Lecture Notes on Data Engineering and Communications Technologies 180

Zhengbing Hu
Qingying Zhang
Matthew He *Editors*

Advances in Artificial Systems for Logistics Engineering III

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Lecture Notes on Data Engineering and Communications Technologies 180

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Advances in Artificial Systems for Logistics Engineering III

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Preface

The development of artificial intelligence (AI) systems and their applications in various fields is one of the modern science and technology's most pressing challenges. One of these areas is AI and logistics engineering, where their application aims to increase the effectiveness of AI generation and distribution for the world's population's life support, including tasks such as developing industry, agriculture, medicine, transportation, and so on. The rapid development of AI systems necessitates an increase in the training of an increasing number of relevant specialists. AI systems have a lot of potential for use in education technology to improve the quality of training for specialists by taking into account the personal characteristics of these specialists as well as the new computing devices that are coming out.

As a result of these factors, the 3rd International Conference on Artificial Intelligence and Logistics Engineering (ICAILE2023), held in Wuhan, China, on March 11–12, 2023, was organized jointly by Wuhan University of Technology, Nanning University, the National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute", Huazhong University of Science and Technology, the Polish Operational and Systems Society, Wuhan Technology and Business University, and the International Research Association of Modern Education and Computer Science. The ICAILE2023 brings together leading scholars from all around the world to share their findings and discuss outstanding challenges in computer science, logistics engineering, and education applications.

Out of all the submissions, the best contributions to the conference were selected by the program committee for inclusion in this book.

March 2023

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Contents

Knowledge Associated with a Question-Answer Pair

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Abstract. The article is devoted to the modeling and presentation of declarative knowledge, which exchanged by participants of a question-answer dialogue. The knowledge of the reactive (responding) agent of the dialogue is considered from the point of view of the classical epistemological understanding of knowledge. It is shown in what cases the epistemological formula "the subject *R* knows that the proposition p'' is not complete and must be supplemented with a question for which the proposition *p* is the true answer. Further, the article examines the logical connection between the question and the relevant answer in the context of the interrogative formula of the question, considered in erotetic logic. Declarative knowledge expressed by the structural component of the interrogative formula, which is called the subject of the question, is proposed to be modeled using linguistic-independent semantic entities in the categories of the Ternary Description Language. The use of the Ternary Description Language makes it possible to construct models of the subject of the question that do not depend on a specific natural language. The final part of the article describes a set of eight patterns that can be used to represent declarative knowledge associated with a question-answer pair.

Keywords: Dialogue · Declarative knowledge · Ternary Description Language

1 Introduction

The words "conversation" and "dialogue" are often understood as synonyms. However, in what follows we will prefer the word "dialogue", and the participants in the dialogue will be called dialogue agents. We are primarily interested in the dialogue that takes place between an artificial dialogue agent (for example, a chatbot) and a human (a chatbot user).

In the process of the dialogue, the dialogue agents form a dialogue transaction, which is an elementary complete cycle of knowledge exchange between the agents. Although there can be many participants in a dialogue, only two dialogue agents form a dialogue transaction.

A dialogue agent, in the process of dialogue interaction with its partner, can perform one of two alternative roles: (1) the role of an active dialogue agent; (2) the role of a reactive dialogue agent. An active agent is an inquiring agent. The part of the dialogue

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transaction that the active agent forms is not necessarily a single verbal question, but always has the status of an interrogative. In goal-oriented dialogues, the main motivation for a dialogue agent to play the role of an active agent is the lack of knowledge necessary to continue the dialogue. An agent plays the role of an active dialogue agent in case when he needs additional knowledge that he expects to receive from his dialogue partner. A reactive agent is a responding agent, and the part of a dialogue transaction that it forms has a response status with respect to the active agent. A dialogue agent who honestly plays the role of a reactive agent provides the partner with the knowledge that, from his point of view, is relevant to the active agent question.

A chatbot can be viewed as an artificial agent participating in an unstructured verbal question-answering dialogue. Often a chatbot is a reactive agent and must be able to generate answers to human questions. In a dialogue transaction, the chatbot and its partner exchange knowledge. Thus, a chatbot is a knowledge-based system, and when designing it, it is important to rely on a model for representing knowledge in a question-answer transaction. Knowledge bases, which are used by modern chatbots, are connected in one way or another with natural language [1, 2]. Representing knowledge using natural language sentences seems to be the norm since the dialogue between the chatbot and its user is verbal. However, this should not be imperative. We will consider a possible way of representing declarative knowledge associated with a question-answer transaction in semantic categories that are invariant to a particular natural language. The article develops the direction of research published in [3]. In the initial part of the article, attention is focused on understanding the knowledge of the reactive agent of dialogue from the point of view of the classic epistemological formula "true and justified belief". The subsequent part of the article analyzes the logical connection between the structure of the question and the structure of the relevant answer from the point of view of the interrogative formula of Belnap and Steel [4]. The structural component of the interrogative formula, called the subject of the question, is considered an indefinite relevant answer. The subject of the question, as a rule, is modeled by a set of propositions and is represented by sentences of a natural language. The article discusses the possibility of modeling the subject of the question using linguistically independent entities in the categories of the Language of Ternary Description [5–8]. The final part of the article describes the declarative knowledge models and patterns associated with a question-answer transaction.

