

Ripple Down Rules for Question Answering

Editor(s): Christina Unger, Bielefeld University, Germany; Axel-Cyrille Ngonga Ngomo, University of Leipzig, Germany; Philipp Cimiano, Bielefeld University, Germany; Sören Auer, University of Bonn, Germany; George Paliouras, NCSR Demokritos, Greece
Solicited review(s): Gosse Bouma, University of Groningen, Netherlands; Konrad Höffner, University of Leipzig, Germany; Shizhu He, Chinese Academy of Sciences, China; Christina Unger, Bielefeld University, Germany

Dat Quoc Nguyen^{a,*}, Dai Quoc Nguyen^b and Son Bao Pham^c

^a *Department of Computing, Macquarie University, Australia*

E-mail: dat.nguyen@students.mq.edu.au

^b *Department of Computational Linguistics, Saarland University, Germany*

E-mail: daiquocn@coli.uni-saarland.de

^c *VNU University of Engineering and Technology, Vietnam National University, Hanoi, Vietnam*

E-mail: sonpb@vnu.edu.vn

Abstract. Recent years have witnessed a new trend of building ontology-based question answering systems. These systems use semantic web information to produce more precise answers to users' queries. However, these systems are mostly designed for English. In this paper, we introduce an ontology-based question answering system named KbQAS which, to the best of our knowledge, is the first one made for Vietnamese. KbQAS employs our question analysis approach that systematically constructs a knowledge base of grammar rules to convert each input question into an intermediate representation element. KbQAS then takes the intermediate representation element with respect to a target ontology and applies concept-matching techniques to return an answer. On a wide range of Vietnamese questions, experimental results show that the performance of KbQAS is promising with accuracies of 84.1% and 82.4% for analyzing input questions and retrieving output answers, respectively. Furthermore, our question analysis approach can easily be applied to new domains and new languages, thus saving time and human effort.

Keywords: Question answering, Question analysis, Single Classification Ripple Down Rules, Knowledge acquisition, Ontology, Vietnamese, English, DBpedia, Biomedical

1. Introduction

Accessing online resources often requires the support from advanced information retrieval technologies to produce expected information. This brings new challenges to the construction of information retrieval systems such as search engines and question answering (QA) systems. Given an input query expressed in a keyword-based mechanism, most search engines return a long list of title and short snippet pairs ranked by their relevance to the input query. Then the user has to scan the list to get the expected information, so this is a time consuming task [66]. Unlike search engines,

QA systems directly produce an exact answer to an input question. In addition, QA systems allow to specify the input question in natural language rather than as keywords.

In general, an open-domain QA system aims to potentially answer any user's question. In contrast, a restricted-domain QA system only handles the questions related to a specific domain. Specifically, traditional restricted-domain QA systems make use of relational databases to represent target domains. Subsequently, with the advantages of the semantic web, the recent restricted-domain QA systems employ knowledge bases such as ontologies as the target domains [30]. Thus, semantic markups can be used to add meta-information to return precise answers for complex nat-

*The first two authors contributed equally to this work. Corresponding author's e-mail: dat.nguyen@students.mq.edu.au.

ural language questions. This is an avenue which has not been actively explored for Vietnamese.

In this paper, we introduce the first ontology-based QA system for Vietnamese, which we call KbQAS. KbQAS consists of question analysis and answer retrieval components. The question analysis component uses a knowledge base of grammar rules for analyzing input questions; and the answer retrieval component is responsible for interpreting the input questions with respect to a target ontology. The association between the two components is an intermediate representation element which captures the semantic structure of any input question. This intermediate element contains properties of the input question including question structure, question category, keywords and semantic constraints between the keywords.

The *key innovation* of KbQAS is that it proposes a knowledge acquisition approach to systematically build a knowledge base for analyzing natural language questions. To convert a natural language question into an explicit representation in a QA system, most previous works so far have used rule-based approaches, to the best of our knowledge. The manual creation of rules in an ad-hoc manner is more expensive in terms of time and effort, and it is error-prone because of the representation complexity and the variety of structure types of the questions. For example, rule-based methods, such as for English [26] and for Vietnamese as described in the first KbQAS version [35], manually define a list of pattern structures to analyze the questions. As rules are created in an ad-hoc manner, these methods share common difficulties in controlling the interaction between the rules and keeping the consistency among them. In our question analysis approach, however, we apply Single Classification Ripple Down Rules knowledge acquisition methodology [10,47] to acquire the rules in a systematic manner, where consistency between rules is maintained and an unintended interaction among rules is avoided. Our approach allows an easy adaptation to a new domain and a new language and saves time and effort of human experts.

The paper is organized as follows. We provide related work in Section 2. We describe KbQAS and our knowledge acquisition approach for question analysis in Section 3 and Section 4, respectively. We evaluate KbQAS in Section 5. The conclusion will be presented in Section 6.

2. Short overview of question answering

2.1. Open-domain question answering

The goal of an open-domain QA system is to automatically return an answer for every natural language question [21,63,31]. For example, such systems as START [23], FAQFinder [8] and AnswerBus [68] answer questions over the Web. Subsequently, the question paraphrase recognition task is considered as one of the important tasks in QA. Many proposed approaches for this task are based on machine learning as well as knowledge representation and reasoning [7,22,48,67,16,5].

Since aroused by the QA track of the Text Retrieval Conference [59] and the multilingual QA track of the CLEF conference [42], many open-domain QA systems from the information retrieval perspective [24] have been introduced. For example, in the TREC-9 QA competition [58], the Falcon system [20] achieved the highest results. The innovation of Falcon focused on a method using WordNet [17] to boost its knowledge base. In the QA track of the TREC-2002 conference [60], the PowerAnswer system [33] was the most powerful system, using a deep linguistic analysis.

2.2. Traditional restricted-domain question answering

Usually linked to relational databases, traditional restricted-domain QA systems are called natural language interfaces to databases. A natural language interface to a database (NLIDB) is a system that allows the users to access information stored in a database by typing questions using natural language expressions [2]. In general, NLIDB systems focus on converting the input question into an expression in the corresponding database query language. For example, the LUNAR system [64] transfers the input question into a parsed tree, and the tree is then directly converted into an expression in a database query language. However, it is difficult to create converting rules that directly transform the tree into the query expression.

Later NLIDBs, such as Planes [61], Eufid [51], PRECISE [46], C-Phrase [32] and the systems presented in [50,34], use semantic grammars to analyze questions. The semantic grammars consist of the hard-wired knowledge orienting a specific domain, so these NLIDB systems need to develop new grammars when ever porting to a new knowledge domain.

Furthermore, some systems, such as TEAM [29] and MASQUE/SQL [1], use syntactic-semantic interpretation rules driving logical forms to process the input question. These systems firstly transform the input question into an intermediate logical expression of high-level world concepts without any relation to the database structure. The logical expression is then converted to an expression in the database query language. Here, using the logical forms enables those systems to adapt to other domains as well as to different query languages [49]. In addition, there are many systems also using logical forms to process the input question, e.g. [52,33,56,18,15,25,6].

2.3. *Ontology-based question answering*

As a knowledge representation of a set of concepts and their relations in a specific domain, an ontology can provide semantic information to handle ambiguities, to interpret and answer user questions in terms of QA [27]. A discussion on the construction approach of an ontology-based QA system can be found in [4]. This approach was then applied to build the MOSES system [3], with the focus on the question analysis. The following systems are some typical ontology-based QA systems.

The AquaLog system [26] performs semantic and syntactic analysis of the input question using resources including word segmentation, sentence segmentation and part-of-speech tagging, provided by the GATE framework [11]. When a question is asked, AquaLog transfers the question into a query-triple form of (generic term, relation, second term) containing the keyword concepts and relations in the question, using JAPE grammars in GATE. AquaLog then matches each element in the query-triple to an element in the target ontology to create an onto-triple, using string-based comparison methods and WordNet [17]. Evolved from AquaLog, the PowerAqua system [28] is an open-domain system, combining the knowledge from various heterogeneous ontologies which were autonomously created on the semantic web. Meanwhile, the PANTO system [62] relies on the statistical Stanford parser to map an input question into a query-triple; the query-triple is then translated into an onto-triple with the help of a lexicon of all entities from a given target ontology enlarged with WordNet synonyms; finally, the onto-triple and potential words derived from the parse tree are used to produce a SPARQL query on the target ontology.

Using the gazetteers in the GATE framework, the QuestIO system [12] identifies the keyword concepts in an input question. Then QuestIO retrieves potential relations between the concepts before ranking these relations based on their similarity, distance and specificity scores; and so QuestIO creates formal SeRQL or SPARQL queries based on the concepts and the ranked relations. Later the FREyA system [13], the successor of QuestIO, allows users to enter questions in any form and interacts with the users to handle ambiguities if necessary.

In the ORAKEL system [9], wh-questions are converted to F-Logic or SPARQL queries by using domain-specific Logical Description Grammars. Although ORAKEL supports compositional semantic constructions and obtains a promising performance, it involves a customization process of the domain-specific lexicon. Also, another interesting work over linked data as detailed in [55] proposed an approach to convert the syntactic-semantic representations of the input questions into the SPARQL templates. Furthermore, the Pythia system [54] relies on ontology-based grammars to process complex questions. However, Pythia requires a manually created lexicon.

2.4. *Question answering and question analysis for Vietnamese*

Turning to Vietnamese question answering, Nguyen and Le [34] introduced a Vietnamese NLIDB system using semantic grammars. Their system includes two main modules: the query translator (QTRAN) and the text generator (TGEN). QTRAN maps an input natural language question to an SQL query, while TGEN generates an answer based on the table result of the SQL query. The QTRAN module uses limited context-free grammars to convert the input question into a syntax tree by means of the CYK algorithm [65]. The syntax tree is then converted into an SQL query by using a dictionary to identify names of attributes in the database and names of individuals stored in these attributes. The TGEN module combines pattern-based and keyword-based approaches to make sense of the meta-data and relations in database tables to produce the answer.

In our first KbQAS conference publication [35], we reported a hard-wired approach to convert input questions into intermediate representation elements which are then used to extract the corresponding elements from a target ontology to return answers. Later, Phan and Nguyen [45] described a method to map Vietnamese questions into triple-like formats (Subject,

Verb, Object). Subsequently, Nguyen and Nguyen [40] presented another ontology-based QA system for Vietnamese, where keywords in an input question are identified by using pre-defined templates, and these keywords are then used to produce a SPARQL query to retrieve a triple-based answer from a target ontology. In addition, Tran et al. [53] described the VPQA system to answer person name-related questions while Nguyen et al. [41] presented another NLIDB system to answer questions in the economic survey domain.

3. Our KbQAS question answering system

This section gives an overview of KbQAS. The architecture of KbQAS, as shown in Figure 1, contains two components: the natural language question analysis engine and the answer retrieval component.

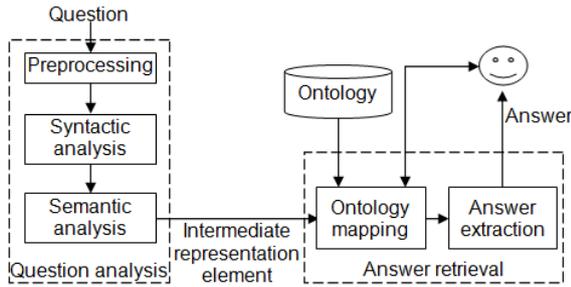


Figure 1. System architecture of KbQAS.

The question analysis component consists of three modules: preprocessing, syntactic analysis and semantic analysis. This component takes the user question as an input and returns an intermediate element representing the input question in a compact form. The role of the intermediate representation element is to provide the structured information about the input question for the later process of answer retrieval.

The answer retrieval component contains two modules: ontology mapping and answer extraction. It takes the intermediate representation element produced by the question analysis component and an ontology as its input to generate the answer.

