntactic [3]. Each text abstraction level should have a model component with array of rules and libraries and have custom query image such as morphological and syntactic structures.

There is no need to use the semantic analysis phase because subject field are known beforehand and linguistic analyser should be therefore named as linguistic translator.

Acceptable quality level of natural language query processing achieved without full grammatical sentence analysis. It is enough to extract the most informative parts of texts such as keywords, phrases and fragments. Next step is creation of morphological and syntactic models using morphological and syntactic analysis methods [4].

Source data is user's query to relational database that has such limits as:

- Query consists of one or more simple sentences in Russian language.
- If query contains multiple simple sentences then each next sentence should contain noun from one of previous sentences.
- Query should request information relevant to database.
- Query should has clear nature: shouldn't use demonstrative and personal pronouns ("I, you, he/she/it, they, this, that") and particles ("whether, or, which").
- It is recommended start query with special words such as "get", "show", "enumerate", "when", "which time", "what", "which".

Example of translating natural language query in Russian to SQL:

"Показать библиотеки для C++" ("Show C++ programming libraries")

SELECT Name,Url FROM Data WHERE Type='library' AND Language='cpp'

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