3.1. Intermediate representation of an input question

Unlike AquaLog [26], the intermediate representation element in KbQAS covers a wider variety of question types. This element consists of a question structure and one or more query tuples in the following format:

(sub-structure, question category, $Term_1$, $Relation$, $Term_2$, $Term_3$)

where $Term_1$ represents a concept (i.e. an object class), excluding the cases of *Affirm*, *Affirm_3Term* and *Affirm_MoreTuples* question structures. In addition, $Term_2$ and $Term_3$ represent entities (i.e. objects or instances), excluding the cases of *Definition* and *Compare* question structures. Furthermore, $Relation$ is a semantic constraint between the terms.

We define the following question structures: *Normal*, *UnknTerm*, *UnknRel*, *Definition*, *Compare*, *ThreeTerm*, *Clause*, *Combine*, *And*, *Or*, *Affirm_MoreTuples*, *Affirm*, *Affirm_3Term*, and question categories: *What*, *When*, *Where*, *Who*, *HowWhy*, *YesNo*, *Many*, *ManyClass*, *List* and *Entity*. See Appendix A and Appendix B for details of these definitions.

A simple question has only one query tuple and its question structure is the sub-structure in the query tuple. A complex question, such as a composite one, has several sub-questions, where each sub-question is represented by a separate query tuple, and the question structure captures this composite factor.

For example, the question “Phạm Đức Đăng học trường đại học nào và được hướng dẫn bởi ai ?” (“Which university does Phạm Đức Đăng enroll in and who tutors him ?”) has the *Or* question structure and two query tuples where ? represents a missing attribute: (*Normal*, *Entity*, trường đại học_{university}, học_{enroll}, Phạm Đức Đăng_{Phạm Đức Đăng}, ?) and (*UnknTerm*, *Who*, ?, hướng dẫn_{tutor}, Phạm Đức Đăng_{Phạm Đức Đăng}, ?).

The intermediate representation element is designed so that it can represent various types of question structures. Therefore, attributes such as *Relation* or terms in the query tuple can be missing. For example, a question has the *Normal* question structure if it has only one query tuple and $Term_3$ is missing.

3.2. An illustrative example

For demonstration¹ [38] and evaluation purposes, we reuse an ontology which models the organizational system of the VNU University of Engineering and Technology, Vietnam. The ontology contains 15 concepts such as “trường_{school}”, “giảng viên_{lecturer}” and “sinh viên_{student}”, 17 relations or properties such as “học_{enroll}”, “giảng dạy_{teach}” and “là sinh viên của

¹The KbQAS is available at <http://150.65.242.39:8080/KbQAS/> with an intro video on YouTube at <http://youtu.be/M1PHvJv1Z8>.

The figure illustrates the question analysis and answering process in the KbQAS system. It is divided into two main sections: the top section for a Vietnamese question and the bottom section for an English question.

Top Section (Vietnamese Question):

- Question:** "Liệt kê tất cả sinh viên học lớp K50 khoa học máy tính mà có quê ở Hà Nội?"
- Intermediate Representation Element:**
 - Question-structure: And
 - The number of tuples: 2
 - Sub-structure: Normal
 - Question-class: List
 - Term 1: sinh viên
 - Relation: học
 - Term 2: lớp K50 khoa học máy tính
 - Term 3: Hà Nội
- The answer:** "nguyễn bá đạt", "nguyễn quốc đại", "nguyễn quốc đạt"

Bottom Section (English Question):

- Question:** "Who is the director of the compendium project in Knowledge Media?"
- Intermediate Representation Element:**
 - Question-structure: ThreeTerm
 - The number of tuples: 1
 - Sub-structure: ThreeTerm
 - Question-class: QU-who-what
 - Term 1: director
 - Term 2: compendium project
 - Term 3: Knowledge Media
- Answer:** "Who is member of the Open University?"

Figure 2. Illustrations of question analysis and question answering.

is student of”, and 78 instances, as described in our first KbQAS version [35].

Given a complex-structure question “Liệt kê tất cả sinh viên học lớp K50 khoa học máy tính mà có quê ở Hà Nội” (“List all students enrolled in the K50 computer science course, whose hometown is Hanoi”), the question analysis component determines that this question has the *And* question structure with two query tuples (*Normal, List, sinh viên_{student}, học_{enrolled}, lớp K50 khoa học máy tính_{K50 computer science course}, ?*) and (*Normal, List, sinh viên_{student}, có quê_{has hometown}, Hà Nội_{Hanoi}, ?*).

In the answer retrieval component, the ontology mapping module maps the query tuples to ontology tuples: (*sinh viên_{student}, học_{enrolled}, lớp K50 khoa học máy tính_{K50 computer science course}*) and (*sinh viên_{student}, có quê_{has hometown}, Hà Nội_{Hanoi}*). For each ontology tuple, the answer extraction module finds all satisfied instances in the target ontology, and it then generates an answer based on the *And* question structure and the *List* question category. Figure 2 shows the answer.

3.3. Natural language question analysis component

The natural language question analysis component is the first component in any QA system. When a question is asked, the task of this component is to convert

the input question into an intermediate representation which is then used in the rest of the system.

KbQAS makes use of the JAPE grammars in the GATE framework [11] to specify semantic annotation-based regular expression patterns for question analysis, in which existing linguistic processing modules for Vietnamese including word segmentation and part-of-speech tagging [43] are wrapped as GATE plug-ins. The results of the wrapped plug-ins are annotations covering sentences and segmented words. Each annotation has a set of feature-value pairs. For example, a word has a *category* feature storing its part-of-speech tag. This information can then be reused for further processing in subsequent modules. The new question analysis modules of preprocessing, syntactic analysis and semantic analysis in KbQAS are specifically designed to handle Vietnamese questions using patterns over existing linguistic annotations.

3.3.1. Preprocessing module

The preprocessing module generates *TokenVn* annotations representing a Vietnamese word with features, such as part-of-speech, as displayed in Figure 3. Vietnamese is a monosyllabic language; hence, a word can contain more than one token. So there are words or word phrases which are indicative of the question categories, such as “phải không_{is that / are there}”, “là bao

nhiều_{how many}”, “ở đâu_{where}”, “khi nào_{when}” and “là cái gì_{what}”. However, the Vietnamese word segmentation module was not trained on the question domain. In this module, therefore, we identify those words or phrases and label them as single *TokenVn* annotations with the *question-word* feature and its semantic category, like *HowWhy*_{cause / method}, *YesNo*_{true or false}, *What*_{something}, *When*_{time / date}, *Where*_{location}, *Many*_{number} or *Who*_{person}. In fact, this information will be used to create rules in the syntactic analysis module at a later stage.

Type	Set	Start	End	Id	Features
TokenVn		0	8	42	{question-word=Many, string=Số lượng}
TokenVn		9	18	29	{category=Nc, kind=word, string=sinh viên}
TokenVn		19	22	30	{category=Vt, kind=word, string=học}
TokenVn		23	26	31	{category=Nc, kind=word, string=lớp}
TokenVn		27	35	32	{category=Na, kind=word, string=khoa học}
TokenVn		36	44	33	{category=Nc, kind=word, string=máy tính}

Figure 3. Examples of *TokenVn* annotations.

We also label special words, such as abbreviations of words on a special domain, and phrases that refer to a comparison, such as “lớn hơn_{greater than}”, “nhỏ hơn hoặc bằng_{less than or equal to}” and the like, by single *TokenVn* annotations.

3.3.2. Syntactic analysis

The syntactic analysis module is responsible for identifying concepts, entities and the relations between them in the input question. This module uses the *TokenVn* annotations which are the output of the preprocessing module.

Concepts and entities are normally expressed in noun phrases. Therefore, it is crucial to identify noun phrases in order to generate the query tuple. Based on the Vietnamese language grammar [14], we use the JAPE grammars to specify patterns over annotations as shown in Table 1. When a noun phrase is matched, a *NounPhrase* annotation is created to mark up the noun phrase. In addition, a *type* feature of the *NounPhrase* annotation is used to determine whether concept or entity is covered by the noun phrase, using the following heuristics: if the noun phrase contains a single noun (not including numeral nouns) and does not contain a proper noun, it covers a concept. If the noun phrase contains a proper noun or at least three single nouns,

Table 1

JAPE grammar for identifying Vietnamese noun phrases.

({TokenVn.category == “Pn” }) ?	Quantity pronoun
({TokenVn.category == “Nu” } {TokenVn.category == “Nn” }) ?	Concrete noun Numeral noun
({TokenVn.string == “cái” } {TokenVn.string == “chiếc” }) ?	“cái _{the} ” “chiếc _{the} ”
({TokenVn.category == “Nt” }) ?	Classifier noun
({TokenVn.category == “Nc” } {TokenVn.category == “Ng” } {TokenVn.category == “Nu” } {TokenVn.category == “Na” } {TokenVn.category == “Np” }) +	Countable noun Collective noun Abstract noun Proper noun
({TokenVn.category == “Aa” } {TokenVn.category == “An” }) ?	Quality adjective Quantity adjective
({TokenVn.string == “này” } {TokenVn.string == “kia” } {TokenVn.string == “ấy” } {TokenVn.string == “đó” }) ?	“này _{this; these} ” “kia _{that; those} ” “ấy _{that; those} ” “đó _{that; those} ”

it covers an entity. Otherwise, the *type* feature value is determined by using a dictionary².

Furthermore, the question phrases are detected by using the matched noun phrases and the question words which are identified by the preprocessing module. *QuestionPhrase* annotations are generated to cover the question phrases, with a *category* feature that gives information about question categories.

The next step is to identify relations between noun phrases or between a noun phrase and a question phrase. When a phrase is matched by one of the relation patterns, a *Relation* annotation is created to markup the relation. We use the following four grammar patterns to determine relation phrases:

(Verb)+
(Noun Phrase _{type == Concept})
(Preposition)(Verb)?
(Verb)+((Preposition)(Verb))?
((“có _{have/has} ”) (Verb))+
(Adjective)
(Preposition)
(Verb)?
(“có _{have/has} ”)
((Noun Phrase _{type == Concept}) (Adjective))
(“là _{is/are} ”)

²The dictionary contains concepts which are extracted from the target ontology. However, there is no publicly available WordNet-like lexicon for Vietnamese. So we manually add synonyms of the extracted concepts to the dictionary.

Liệt kê tất cả các sinh viên có quê quán ở Hà Nội ?					
Danh sách tất cả các sinh viên có quê quán ở Hà Nội mà học lớp khoa học máy tính ?					
Type	Set	Start	End	Id	Features
QuestionPattern		0	49	89	{category=Normal, pattern=QuestionPhrase Relation NounPhrase}
QuestionPattern		53	133	90	{category=And, pattern=QuestionPhrase Relation NounPhrase And Relation NounPhrase}

Figure 4. Examples of question structure patterns.

For example, we can describe the first question “Liệt kê tất cả các sinh viên có quê quán ở Hà Nội” (“List all students whose hometown is Hanoi”) in Figure 4, using *NounPhrase*, *Relation* and *QuestionPhrase* annotations as follows:

[QuestionPhrase: Liệt kê_{list} [NounPhrase: tất cả các sinh viên_{all students}]] [Relation: có quê quán ở_{have hometown}] [NounPhrase: Hà Nội_{Hanoi}]

The phrase “có quê quán ở_{have hometown}” is the relation linking the question phrase “liệt kê tất cả các sinh viên_{list all students}” and the noun phrase “Hà Nội_{Hanoi}”.

3.3.3. Semantic analysis module

The semantic analysis module aims to identify the question structure and produce the query tuples (substructure, question category, *Term*₁, *Relation*, *Term*₂, *Term*₃) as the intermediate representation element of the input question, using the *TokenVn*, *NounPhrase*, *Relation* and *QuestionPhrase* annotations returned by the two previous modules. Existing *NounPhrase* annotations and *Relation* annotations are potential candidates for terms and relations in the query tuples, respectively. In addition, *QuestionPhrase* annotations are used to detect the question category.

In the first KbQAS version [35], following AquaLog [26], we developed an ad-hoc approach to detect structure patterns of questions and then use these patterns to generate the intermediate representation elements. For example, Figure 4 presents the detected structure patterns of the two example questions “Liệt kê tất cả các sinh viên có quê quán ở Hà Nội” (“List all students whose hometown is Hanoi”) and “Danh sách tất cả các sinh viên có quê quán ở Hà Nội mà học lớp khoa học máy tính” (“List all students enrolled in the computer science course, whose hometown is Hanoi”). We can describe these questions by using annotations generated by the preprocessing and syntactic analysis modules as follows:

[QuestionPhrase: Liệt kê tất cả các sinh viên_{List all students}] [Relation: có quê quán ở_{have hometown}] [NounPhrase: Hà Nội_{Hanoi}]

and

[QuestionPhrase: Liệt kê tất cả các sinh viên_{List all students}] [Relation: có quê quán ở_{have hometown}] [NounPhrase: Hà Nội_{Hanoi}] [And: [TokenVn: mà_{and}]] [Relation: học_{enrolled}] [NounPhrase: lớp khoa học máy tính_{computer science course}]

The intermediate representation element of an input question is created in a hard-wired manner linking every detected structure pattern via JAPE grammars. This hard-wired manner takes a lot of time and effort to handle new patterns. For example in Figure 4, the hard-wired approach is unable to reuse the detected structure pattern of the first question to identify the structure pattern of the second question. Since JAPE grammar rules were created in an ad-hoc manner, the hard-wired approach encounters common difficulties in managing the interaction among rules and keeping consistency.

Consequently, in this module, we solve the mentioned difficulties by proposing a knowledge acquisition approach for the semantic analysis of input questions, as detailed in Section 4. In this paper, this is considered as the key innovation of KbQAS.

3.4. Answer retrieval component

As presented in the first KbQAS version [35], the answer retrieval component includes two modules: ontology mapping and answer extraction, as shown in Figure 1. It takes the intermediate representation produced by the question analysis component and a target ontology as its input to generate an answer. To develop the answer retrieval component in KbQAS, we employed the relation similarity service component of AquaLog [26].

The task of the ontology mapping module is to map terms and relations in the query tuple to concepts, instances and relations in the target ontology by using string names. If an exact match is not possible, we use a string distance algorithm [57] and the dictionary

containing concepts and their synonyms to find near-matched elements from the target ontology, with the similarity measure above a certain threshold.

In case the ambiguity is still present, KbQAS interacts with users by showing different options, and the users then choose the suitable ontology element. For example, given the question “Liệt kê tất cả các sinh viên học lớp khoa học máy tính” (“List all students enrolled in the computer science course”), the question analysis component produces a query tuple (*Normal, List, sinh viên_{student}, học_{enrolled}, lớp khoa học máy tính_{computer science course}, ?*). Because the ontology mapping module cannot find the exact instance corresponding to “lớp khoa học máy tính_{computer science course}” in the target ontology, it requires the user to select between “lớp K50 khoa học máy tính_{K50 computer science course}” - an instance of class “lớp_{course}”, and “bộ môn khoa học máy tính_{computer science department}” - an instance of class “bộ môn_{department}”.

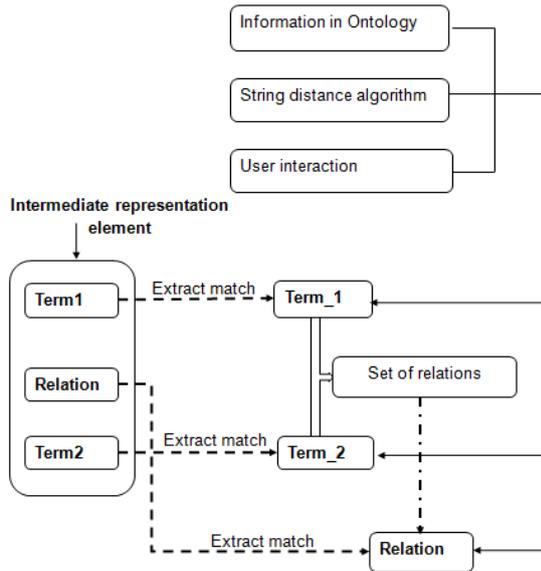


Figure 5. Ontology mapping module for the query tuple with two terms and one relation.

Following AquaLog, for each query tuple, the result of the ontology mapping module is an ontology tuple where the terms and relations in the query tuple are now the corresponding elements from the target ontology. How the ontology mapping module finds the corresponding elements from the target ontology depends on the question structure. For example, when the query tuple contains $Term_1$, $Term_2$ and $Relation$ with $Term_3$ missing, the mapping process follows the diagram shown in Figure 5. The mapping process first

tries to match $Term_1$ and $Term_2$ with concepts or instances in the target ontology. Then the mapping process finds a set of potential relations between the two mapped concepts/instances from the target ontology. The ontology relation is finally identified by mapping *Relation* to a relation in the potential relation set, using a manner similar to mapping a term to a concept or an instance.

With the ontology tuple, the answer extraction module finds all individuals of the ontology concept corresponding to $Term_1$, having the ontology relation with the ontology individual corresponding to $Term_2$. The answer extraction module then returns the answer based on the question structure and question category. See the definitions of question structure and question category types in Appendix A and Appendix B.

4. Single Classification Ripple Down Rules for question analysis

As mentioned in Section 3.3.3, due to the representation complexity and the variety of question structures, manually creating grammar rules in an ad-hoc manner is very expensive and error-prone. For example, such rule-based approaches as presented in [26,35,45] manually defined a list of sequence pattern structures to analyze questions. Since rules were created in an ad-hoc manner, these approaches share common difficulties in managing the interaction between rules and keeping consistency among them.

This section introduces our knowledge acquisition approach³ to analyze natural language questions by applying the Single Classification Ripple Down Rules (SCRDR) methodology [10,47] to acquire rules incrementally. Our contribution focuses on the semantic analysis module by proposing a JAPE-like rule language and a systematic processing to create rules in a manner that the interaction among rules is controlled and consistency is maintained. Compared to the first KbQAS version [35], this is the key innovation of the current KbQAS version.

A SCRDR knowledge base is built to identify the question structures and to produce the query tuples as the intermediate representations of the input questions. We outline the SCRDR methodology and propose a

³The English question analysis demonstration is available online at <http://150.65.242.39:8080/KbEnQA/>, and the Vietnamese question analysis demonstration is available online at <http://150.65.242.39:8080/KbVnQA/>.

rule language for extracting the intermediate representation of a given question in Section 4.1 and Section 4.2, respectively. We then illustrate the process of systematically constructing a SCRDR knowledge base for analyzing questions in Section 4.3.

4.1. Single Classification Ripple Down Rules

This section presents the basic idea of Single Classification Ripple Down Rules (SCRDR) [10,47] which inspired our knowledge acquisition approach for question analysis. A SCRDR tree is a binary tree with two distinct types of edges. These edges are typically called *except* and *false* edges. Associated with each node in a tree is a *rule*. A rule has the form: *if* α *then* β where α is called the *condition* and β is called the *conclusion*.

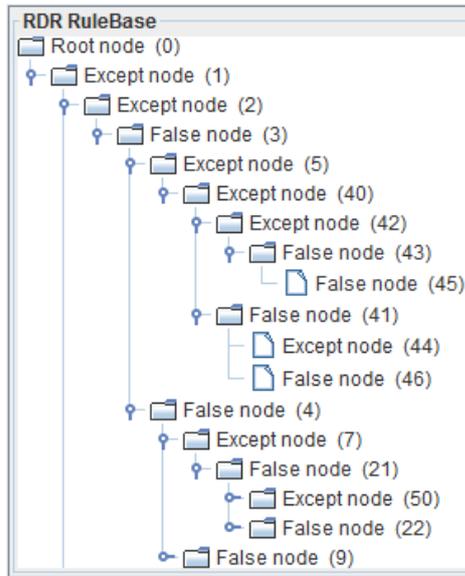


Figure 6. A part of the SCRDR tree for English question analysis.

Cases in SCRDR are evaluated by passing a case to the root node of the SCRDR tree. At any node in the SCRDR tree, if the condition of the rule at a node η is satisfied by the case (so the node η *fires*), the case is passed on to the *except* child node of the node η using the *except* edge if it exists; otherwise, the case is passed on to the *false* child node of the node η . The conclusion given by this process is the conclusion from the node which *fired* last.

Given the question “Who are the partners involved in AKT project ?” and the SCRDR tree in Figure 6, it is satisfied by the rule at the root node (0). Then it is passed to node (1) using the *except* edge. As the case satisfies the condition of the rule at node (1), it

is passed to node (2) using the *except* edge. Because the case does not satisfy the condition of the rule at node (2), it is then passed to node (3) using the *false* edge. As the case satisfies the conditions of the rules at nodes (3), (5) and (40), it is passed to node (42), using *except* edges. Since the case does not satisfy the conditions of the rules at nodes (42), (43) and (45), we have the evaluation path (0)-(1)-(2)-(3)-(5)-(40)-(42)-(43)-(45) with the last fired node (40). Given another case of “In which projects is enrico motta working on”, it satisfies the conditions of the rules at nodes (0), (1) and (2); as node (2) has no *except* child node, we have the evaluation path (0)-(1)-(2) and the last fired node (2).

A new node containing a new exception rule is added to an SCRDR tree when the evaluation process returns an *incorrect* conclusion. The new exception node is attached to the last node in the evaluation path of the given case as an *except* edge if the last node is the fired node; otherwise, it is attached as an *false* edge.

To ensure that a conclusion is always reached, the root node, called the *default* node, typically contains a trivial condition which is always satisfied. The rule at the default node, the default rule, is the unique rule which is not an exception rule of any other rule. For example, the default rule “*if True then null*” from the SCRDR tree in Figure 6 means that its *True* condition satisfies every question, however, its *null* conclusion produces an empty intermediate representation element for every question. Started with a SCRDR knowledge base consisting of only the default node, the process of building the knowledge base can be performed automatically [37,39] or manually [44,36].

In the SCRDR tree from Figure 6, the rule at node (1) (simply, rule 1) is an exception rule of the default rule 0. Rule 2 is an exception rule of rule 1. As node (3) is the *false*-child node of node (2), the rule 3 is also an exception rule of rule 1. Furthermore, both rules 4 and 9 are also exception rules of rule 1. Similarly, all rules 40, 41 and 46 are exception rules of rule 5 while all rules 42, 43 and 45 are exception rules of rule 40. Therefore, the exception structure of the SCRDR tree extends to 5 levels, for examples: rules 1 at layer 1; rules 2, 3, 4 and 9 at layer 2; rules 5, 7, 21 and 22 at layer 3; and rules 40, 41, 46 and 50 at layer 4; and rules 42, 43, 44 and 45 at the layer 5 exception structure.

4.2. Rule language

A rule is composed of a condition part and a conclusion part. A condition is a regular expression pattern

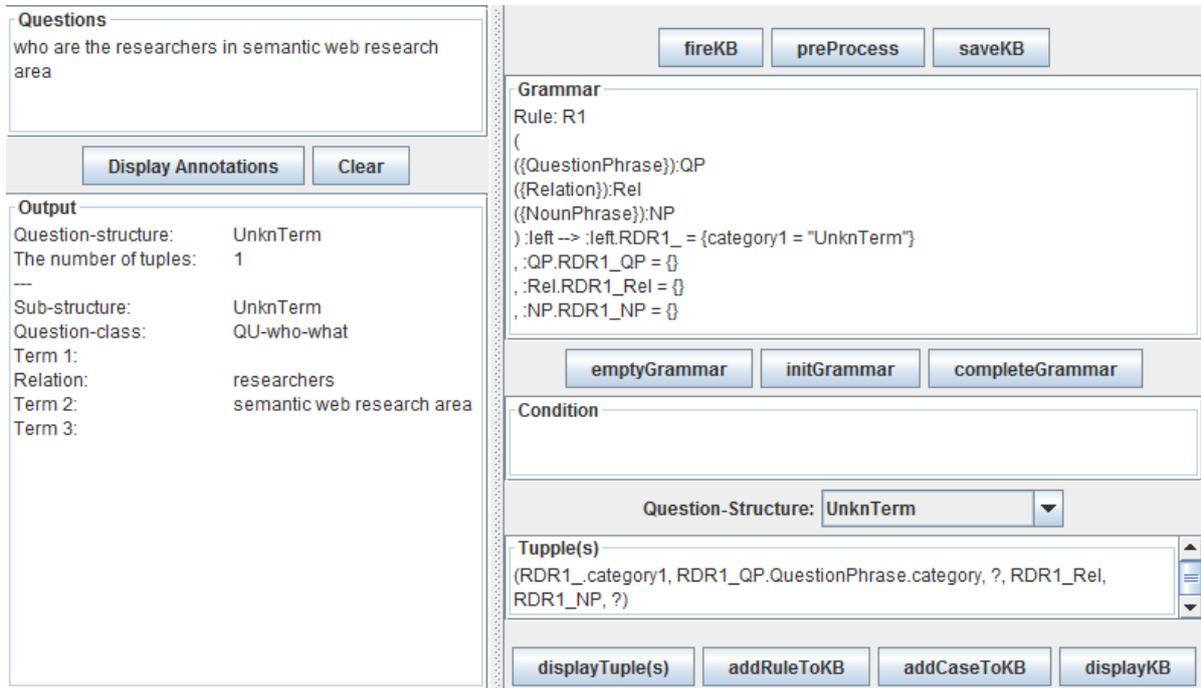


Figure 7. The graphic user interface for knowledge base construction.

over annotations using JAPE grammars in GATE [11]. It can also post new annotations over matched phrases of the pattern's sub-components. As annotations have feature-value pairs, we can impose constraints on the annotations in the pattern by specifying that a feature of an annotation must have a particular value. The following example shows the posting of an annotation over the matched phrase:

```
((TokenVn.string == "liệt kêlist") |
{TokenVn.string == "chỉ rashow"})
{NounPhrase.type == "Concept"}:qp
--> :qp.QuestionPhrase = {category = "List"}
```

Every complete pattern followed by a label must be enclosed by round brackets. In the above pattern, the label is *qp*. The pattern would match phrases starting with a *TokenVn* annotation covering either the word “liệt kê_{list}” or the word “chỉ ra_{show}”, followed by a *NounPhrase* annotation covering a *concept*-typed noun phrase. When applying this pattern on a text fragment, *QuestionPhrase* annotations having the *category* feature with its *List* value would be posted over phrases matched by the pattern. Furthermore, the condition part of a rule can include additional constraints. See examples of the additional constraints from the constructions of rules (40) and (45) in Section 4.3.

The conclusion part of a rule produces an intermediate representation containing the question structure

and the query tuples, where each attribute in the query tuples is specified by a newly posted annotation from matching the rule's condition, in the following order:

(sub-structure, question category, *Term*₁, *Relation*, *Term*₂, *Term*₃)

All newly posted annotations have the same *RDR* prefix and the rule index so that a rule can refer to annotations of its parent rules. Examples of rules and how rules are created and stored in an exception structure will be explained in details in Section 4.3.

Given an input question, the condition of a rule is satisfied if the whole input question is matched by the condition pattern. The conclusion of the fired rule produces the intermediate representation element of the input question. To create rules for matching the structures of questions, we use patterns over annotations returned by the preprocessing and syntactic analysis modules.

4.3. Knowledge acquisition process

Our approach is language-independent, because the main focus is on the process of creating the rule-based system. The language-specific part is in the rules itself. So, in this section, we illustrate the process of building a SCRDR knowledge base to analyze English ques-

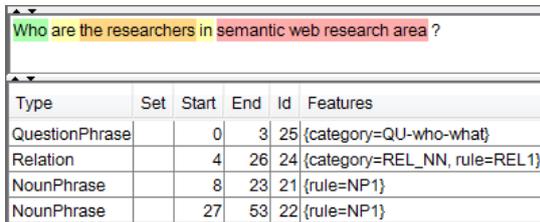
tions. Figure 7 shows the graphic user interface to construct SCRDR knowledge bases.

We reused the JAPE grammars which were developed to identify noun phrases, question phrases and relation phrases in AquaLog [26]. Based on *Token* annotations which are generated as output of the English tokenizer, sentence splitter and part-of-speech tagger in the GATE framework [11], the JAPE grammars produce *NounPhrase*⁴, *QuestionPhrase* and *Relation* annotations, and other annotation kinds such as *Noun*, *Verb* or *Preps* annotations for covering nouns, verbs or prepositions, respectively. We also reused question category definitions from AquaLog.

For illustrations in Section 4.3.1 and Section 4.3.2, we employed a training set of 170 English questions⁵, which AquaLog [26] analyzed successfully, to construct the SCRDR knowledge base in Figure 6. These questions concern the Knowledge Media Institute and its research area on the semantic web.

4.3.1. Reusing detected question structures

In contrast to the example in Section 3.3.3 with respect to Figure 4, we start with demonstrations of reusing detected question structure patterns.



Type	Set	Start	End	Id	Features
QuestionPhrase		0	3	25	{category=QU-who-what}
Relation		4	26	24	{category=REL_NN, rule=REL1}
NounPhrase		8	23	21	{rule=NP1}
NounPhrase		27	53	22	{rule=NP1}

Figure 8. Examples of annotations.

For the question “Who are the researchers in semantic web research area?”, we can represent this question using *NounPhrase*, *QuestionPhrase* and *Relation* annotations as shown in Figure 8 as follows:

[QuestionPhrase: Who] [Relation: are the researchers in] [NounPhrase: semantic web research area]

Supposed we start with a knowledge base containing only the default rule **R0**. Given the question, **R0** is the fired rule that gives an incorrect conclusion of an empty intermediate representation element. This can be corrected by adding the following rule **R1** as an exception rule of **R0**. In the knowledge base, node (1) containing **R1** is added as the except-child node of the default node, as shown in Figure 6.

⁴Here annotations are generated without any concept or entity type information.

⁵<http://technologies.kmi.open.ac.uk/aqualog/examples.html>

Rule: R1

```
(
  ({QuestionPhrase}):qp
  ({Relation}):rel
  ({NounPhrase}):np
):left
--> :left.RDR1_ = {category1 = "UnknTerm"}
, :qp.RDR1_QP = {}
, :rel.RDR1_Rel = {}
, :np.RDR1_NP = {}
```

Conclusion:

UnknTerm question structure and one query tuple (RDR1_category1, RDR1_QP.QuestionPhrase.category, ?, RDR1_Rel, RDR1_NP, ?)

If the condition of **R1** matches the whole input question, a new *RDR1_* annotation will be created to entirely cover the input question. In addition, new annotations *RDR1_QP*, *RDR1_Rel* and *RDR1_NP* will be created to cover the same question phrase, relation phrase and noun phrase as the *QuestionPhrase*, *Relation* and *NounPhrase* annotations, respectively.

When node (1) fired, the input question has one query tuple where the sub-structure attribute takes the value of the *category1* feature of the *RDR1_* annotation; the question category attribute takes the value of the *category* feature of the *QuestionPhrase* annotation which is in the same span as the *RDR1_QP* annotation. In addition, the *Relation* and *Term₂* attributes take values of the strings covered by the *RDR1_Rel* and *RDR1_NP* annotations, respectively, while *Term₁* and *Term₃* are missing. The example of firing the question at node (1) is displayed in Figure 7.

Assume that, in addition to **R0** and **R1**, the current knowledge base contains rule **R2** as an exception rule of **R1**, for which node (2) containing **R2** is the except-child node of node (1), as shown in Figure 6.

For the question “Which universities are Knowledge Media Institute collaborating with?”, the following annotation-based representation is constructed:

[RDR1_: [RDR1_QP: Which universities] [RDR1_Rel: are] [RDR1_NP: Knowledge Media Institute]] [Relation: collaborating with]

We have the evaluation path of (0)-(1)-(2) with the last fired node (1). However, **R1** produces an incorrect conclusion of the *UnknTerm* question structure and one query tuple (*UnknTerm*, *QU-whichClass*, ?, ?, Knowledge Media Institute, ?). It is because the *RDR1_* annotation only covers a part of the question and “are” is not considered as a relation. The following rule **R3** is added as an exception rule of **R1**:

Rule: R3

```
(
  {RDR1_} ({Relation}):rel
):left
--> :left.RDR3_ = {category1 = "Normal"}
, :rel.RDR3_Rel = {}
```

Conclusion:

Normal question structure and one query tuple
(RDR3_.category1, RDR1_QP.QuestionPhrase.category,
RDR1_QP, RDR3_Rel, RDR1_NP, ?)

In the knowledge base, node (3) containing **R3** is appended as the false-child node of node (2) which is the last node in the evaluation path. Regarding the input question “Which universities are Knowledge Media Institute collaborating with?”, we have a new evaluation path of (0)-(1)-(2)-(3) with the last fired node (3). So **R3** produces a correct intermediate representation element of the question, consisting of the *Normal* question structure and one query tuple (*Normal*, *QU-whichClass*, universities, collaborating, Knowledge Media Institute, ?).

Subsequently, another question makes an addition of rule **R4** which is also an exception rule of **R1**. In the knowledge base, node (4) containing **R4** is appended as the false-child node of node (3).

For the question “Who are the partners involved in AKT project?”, we have an annotation-based representation as follows:

```
[RDR3_: [RDR1_QP: Who] [RDR1_Rel: are] [RDR1_NP:
the partners] [RDR3_Rel: involved in]] [NounPhrase: AKT
project]
```

We have the evaluation path (0)-(1)-(2)-(3) and node (3) is the last fired node. But **R3** returns a wrong conclusion as the *RDR3_* annotation covers a part of the question. The following rule **R5** is added as an exception rule of **R3** to correct the returned conclusion:

Rule: R5

```
(
  {RDR3_} ({NounPhrase}):np
):left
--> :left.RDR5_ = {category1 = "Normal"}
, :np.RDR5_NP = {}
```

Conclusion:

Normal question structure and one query tuple
(RDR5_.category1, RDR1_QP.QuestionPhrase.category,
RDR1_NP, RDR3_Rel, RDR5_NP, ?)

As node (3) is the last node in the evaluation path, node (5) containing **R5** is attached as the except-child node of node (3). Using **R5**, we get a correct conclu-

sion consisting of the *Normal* question structure and one query tuple (*Normal*, *QU-who-what*, partners, involved, AKT project, ?).

4.3.2. Solving question structure ambiguities

The process of adding the rules above illustrates the ability of quickly handling new question structure patterns of our knowledge acquisition approach against the ad-hoc approaches [26,35]. The following examples demonstrate the ability of our approach to solve question structure ambiguities.

For the question “Which researchers wrote publications related to semantic portals?”, the following representation is produced:

```
[RDR5_: [RDR1_QP: Which researchers] [RDR1_Rel:
wrote] [RDR1_NP: publications] [RDR3_Rel: related to]
[RDR5_NP: semantic portals]]
```

This question is fired at node (5) which is the last node in the evaluation path (0)-(1)-(2)-(3)-(5). But **R5** gives a wrong conclusion of the *Normal* question structure and one query tuple (*Normal*, *QU-whichClass*, publications, related to, semantic portals, ?). We add the following rule **R40** as an exception rule of **R5** to correct the conclusion returned by **R5**:

Rule: R40

```
(
  {RDR5_}
):left
--> :left.RDR40_ = {category1 = "Normal",
category2 = "Normal"}
```

Condition:

```
RDR1_QP.hasAnno == QuestionPhrase.category ==
QU-whichClass
```

Conclusion:

Clause question structure⁶ and two query tuples
(RDR40_.category1, RDR1_QP.QuestionPhrase.category,
RDR1_QP, RDR1_Rel, ?, ?) and
(RDR40_.category2, RDR1_QP.QuestionPhrase.category,
RDR1_NP, RDR3_Rel, RDR5_NP, ?)

The extra annotation constraint of *hasAnno* requires that the text covered by an annotation must contain another specified annotation. For example, the additional condition in **R40** only matches the *RDR1_QP* annotation that has a *QuestionPhrase* annotation covering its

⁶A *Clause* structure question has two query tuples where the answer returned for the second query tuple indicates the missing *Term₂* attribute in the first query tuple. See more details of our question structure definitions in appendix A.

substring⁷. Additionally, this *QuestionPhrase* annotation must have “QU-whichClass” as the value of its *category* feature.

In the knowledge base, node (40) containing **R40** is added as the except-child node of node (5). Given the question, the last fired node now is node (40); and the conclusion of **R40** produces a correct intermediate representation consisting of the *Clause* question structure and two query tuples (*Normal, QU-whichClass, projects, sponsored, ?, ?*) and (*Normal, QU-whichClass, eprsc, related to, semantic web, ?*). In the knowledge base, the associated node (45) is attached as the false-child node of node (43).

For the question “Which projects sponsored by eprsc are related to semantic web?”, we have part-of-speech and annotation-based representations as follows:

Which/WDT projects/NNS sponsored/VBN by/IN eprsc/NN are/VBP related/VBN to/TO semantic/JJ web/NN

```
[RDR40_: [RDR1_QP: [QuestionPhrase category =
QU-whichClass: Which projects]] [RDR1_Rel: sponsored
by] [RDR1_NP: eprsc] [RDR3_Rel: are related to]
[RDR5_NP: semantic web]]
```

The current knowledge base generates an evaluation path (0)-(1)-(2)-(3)-(5)-(40)-(42)-(43) with the last fired node (40). However, **R40** returns a wrong conclusion with the *Clause* question structure and two query tuples (*Normal, QU-whichClass, projects, sponsored, ?, ?*) and (*Normal, QU-whichClass, eprsc, related to, semantic web, ?*) since *Term₁* cannot be assigned to the instance “eprsc”. The following rule **R45** which is a new exception rule of **R40** is added to correct the conclusion given by **R40**:

Rule: R45

```
(
{RDR40_}
):left
--> :left.RDR45_ = {category1 = "Normal",
category2 = "Normal"}
```

Condition:

RDR1_Rel.hasAnno == Token.category == VBN

Conclusion:

And question structure and two query tuples (RDR45_category1, RDR1_QP.QuestionPhrase.category, RDR1_QP, RDR1_Rel, RDR1_NP, ?) and (RDR45_category2, RDR1_QP.QuestionPhrase.category, RDR1_QP, RDR3_Rel, RDR5_NP, ?)

R45 enables to return a correct intermediate representation element for the question with the *And* ques-

tion structure and two query tuples (*Normal, QU-whichClass, projects, sponsored, eprsc, ?*) and (*Normal, QU-whichClass, projects, related to, semantic web, ?*). In the knowledge base, the associated node (45) is attached as the false-child node of node (43).

4.3.3. *Porting to other domains*

As illustrated in Section 4.3.1 and Section 4.3.2, using the set of 170 questions from AquaLog [26], we constructed a knowledge base of 59 rules for question analysis. Similarly, in this section, we illustrate the process of adding more exception rules into the knowledge base to handle DBpedia and biomedical test questions.

For the DBpedia test question “Which presidents of the United States had more than three children?”, the following representations are constructed:

Which/WDT presidents/NNS of/IN the/DT United/NNP States/NNPS had/VBD more/JJR than/IN three/CD children/NNS

```
[RDR27_: [RDR10_: [RDR10_QP: Which presidents]
[Preps: of] [RDR10_NP: the United States]] [RDR27_Rel:
had more than] [RDR27_NP: three children]]
```

The last fired node for this DBpedia question is node (27). However, the conclusion of rule **R27** at node (27) produced an incorrect intermediate representation element for the question. So a new exception rule of **R27** is added to the knowledge base to correct the conclusion returned by **R27** as follows:

Rule: R67

```
(
{RDR10_} {Verb}
({Token.category == JJR}
{Token.string == than}
{Token.category == CD}):cp
({Noun}):np
):left
--> :left.RDR67_ = {category1 = "Compare",
category2 = "UnknRel"}
, :cp.RDR67_Compare = {}
, :np.RDR67_NP = {}
```

Conclusion:

Clause question structure and two query tuples (RDR67_category1, RDR10_QP.QuestionPhrase.category, ?, RDR67_NP, ?, RDR67_Compare) and (RDR67_category2, RDR10_QP.QuestionPhrase.category, RDR10_QP, ?, RDR10_NP, ?)

Given the question, **R67** produces a correct intermediate representation element of the *Clause* question structure and two query tuples (*Compare, QU-*

⁷A whole string is also considered as its substring.

whichClass, ?, children, ?, more than three) and (*UnknRel*, *QU-whichClass*, presidents, ?, United States, ?).

For the biomedical test question “List drugs that lead to strokes and arthritis”, we have the following representations:

List/NN drugs/NNS that/WDT lead/VBP to/TO strokes/NNS and/CC arthritis/NNS

[QuestionPhrase: List drugs] [RDR1_: [RDR1_QP: that] [RDR1_Rel: lead to] [RDR1_NP: strokes and arthritis]]

The last fired node for this biomedical question is node (1). However, **R1** returned an incorrect intermediate representation element. So a new exception rule of **R1** is added to the knowledge base as follows:

Rule: R80

```
(
  ({QuestionPhrase}):qp
  {RDR1_QP} {RDR1_Rel}
  ({Noun}):np1
  {Token.category == CC}
  ({Noun}):np2
):left
--> :left.RDR80_ = {category1 = "Normal",
category2 = "Normal"}
, :qp.RDR80_QP = {}
, :np1.RDR80_NP1 = {}
, :np2.RDR80_NP2 = {}
```

Condition:

RDR80_QP.hasAnno == Noun

Conclusion:

And question structure and two query tuples (RDR80_category1, RDR80_QP.QuestionPhrase.category, RDR80_QP, RDR1_Rel, RDR80_NP1, ?) and (RDR80_category2, RDR80_QP.QuestionPhrase.category, RDR80_QP, RDR1_Rel, RDR80_NP2, ?)

Given the question, **R80** returns a correct intermediate representation element of the *And* question structure and two query tuples (*Normal*, *QU-listClass*, drugs, lead to, strokes, ?) and (*Normal*, *QU-listClass*, drugs, lead to, arthritis, ?).

5. Experiments

In KbQAS, the question analysis component employs our language-independent knowledge acquisition approach, while the answer retrieval component produces answers from a domain-specific Vietnamese ontology. So we separately evaluate the question analysis

and answer retrieval components in Section 5.1 and Section 5.2, respectively.

5.1. Experiments on analyzing questions

This section indicates the abilities of our question analysis approach for quickly building a new knowledge base and easily adapting to a new domain and a new language. We evaluate both our approaches of ad-hoc manner (see Section 3.3.3) and knowledge acquisition (see Section 4) on Vietnamese question analysis, and then present the experiment of building a knowledge base for processing English questions.

5.1.1. Question analysis for Vietnamese

We used a training set of 400 questions of various structures generated by four volunteer students. We then evaluated our question analysis approach on an unseen list of 88 questions related to the VNU University of Engineering and Technology, Vietnam. In this experiment, we also compare both our ad-hoc and knowledge acquisition approaches for question analysis, using the same training set of 400 questions and test set of 88 questions.

Table 2

Time to create rules and number of successfully analyzed questions.

Type	Time	#questions
Ad-hoc	75 hours	70/88 (79.5%)
Knowledge acquisition	5 hours	74/88 (84.1%)

With our first approach it took about 75 hours to create rules in an ad-hoc manner, as shown in Table 2. In contrast, with our second approach it took 13 hours to build a Vietnamese knowledge base of rules for question analysis. However, most of the time was spent looking at questions to determine the question structures and the phrases which would be extracted to create intermediate representation elements. So the actual time to create rules in the knowledge base was about 5 hours in total.

Table 3

Number of exception rules in each layer in our Vietnamese knowledge base for question analysis.

Layer	Number of rules
1	26
2	41
3	20
4	4

The knowledge base consists of the default rule and 91 exception rules. Table 3 details the number of exception rules in each layer where every rule in layer n is an exception rule of a rule in layer $n - 1$. The only rule which is not an exception rule of any rule is the default rule at layer 0. This indicates that the exception structure is indeed present and even extends to 4 levels.

Table 2 also shows the number of successfully analyzed questions for each approach. By using the knowledge base to resolve ambiguous cases, our knowledge acquisition approach performs better than our ad-hoc approach. Furthermore, Table 4 provides the error sources for our knowledge acquisition approach, in which most errors come from unexpected question structure patterns. This can be rectified by adding more exception rules to the current knowledge base, especially when having a large training set that contains a variety of question structure patterns.

Table 4

Number of incorrectly analyzed questions accounted for the knowledge acquisition approach.

Reason	#questions
Unknown structure patterns	12/88
Word segmentation and part-of-speech tagging modules were not trained on question domain	2/88

For another example, our knowledge acquisition approach did not return a correct intermediate representation element for the question “Vũ Tiên Thành có quê và có mã sinh viên là gì ?” (“What is the hometown and student code of Vu Tien Thanh ?”) because the existing linguistic processing modules for Vietnamese [43], including word segmentation and part-of-speech tagging, were not trained on the question domain. So these two modules assign the word “quê_{hometown}” as an adjective instead of a noun. Thus, “quê_{hometown}” is not covered by a *NounPhrase* annotation, leading to an unrecognized structure pattern.

Regarding a question structure-based evaluation, Table 5 presents the number of rules in the Vietnamese knowledge base and number of test questions, corresponding to each question structure type. For example, the cell at the second row and the fourth column of Table 5 means that, in 7 test questions tending to have the *UnknRel* question structure, there are 4 test questions correctly analyzed.

Table 5

Number of rules in the question analysis knowledge bases for Vietnamese (#RV) and English (#RE); number of Vietnamese test questions (#TQ) and number of Vietnamese correctly answered questions (#CA) corresponding to each question structure type (QST).

QST	#RV	#CA	#TQ	#RE
Definition	2	1	2/2	4
UnknRel	4	4	4/7	6
UnknTerm	7	6	7/7	4
Normal	7	7	7/7	11
Affirm	10	5	5/5	5
Compare	5	0	2/4	8
ThreeTerm	9	7	7/10	6
Affirm_3Term	5	4	4/4	2
And	9	7	8/8	21
Or	23	18	21/24	1
Affirm_MoreTuples	3	1	2/3	1
Clause	6	0	4/5	20
Combine	1	1	1/2	0
Total	91	61	74/88	89

5.1.2. Question analysis for English

For the experiment in English, we firstly used a set of 170 English questions⁸, which AquaLog [26] analyzed successfully. These questions are about the Knowledge Media Institute and its research area on the semantic web. Using this question set, we constructed a knowledge base of 59 rules for question analysis. It took 7 hours to build the knowledge base, including 3 hours of actual time to create all rules. We then evaluated the knowledge base using a set of 50 DBpedia test questions from the QALD-1 workshop and another set of 25 biomedical test questions from the QALD-4 workshop.⁹

Table 6

Test results of the knowledge base of 59 rules for question analysis on DBpedia and biomedical domains.

Factor	DBpedia	Biomedical
Successfully processed	24/50	9/25
Unknown structure patterns	18/50	9/25
Incorrect word segmentation	3/50	3/25
Incorrect part-of-speech tagging	5/50	4/25

Table 6 presents evaluation results of analyzing the test questions from the DBpedia and biomedical domains, using the knowledge base of 59 rules for question analysis. It is not surprising that most errors come

⁸<http://technologies.kmi.open.ac.uk/aqualog/examples.html>

⁹<http://www.sc.cit-ec.uni-bielefeld.de/qald/>

from unknown question structure patterns. Furthermore, just as in Vietnamese, the existing linguistic processing modules in the GATE framework [11], including the English tokenizer and part-of-speech tagger, are also error sources, leading to unrecognized structure patterns. For example, such questions as “Which U.S. states possess gold minerals ?” and “Which drugs have a water solubility of 2.78e-01mg/mL ?” are tokenized into “Which U . S . states possess gold minerals ?” and “Which drugs have a water solubility of 2 . 78 e- 01 mg / mL ?”, respectively. In addition, such other questions as “Which river does the Brooklyn Bridge cross ?”, “Which states border Utah ?” or “Which experimental drugs interact with food ?” are tagged with noun labels for the words “cross”, “border” and “interact” instead of verb labels.

Table 7

Test results of the English knowledge base of 90 rules for question analysis on DBpedia and biomedical domains.

Factor	DBpedia	Biomedical
Successfully processed	47/50	21/25
Unknown structure patterns	0/50	0/25
Incorrect word segmentation	3/50	3/25
Incorrect part-of-speech tagging	0/50	1/25

To correct the question analysis errors on the two sets of test questions, we spent 5 further hours to add 31 exception rules to the knowledge base. Finally, in total 12 hours, we constructed a knowledge base of 90 rules for English question analysis, including the default rule and 89 exception rules. The new evaluation results of question analysis on the DBpedia and biomedical domains are presented in Table 7.

Table 8 shows the number of exception rules in each exception layer of the knowledge base while the number of rules corresponding to each question structure type is presented in Table 5.

Table 8

Number of exception rules in layers in our English knowledge base.

Layer	Number of rules
1	10
2	21
3	31
4	20
5	7

As the intermediate representation in KbQAS is different from AquaLog, it is difficult to directly compare our knowledge acquisition approach with the ad-hoc

question analysis approach in AquaLog on the English domain. However, this experiment on English questions shows the abilities to quickly build a new knowledge base and easily adapt to a new domain and a new language.

As illustrated in Section 4.3, this experiment also presented a process of building a knowledge base for question analysis without any concept or entity type information. However, we found that the concept or entity type information in noun phrases is useful and can help to reduce ambiguities in question structure patterns. When adapting our knowledge acquisition approach for question analysis to another target domain (or language), we can simply use the heuristics presented in Section 3.3.2 and a dictionary to determine whether a noun phrase is a concept or entity type. The dictionary can be (automatically) constructed by extracting concepts from the target domain and their synonyms from available semantic lexicons such as WordNet [17].

5.2. Experiment on answering Vietnamese questions

To evaluate the answer retrieval component of KbQAS, we used the ontology modeling the organizational structure of the VNU University of Engineering and Technology, as mentioned in Section 3.2, as target domain. This ontology was manually constructed by using the Protégé platform [19]. From the list of 88 questions, as mentioned in Section 5.1.1, we employed 74 questions which were successfully analyzed by the question analysis component.

Table 9

Questions successfully answered.

Type	# questions
No interaction with users	30/74
With interactions with users	31/74
Overall	61/74 (82.4%)

The performance result is presented in Table 9. The answer retrieval component produces correct answers for 61 out of 74 questions, obtaining a promising accuracy of 82.4%. The number of correctly answered questions corresponding to each question structure type can be found in the third column of Table 5. Out of those, 30 questions can be answered automatically without interaction with users. In addition, 31 questions are correctly answered with the help from the users to handle ambiguity cases, as illustrated in the first example in Section 3.4.

Table 10

Questions with unsuccessful answers.	
Type	# questions
Ontology mapping errors	6/74
Answer extraction errors	7/74

Table 10 gives the limitations that will be handled in future KbQAS versions. The errors raised by the ontology mapping module are due to the target ontology construction lacking a full domain-specific conceptual coverage and some relationships between concept pairs. So specific terms or relations in query tuples cannot be mapped or are incorrectly mapped to the corresponding elements in the target ontology to produce the ontology tuples. Furthermore, the answer extraction module fails to extract the answers for 7 questions because: (i) Dealing with questions having the *Compare* question structure involves specific services. For example, handling the question “sinh viên nào có điểm trung bình cao nhất khoa công nghệ thông tin ?” (“Which student has the highest grade point average in the faculty of Information Technology ?”) requires a comparison mechanism to rank students according to their GPA. (ii) In terms of four *Clause* structure questions and one *Affirm_MoreTuples* structure question for which KbQAS failed to return answers (see Table 5), combining their sub-questions triggers complex inference tasks and bugs which are difficult to handle in the current KbQAS version.

6. Conclusion and future work

In this paper, we described the first ontology-based question answering system for Vietnamese, namely KbQAS. KbQAS contains two components: natural language question analysis and answer retrieval. The two components are connected by an intermediate representation element capturing the semantic structure of any input question, facilitating the matching process to a target ontology to produce an answer. Experimental results of KbQAS on a wide range of questions are promising. Specifically, the answer retrieval module achieves an accuracy of 82.4%.

In addition, we proposed a question analysis approach for systematically building a knowledge base of rules to convert the input question into an intermediate representation element. Our approach allows for systematic control of interactions between rules and keeping consistency among them. We believe that our approach is important especially for under-resourced lan-

guages where annotated data is not available. Our approach could be combined nicely with the process of annotating corpora where, on top of assigning a label or a representation to a question, the experts just have to add one more rule to justify their decision. Incrementally, an annotated corpus and a rule-based system can be obtained simultaneously. Furthermore, our approach can be applied to open-domain question answering where the technique requires an analysis to transform an input question into an explicit representation of some sort. Obtaining a question analysis accuracy of 84.1% on Vietnamese questions and taking 12 hours to build a knowledge base of 90 rules for analyzing English questions, the question analysis experiments show that our approach enables individuals to easily build a new knowledge base or adapt an existing knowledge base to a new domain or a new language.

In the future, we will extend KbQAS to be an open-domain question answering system which can answer various questions over Linked Open Data such as DBpedia or YAGO. In addition, it would be interesting to investigate the process of building a knowledge base for question analysis, which directly converts the input questions into queries (e.g. SPARQL queries) on Linked Open Data.

Acknowledgments

This work is partially supported by the Research Grant No. QG.14.04 from Vietnam National University, Hanoi (VNU). Most of this work was done while the first two authors was at the VNU University of Engineering and Technology. The first author is supported by an International Postgraduate Research Scholarship and a NICTA NRPA Top-Up Scholarship.

Appendix

A. Definitions of question structure types

We define question structures types: *Normal*, *UnknTerm*, *UnknRel*, *Definition*, *Affirm*, *ThreeTerm*, *Affirm_3Term*, *Affirm_MoreTuples*, *Compare*, *And*, *Or*, *Combine*, *Clause* as follows:

- A *Normal* structure question has only one query tuple in which *Term₃* is missing.
- An *UnknTerm* structure question has only one query tuple in which *Term₁* and *Term₃* are missing.

- An *UnknRel* structure question has only one query tuple in which *Relation* and *Term₃* are missing. For example, the question “List all the publications in knowledge media institute” has one query tuple (*UnknRel*, *QU-listClass*, publications, ?, knowledge media institute, ?).

- A *Definition* structure question has only one query tuple which lacks *Term₁*, *Relation* and *Term₃*. For example, the question “What are research areas ?” has one query tuple (*Definition*, *QU-who-what*, ?, ?, research areas, ?).

- An *Affirm* structure question is a question which belongs to one of three types *Normal*, *UnknRel* and *UnknTerm*, and has the *YesNo* question category. For example, the question “Is Tran Binh Giang a PhD student ?” has the *Affirm* question structure and one query tuple (*UnknRel*, *YesNo*, PhD student, ?, Tran Binh Giang, ?).

- A *ThreeTerm* structure question has only one query tuple where *Term₁* or *Relation* could be missing. An example for this structure type is illustrated in Figure 2.

- An *Affirm_3Term* structure question is the question which belongs to *ThreeTerm* and has the *YesNo* question category. For example, the question “số lượng sinh viên học lớp K50 khoa học máy tính là 45 phải không ?” (“45 is the number of students enrolled in the K50 computer science course, is it not ?”) has the *Affirm_3Term* question structure and one query tuple (*ThreeTerm*, *ManyClass*, sinh viên_{student}, học_{enrolled}, lớp K50 khoa học máy tính_{K50 computer science course}, 45).

- An *Affirm_MoreTuples* structure question has more than one query tuple and belongs to the *YesNo* question category. For example, the question “tồn tại sinh viên có quê ở Hà Tây và học khoa toán phải không ?” (“Is there some student enrolled in the faculty of Mathematics, whose hometown is Hatay ?”) has the *Affirm_MoreTuples* question structure and two query tuples (*Normal*, *YesNo*, sinh viên_{student}, có quê_{have hometown}, Hà Tây_{Hatay}, ?) and (*Normal*, *YesNo*, sinh viên_{student}, học_{enrolled}, khoa Toán_{faculty of Mathematics}, ?).

- A *Compare* structure question is a question which belongs to one of three types *Normal*, *UnknRel* and *UnknTerm*, and it contains a comparison phrase which is detected by the preprocessing module. In this case, *Term₃* is used to hold the comparison information. For example, the question “sinh viên nào có điểm trung bình cao nhất khoa công nghệ thông tin ?” (“Which student has the highest grade point average in the faculty of Information Technology ?”) has the *Com-*

pare question structure and one query tuple (*Normal*, *Entity*, sinh viên_{student}, điểm trung bình_{grade point average}, khoa công nghệ thông tin_{faculty of Information Technology}, cao nhất_{highest}).

- An *And* or *Or* structure question contains the word “và_{and}” (“và_{and}”) or “hoặc_{or}”, respectively, and it has more than one query tuple (i.e. two or more sub-questions). The *And* type returns the final answer as an intersection (i.e. overlap) of the answers of the sub-questions, while the *Or* type returns the final answer as a union of the answers for the sub-questions.

For example, the question “Which projects are about ontologies and the semantic web ?” has the *And* question structure and two query tuples (*UnknRel*, *QU-whichClass*, projects, ?, ontologies, ?) and (*UnknRel*, *QU-whichClass*, projects, ?, semantic web, ?).

The question “Which publications are in knowledge media institute related to compendium ?” has the *And* question structure and two query tuples (*UnknRel*, *QU-whichClass*, publications, ?, knowledge media institute, ?) and (*Normal*, *QU-whichClass*, publications, related to, compendium, ?).

The question “Who is interested in ontologies or in the semantic web ?” has the *Or* question structure and two query tuples (*UnknTerm*, *QU-who-what*, ?, interested, ontologies, ?) and (*UnknTerm*, *QU-who-what*, ?, interested, semantic web, ?).

However, such question as “Phạm Đức Đăng học trường đại học nào và được hướng dẫn bởi ai ?” (“Which university does Pham Duc Dang enroll in and who tutors him ?”) contains “và_{and}”, but it will have the *Or* question structure and two query tuples (*Normal*, *Entity*, trường đại học_{university}, học_{enroll}, Phạm Đức Đăng_{Pham Duc Dang}, ?) and (*UnknTerm*, *Who*, ?, hướng dẫn_{tutor}, Phạm Đức Đăng_{Pham Duc Dang}, ?).

- A *Combine* structure question is constructed from two or more independent sub-questions. Unlike the *Or* structure type, the query tuples in the *Combine* type do not share the same term or *Relation*. For example, the question “Ai có quê quán ở Hà Tây và ai học khoa công nghệ thông tin ?” (“Who has hometown of Hatay, and who enrolls in the faculty of Information Technology ?”) has the *Combine* question structure and two query tuples (*UnknTerm*, *Who*, ?, có quê quán_{has hometown}, Hà Tây_{Hatay}, ?) and (*UnknTerm*, *Who*, ?, học_{enroll}, khoa công nghệ thông tin_{faculty of Information Technology}, ?).

- A *Clause* structure question has two query tuples, where the answer returned for the second query tuple indicates the missing *Term₂* attribute in the first query tuple. For example, the question “số lượng sinh viên học lớp K50 khoa học máy tính lớn hơn 45 phải không

?”¹⁰ (“The number of students enrolled in K50 computer science course is higher than 45, is it not ?”) has the *Clause* question structure and two query tuples (*Compare*, *YesNo*, 45, ?, ?, lớn hơn_{higher than}) and (*Normal*, *ManyClass*, sinh viên_{student}, học_{enrolled}, lớp K50 khoa học máy tính_{K50 computer science course}, ?). Another example of this *Clause* structure is presented in Section 4.3.2.

In general, *Term*₁ represents a concept, excluding cases of *Affirm*, *Affirm_3Term* and *Affirm_MoreTuples*. In addition, *Term*₂ and *Term*₃ represent entities (i.e. objects or instances), excluding the cases of *Definition* and *Compare*.

B. Definitions of Vietnamese question categories

In KbQAS, a question is classified as one of the following classes: *HowWhy*, *YesNo*, *What*, *When*, *Where*, *Who*, *Many*, *ManyClass*, *List*, and *Entity*. To identify question categories, we specify a number of JAPE grammars using the *NounPhrase* annotations and the question-word information given by the preprocessing module.

- A *HowWhy*-category question refers to a cause or a method, containing a *TokenVn* annotation covering such strings as “tại sao_{why}” or “vì sao_{why}” or “thế nào_{how}” or “là như thế nào_{how}”. This is similar to *Why*-questions or *How is/are* questions in English.

- A *YesNo*-category question requires a true or false answer, containing a *TokenVn* annotation covering such strings as “có đúng là_{is that}” or “đúng không_{are those}” or “phải không_{are there}” or “có phải là_{is this}”.

- A *What*-category question contains a *TokenVn* annotation covering such strings as “cái gì_{what}” or “là gì_{what}” or “là những cái gì_{what}”. This question type is similar to *What is/are* questions in English.

- A *When*-category question contains a *TokenVn* annotation covering such strings as “khi nào_{when}” or “vào thời gian nào_{which time}” or “lúc nào_{when}” or “ngày nào_{which date}”.

- A *Where*-category question contains a *TokenVn* annotation covering such strings as “ở nơi nào_{where}” or “là ở nơi đâu_{where}” or “ở chỗ nào_{where}”.

- A *Who*-category question contains a *TokenVn* annotation covering such strings as “là những ai_{who}” or “là người nào_{who}” or “những ai_{who}”.

- A *Many*-category question contains a *TokenVn* annotation covering such strings as “số lượng_{how many}” or “là bao nhiêu_{how much/many}” or “bao nhiêu_{how much/many}”. This question type is similar to *How much/many is/are* questions in English.

- A *ManyClass*-category question contains a *TokenVn* annotation covering such strings as “số lượng_{how many}” or “là bao nhiêu_{how much/many}” or “bao nhiêu_{how much/many}”, followed by a *NounPhrase* annotation. This type is similar to *How many NounPhrase*-questions in English.

- An *Entity*-category question contains a *NounPhrase* annotation followed by a *TokenVn* annotation covering such strings as “nào_{which}” or “gì_{what}”. This type is similar to *which/what NounPhrase*-questions in English.

- A *List*-category question contains a *TokenVn* annotation covering such strings as “cho biết_{give}” or “chỉ ra_{show}” or “kể ra_{tell}”, or “tìm_{find}” or “liệt kê_{list}”, followed by a *NounPhrase* annotation.

References

- [1] I. Androutsopoulos, G. Ritchie, and P. Thanisch. MASQUE/SQL: An Efficient and Portable Natural Language Query Interface for Relational Databases. In *Proceedings of the 6th International Conference on Industrial and Engineering Applications of Artificial Intelligence and Expert Systems*, IEA/AIE’93, pages 327–330. Gordon & Breach Science Publishers, 1993.
- [2] I. Androutsopoulos, G. Ritchie, and P. Thanisch. Natural Language Interfaces to Databases - An Introduction. *Natural Language Engineering*, 1:29–81, 3 1995. URL <http://dx.doi.org/10.1017/S135132490000005X>.
- [3] P. Atzeni, R. Basili, D. Hansen, P. Missier, P. Paggio, M. Pazienza, and F. Zanzotto. Ontology-Based Question Answering in a Federation of University Sites: The MOSES Case Study. In F. Meziane and E. Métais, editors, *Natural Language Processing and Information Systems*, volume 3136 of *Lecture Notes in Computer Science*, pages 413–420. Springer Berlin Heidelberg, 2004. URL http://dx.doi.org/10.1007/978-3-540-27779-8_40.
- [4] R. Basili, D. H. Hansen, P. Paggio, M. T. Pazienza, and F. M. Zanzotto. Ontological Resources and Question Answering. In S. Harabagiu and F. Lacatusu, editors, *HLT-NAACL 2004: Workshop on Pragmatics of Question Answering*, pages 78–84. Association for Computational Linguistics, 2004.
- [5] J. Berant and P. Liang. Semantic Parsing via Paraphrasing. In *Proceedings of the 52nd Annual Meeting of the Association for Computational Linguistics (Volume 1: Long Papers)*, pages 1415–1425. Association for Computational Linguistics, 2014. URL <http://www.aclweb.org/anthology/P14-1133>.
- [6] J. Berant, A. Chou, R. Frostig, and P. Liang. Semantic Parsing on Freebase from Question-Answer Pairs. In *Proceedings of the 2013 Conference on Empirical Methods in Natu-*

¹⁰This is the case of our system failing to correctly analyze due to an unknown structure pattern.

- ral Language Processing, pages 1533–1544. Association for Computational Linguistics, 2013. URL <http://www.aclweb.org/anthology/D13-1160>.
- [7] D. Bernhard and I. Gurevych. Answering Learners' Questions by Retrieving Question Paraphrases from Social Q&A Sites. In *Proceedings of the Third Workshop on Innovative Use of NLP for Building Educational Applications*, pages 44–52. Association for Computational Linguistics, June 2008. URL <http://www.aclweb.org/anthology/W08-0906>.
- [8] R. D. Burke, K. J. Hammond, V. A. Kulyukin, S. L. Lytinen, N. Tomuro, and S. Schoenberg. Question Answering from Frequently Asked Question Files: Experiences with the FAQ FINDER System. *AI Magazine*, 18(2):57–66, 1997. URL <http://dx.doi.org/10.1609/aimag.v18i2.1294>.
- [9] P. Cimiano, P. Haase, J. Heizmann, M. Mantel, and R. Studer. Towards Portable Natural Language Interfaces to Knowledge Bases - The Case of the ORAKEL System. *Data & Knowledge Engineering*, 65(2):325–354, 2008. URL <http://dx.doi.org/10.1016/j.datak.2007.10.007>.
- [10] P. Compton and R. Jansen. A Philosophical Basis for Knowledge Acquisition. *Knowledge Acquisition*, 2(3):241–257, 1990. URL [http://dx.doi.org/10.1016/S1042-8143\(05\)80017-2](http://dx.doi.org/10.1016/S1042-8143(05)80017-2).
- [11] H. Cunningham, D. Maynard, K. Bontcheva, and V. Tablan. GATE: A Framework and Graphical Development Environment for Robust NLP Tools and Applications. In *Proceedings of 40th Annual Meeting of the Association for Computational Linguistics*, pages 168–175. Association for Computational Linguistics, 2002. URL <http://www.aclweb.org/anthology/P02-1022>.
- [12] D. Damljjanovic, V. Tablan, and K. Bontcheva. A Text-based Query Interface to OWL Ontologies. In N. Calzolari, K. Choukri, B. Maegaard, J. Mariani, J. Odiijk, S. Piperidis, and D. Tapias, editors, *Proceedings of the Sixth International Conference on Language Resources and Evaluation (LREC'08)*, pages 205–212. European Language Resources Association (ELRA), 2008. URL <http://www.lrec-conf.org/proceedings/lrec2008/>.
- [13] D. Damljjanovic, M. Agatonovic, and H. Cunningham. Natural Language Interfaces to Ontologies: Combining Syntactic Analysis and Ontology-based Lookup Through the User Interaction. In *Proceedings of the 7th International Conference on The Semantic Web: Research and Applications - Volume Part I, ESWC'10*, pages 106–120. Springer-Verlag, 2010. URL http://dx.doi.org/10.1007/978-3-642-13486-9_8.
- [14] Q. B. Diep. *Ngữ pháp tiếng Việt (Grammar of Vietnamese Language)*. Vietnam Education Publishing House, 2005.
- [15] T. Dong, U. Furbach, I. Glöckner, and B. Pelzer. A Natural Language Question Answering System as a Participant in Human Q&A Portals. In *Proceedings of the Twenty-Second International Joint Conference on Artificial Intelligence - Volume Volume Three, IJCAI'11*, pages 2430–2435. AAAI Press, 2011. URL [10.5591/978-1-57735-516-8/IJCAI11-405](http://dx.doi.org/10.5591/978-1-57735-516-8/IJCAI11-405).
- [16] A. Fader, L. Zettlemoyer, and O. Etzioni. Paraphrase-Driven Learning for Open Question Answering. In *Proceedings of the 51st Annual Meeting of the Association for Computational Linguistics (Volume 1: Long Papers)*, pages 1608–1618. Association for Computational Linguistics, 2013. URL <http://www.aclweb.org/anthology/P13-1158>.
- [17] C. D. Fellbaum. *WordNet: An Electronic Lexical Database*. MIT Press, 1998.
- [18] U. Furbach, I. Glöckner, and B. Pelzer. An Application of Automated Reasoning in Natural Language Question Answering. *AI Communications*, 23:241–265, 2010. URL <http://dx.doi.org/10.3233/AIC-2010-0461>.
- [19] J. H. Gennari, M. A. Musen, R. W. Ferguson, W. E. Grosso, M. Crubzy, H. Eriksson, N. F. Noy, and S. W. Tu. The Evolution of Protégé: An Environment for Knowledge-Based Systems Development. *International Journal of Human-Computer Studies*, 58:89–123, 2002. URL [http://dx.doi.org/10.1016/S1071-5819\(02\)00127-1](http://dx.doi.org/10.1016/S1071-5819(02)00127-1).
- [20] S. Harabagiu, D. Moldovan, M. Paşca, R. Mihalcea, M. Surdeanu, Z. Bunescu, R. Girju, V. Rus, and P. Morarescu. FALCON: Boosting Knowledge for Answer Engines. In *Proceedings of the Ninth Text REtrieval Conference*, pages 479–488, 2000. URL http://trec.nist.gov/pubs/trec9/t9_proceedings.html.
- [21] L. Hirschman and R. Gaizauskas. Natural Language Question Answering: The View from Here. *Natural Language Engineering*, 7(4):275–300, 2001. URL <http://dx.doi.org/10.1017/S1351324901002807>.
- [22] V. Jijkoun and M. de Rijke. Retrieving Answers from Frequently Asked Questions Pages on the Web. In *Proceedings of the 14th ACM International Conference on Information and Knowledge Management, CIKM '05*, pages 76–83. ACM, 2005. URL <http://doi.acm.org/10.1145/1099554.1099571>.
- [23] B. Katz. Annotating the World Wide Web using Natural Language. In *Proceedings of the 5th RIAO Conference on Computer Assisted Information Searching on the Internet*, pages 136–159, 1997.
- [24] O. Kolomiyets and M.-F. Moens. A Survey on Question Answering Technology from an Information Retrieval Perspective. *Information Sciences*, 181(24):5412–5434, 2011. URL <http://dx.doi.org/10.1016/j.ins.2011.07.047>.
- [25] Z. Liu, X. Qiu, L. Cao, and X. Huang. Discovering Logical Knowledge for Deep Question Answering. In *Proceedings of the 21st ACM International Conference on Information and Knowledge Management, CIKM '12*, pages 1920–1924. ACM, 2012. URL <http://doi.acm.org/10.1145/2396761.2398544>.
- [26] V. Lopez, V. Uren, E. Motta, and M. Pasin. AquaLog: An Ontology-driven Question Answering System for Organizational Semantic Intranets. *Web Semantics: Science, Services and Agents on the World Wide Web*, 5(2):72–105, 2007. URL <http://dx.doi.org/10.1016/j.websem.2007.03.003>.
- [27] V. Lopez, V. Uren, M. Sabou, and E. Motta. Is Question Answering Fit for the Semantic Web?: A Survey. *Semantic Web*, 2(2):125–155, 2011. URL <http://dx.doi.org/10.3233/SW-2011-0041>.
- [28] V. Lopez, M. Fernández, E. Motta, and N. Stieler. PowerAqua: Supporting Users in Querying and Exploring the Semantic Web. *Semantic Web*, 3(3):249–265, 2012. URL <http://dx.doi.org/10.3233/SW-2011-0030>.
- [29] P. Martin, D. E. Appelt, B. J. Grosz, and F. Pereira. TEAM: An Experimental Transportable Natural-language Interface. In *Proceedings of 1986 ACM Fall Joint Computer Conference*, ACM '86, pages 260–267. IEEE Computer Society Press, 1986.
- [30] D. L. McGuinness. Question Answering on the Semantic Web. *IEEE Intelligent Systems*, 19(1):82–85, 2004. URL <http://dx.doi.org/10.1109/MIS.2004.1265890>.
- [31] A. C. Mendes and L. Coheur. When the Answer Comes into Question in Question-Answering: Survey and Open Is-

- sues. *Natural Language Engineering*, 19(1):1–32, 2013. URL <http://dx.doi.org/10.1017/S1351324911000350>.
- [32] M. Minock. C-Phrase: A System for Building Robust Natural Language Interfaces to Databases. *Data & Knowledge Engineering*, 69(3):290–302, 2010. URL <http://dx.doi.org/10.1016/j.datak.2009.10.007>.
- [33] D. Moldovan, S. Harabagiu, R. Girju, P. Morarescu, F. Lăcatusu, A. Novischi, A. Badulescu, and O. Bolohan. LCC Tools for Question Answering. In *Proceedings of the 11th Text REtrieval Conference*, 2002. URL trec.nist.gov/pubs/trec11/papers/lcc.moldovan.pdf.
- [34] A. K. Nguyen and H. T. Le. Natural Language Interface Construction Using Semantic Grammars. In T.-B. Ho and Z.-H. Zhou, editors, *Proceedings of the 10th Pacific Rim International Conference on Artificial Intelligence: Trends in Artificial Intelligence*, Lecture Notes in Computer Science, pages 728–739. Springer Berlin Heidelberg, 2008. URL http://dx.doi.org/10.1007/978-3-540-89197-0_67.
- [35] D. Q. Nguyen, D. Q. Nguyen, and S. B. Pham. A Vietnamese Question Answering System. In *Proceedings of the 2009 International Conference on Knowledge and Systems Engineering*, KSE '09, pages 26–32. IEEE Computer Society, 2009. URL <http://dx.doi.org/10.1109/KSE.2009.42>.
- [36] D. Q. Nguyen, D. Q. Nguyen, and S. B. Pham. Systematic Knowledge Acquisition for Question Analysis. In *Proceedings of the International Conference Recent Advances in Natural Language Processing 2011*, pages 406–412. RANLP 2011 Organising Committee, 2011. URL <http://aclweb.org/anthology/R11-1056>.
- [37] D. Q. Nguyen, D. Q. Nguyen, S. B. Pham, and D. D. Pham. Ripple Down Rules for Part-of-Speech Tagging. In *Proceedings of the 12th international conference on Computational linguistics and intelligent text processing - Volume Part I*, Lecture Notes in Computer Science, pages 190–201. Springer Berlin Heidelberg, 2011. URL http://dx.doi.org/10.1007/978-3-642-19400-9_15.
- [38] D. Q. Nguyen, D. Q. Nguyen, and S. B. Pham. KbQAS: A Knowledge-based QA System. In *Proceedings of the ISWC 2013 Posters & Demonstrations Track*, pages 109–112, 2013. URL http://ceur-ws.org/Vol-1035/iswc2013_demo_28.pdf.
- [39] D. Q. Nguyen, D. Q. Nguyen, D. D. Pham, and S. B. Pham. RDRPOSTagger: A Ripple Down Rules-based Part-Of-Speech Tagger. In *Proceedings of the Demonstrations at the 14th Conference of the European Chapter of the Association for Computational Linguistics*, pages 17–20. Association for Computational Linguistics, 2014. URL <http://www.aclweb.org/anthology/E14-2005>.
- [40] D. T. Nguyen and T. P.-M. Nguyen. A Question Answering Model Based Evaluation for OVL (Ontology for Vietnamese Language). *International Journal of Computer Theory and Engineering*, 3(3):347–351, 2011. URL <http://dx.doi.org/10.7763/IJCTE.2011.V3.330>.
- [41] D. T. Nguyen, T. D. Hoang, and S. B. Pham. A Vietnamese Natural Language Interface to Database. In *Proceedings of the 2012 IEEE Sixth International Conference on Semantic Computing*, ICSC '12, pages 130–133. IEEE Computer Society, 2012. URL <http://dx.doi.org/10.1109/ICSC.2012.33>.
- [42] A. Peñas, B. Magnini, P. Forner, R. Sutcliffe, A. Rodrigo, and D. Giampiccolo. Question Answering at the Cross-Language Evaluation Forum 2003-2010. *Language Resources and Evaluation*, 46(2):177–217, 2012. URL <http://dx.doi.org/10.1007/s10579-012-9177-0>.
- [43] D. D. Pham, G. B. Tran, and S. B. Pham. A Hybrid Approach to Vietnamese Word Segmentation Using Part of Speech Tags. In *Proceedings of the 2009 International Conference on Knowledge and Systems Engineering*, KSE '09, pages 154–161. IEEE Computer Society, 2009. URL <http://dx.doi.org/10.1109/KSE.2009.44>.
- [44] S. B. Pham and A. Hoffmann. Efficient Knowledge Acquisition for Extracting Temporal Relations. In *Proceedings of the 17th European Conference on Artificial Intelligence*, pages 521–525. IOS Press, 2006.
- [45] T. Phan and T. Nguyen. Question Semantic Analysis in Vietnamese QA System. In N. Nguyen, R. Katarzyniak, and S.-M. Chen, editors, *Advances in Intelligent Information and Database Systems*, Studies in Computational Intelligence, pages 29–40. Springer Berlin Heidelberg. URL http://dx.doi.org/10.1007/978-3-642-12090-9_3.
- [46] A.-M. Popescu, O. Etzioni, and H. Kautz. Towards a Theory of Natural Language Interfaces to Databases. In *Proceedings of the 8th International Conference on Intelligent User Interfaces*, IUI '03, pages 149–157. ACM, 2003. URL <http://dx.doi.org/10.1145/604045.604070>.
- [47] D. Richards. Two Decades of Ripple Down Rules Research. *Knowledge Engineering Review*, 24(2):159–184, 2009. URL <http://dx.doi.org/10.1017/S0269888909000241>.
- [48] F. Rinaldi, J. Dowdall, K. Kaljurand, M. Hess, and D. Mollá. Exploiting Paraphrases in a Question Answering System. In *Proceedings of the second international workshop on Paraphrasing - Volume 16*, pages 25–32. Association for Computational Linguistics, 2003. URL <http://dx.doi.org/10.3115/1118984.1118988>.
- [49] S. Silakari, M. Motwani, and N. Nihalani. Natural Language Interface for Database: A Brief Review. *IJCSI International Journal of Computer Science Issues*, 8:600–608, 2011.
- [50] N. Stratica, L. Kosseim, and B. C. Desai. NLIDB Templates for Semantic Parsing. In *Proceedings of the 8th International Conference on Applications of Natural Language to Information Systems*, pages 235–241, 2003.
- [51] M. Templeton and J. Burger. Problems in Natural-Language Interface to DBMS with Examples from EUFID. In *Proceedings of the first conference on Applied natural language processing*, pages 3–16. Association for Computational Linguistics, 1983. URL <http://dx.doi.org/10.3115/974194.974197>.
- [52] C. A. Thompson, R. J. Mooney, and L. R. Tang. Learning to Parse Natural Language Database Queries into Logical Form. In *Proceedings of the ML-97 Workshop on Automata Induction, Grammatical Inference, and Language Acquisition*, 1997.
- [53] M.-V. Tran, D.-T. Le, X.-T. Tran, and T.-T. Nguyen. A Model of Vietnamese Person Named Entity Question Answering System. In *Proceedings of the 26th Pacific Asia Conference on Language, Information, and Computation*, pages 325–332. Faculty of Computer Science, Universitas Indonesia, 2012. URL <http://www.aclweb.org/anthology/Y12-1035>.
- [54] C. Unger and P. Cimiano. Pythia: Compositional Meaning Construction for Ontology-Based Question Answering on the Semantic Web. In R. Muñoz, A. Montoyo, and E. Métais, editors, *Proceedings of the 16th International Conference on Applications of Natural Language to Information Systems*, Lecture Notes in Computer Science, pages 153–160. Springer Berlin Heidelberg, 2011. URL http://dx.doi.org/10.1007/978-3-642-22327-3_15.

- [55] C. Unger, L. Bühmann, J. Lehmann, A.-C. Ngonga Ngomo, D. Gerber, and P. Cimiano. Template-based Question Answering over RDF Data. In *Proceedings of the 21st International Conference on World Wide Web, WWW '12*, pages 639–648. ACM, 2012. URL <http://dx.doi.org/10.1145/2187836.2187923>.
- [56] B. Van Durme, Y. Huang, A. Kupść, and E. Nyberg. Towards Light Semantic Processing for Question Answering. In *Proceedings of the HLT-NAACL 2003 workshop on Text meaning - Volume 9*, pages 54–61. Association for Computational Linguistics, 2003. URL <http://dx.doi.org/10.3115/1119239.1119247>.
- [57] M. Vargas-Vera and E. Motta. An Ontology-Driven Similarity Algorithm. Technical report, Knowledge Media Institute, The Open University, 2004.
- [58] E. M. Voorhees. Overview of the TREC-9 Question Answering Track. In *Proceedings of the 9th Text Retrieval Conference*, pages 71–80, 2000. URL http://trec.nist.gov/pubs/trec9/t9_proceedings.html.
- [59] E. M. Voorhees. The TREC Question Answering Track. *Natural Language Engineering*, 7(4):361–378, 2001. URL <http://dx.doi.org/10.1017/S1351324901002789>.
- [60] E. M. Voorhees. Overview of the TREC 2002 Question Answering Track. In *Proceedings of the 11th Text REtrieval Conference*, pages 115–123, 2002. URL trec.nist.gov/pubs/trec11/papers/QA11.pdf.
- [61] D. L. Waltz. An English Language Question Answering System for a Large Relational Database. *Communications of the ACM*, 21(7):526–539, 1978. URL <http://dx.doi.org/10.1145/359545.359550>.
- [62] C. Wang, M. Xiong, Q. Zhou, and Y. Yu. PANTO: A Portable Natural Language Interface to Ontologies. In E. Franconi, M. Kifer, and W. May, editors, *Proceedings of the 4th European conference on The Semantic Web: Research and Applications*, Lecture Notes in Computer Science, pages 473–487. Springer Berlin Heidelberg, 2007. URL http://dx.doi.org/10.1007/978-3-540-72667-8_34.
- [63] B. Webber and N. Webb. Question Answering. In *The Handbook of Computational Linguistics and Natural Language Processing*, pages 630–654. Wiley-Blackwell, 2010. URL <http://dx.doi.org/10.1002/9781444324044.ch22>.
- [64] W. A. Woods, R. Kaplan, and N. B. Webber. The LUNAR Sciences Natural Language Information System: Final Report. Technical Report BBN Report No. 2378, Bolt Beranek and Newman, 1972.
- [65] D. H. Younger. Recognition and Parsing of Context Free Languages in Time N³. *Information and Control*, 10(2):189–208, 1967. URL [http://dx.doi.org/10.1016/S0019-9958\(67\)80007-X](http://dx.doi.org/10.1016/S0019-9958(67)80007-X).
- [66] H.-J. Zeng, Q.-C. He, Z. Chen, W.-Y. Ma, and J. Ma. Learning to Cluster Web Search Results. In *Proceedings of the 27th Annual International ACM SIGIR Conference on Research and Development in Information Retrieval, SIGIR '04*, pages 210–217. ACM, 2004. URL <http://dx.doi.org/10.1145/1008992.1009030>.
- [67] S. Zhao, M. Zhou, and T. Liu. Learning Question Paraphrases for QA from Encarta Logs. In *Proceedings of the 20th International Joint Conference on Artificial Intelligence, IJCAI'07*, pages 1795–1801. Morgan Kaufmann Publishers Inc., 2007.
- [68] Z. Zheng. AnswerBus Question Answering System. In *Proceedings of the Second International Conference on Human Language Technology Research*, pages 399–404. Morgan Kaufmann Publishers Inc., 2002.