2 Knowledge of the Reactive Agent

What is the declarative knowledge that a reactive agent operates and how can it be understood and represented? Epistemologists propose to understand this knowledge as a proposition and call it knowledge-*that*. The following verbal formula is known: "knowledge-*that* is a Justified and True Belief (JTB)" [9]. According to this verbal formula, the necessary and sufficient conditions for the reactive agent R to know that the proposition p takes place can be formulated as follows:

1) proposition p is true,
2) reactive agent R believes that p, and

3) reactive agent *R* is justified in believing that *p*.

Epistemology is a philosophical science, and therefore, when interpreting the formula JTB and conditions of the reactive agent *R* knowledge, that *p*, pays much attention to philosophical issues, for example, how the phrase "justified belief" should be understood. The only thing that is not questioned is the statement that the proposition must be true. False propositions are not considered knowledge. Thus, the truth of the proposition is understood in the absolute, and not in the relative (in relation to the reactive agent) sense. One can agree with this, however, one can find examples when a proposition that is true for one person is not the same for another person. For example, the proposition represented by the sentence "Tobacco smoking is a virtue" may be true for one reactive agent, but false for another.

The knowledge of the agent *R* that *p* may be represented by a diagrammatic formula in the form of a UML class diagram using the relation of association between the classes *R* and *p*. The UML formula of knowledge-*that* is shown in Fig. 1.

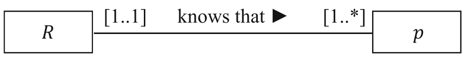

Fig. 1. Diagrammatic formula of knowledge-that of a reactive agent

The multiplicity [1..1] of the pole of the association adjacent to the class *R* means that only one object of the class *R* participates in the association, and the multiplicity [1..*] of the pole adjacent to the class *p* means that one or more objects of the class *p* participate in the association. In other words, one reactive agent can know one or more propositions.

The memory of a reactive agent cannot store all possible knowledge-*that*. This knowledge is formed by the reactive agent in the process of dialogue as a response to the question of the active agent. From the point of view of the way of forming knowledge-*that* by the reactive agent, all questions of the active agent can be divided into two classes: (1) questions of the "search instruction" type and (2) questions of the "task" type.

A question of the "search instruction" type assumes that at the moment the question is received, the requested knowledge is already in the memory of the reactive agent, and the structural elements of the question position the memory to the required area. To form an answer to a question of the "search instruction" type, the use of the attention resource is not required. An example is the following question: "What is your name?" When the active agent, in order to gain access to the knowledge of the reactive agent, uses a question of the "search instruction" type and the requested knowledge is already in the memory of the reactive agent, the diagrammatic formula of knowledge-that shown in Fig. 1 is adequate. Let us show that this formula needs to be refined in the case when a question of the "task" type is used to gain access to the knowledge of a reactive agent.

To obtain the knowledge that is requested using a question of the "task" type, the reactive agent must solve the task associated with this question. The answer is a variant of the solution of the task, obtained by the reactive agent. An example of a question "task" type is: "If Socrates was born in 469 BC, how old would Socrates be today?" It is clear that, most likely, the knowledge requested by this question is not stored in the memory of the reactive agent in a ready-made form, and the use of a mental resource is required for their formation.

From the point of view of the declarative-procedural dichotomy of knowledge, knowledge-*that* is declarative. When forming declarative knowledge, which is the answer to a question of the "task" type, the reactive agent must use procedural knowledge. The procedural knowledge that a reactive agent uses depends on how a question of the "task" type is formulated. Let us illustrate the last statement by the example of convergent questions of the "task" type. Convergent questions are different questions that assume the same true answer. In other words, the same true proposition of the reactive agent can be the answer to different questions of the active agent. Schaffer analyzes various convergent questions, including the following two [10].

(1) Is there a goldfinch in the garden, or a raven?
(2) Is there a goldfinch in the garden, or a canary?

If it is true that there is a goldfinch in the garden, then the reactive agent should give the same answer to both questions: "There is a goldfinch in the garden." However, in order to get this answer in the case of question (1), the reactive agent needs relatively simple procedural knowledge (knowledge that makes it possible to distinguish a goldfinch from a raven), and in order to get the same answer in the case of question (2), the reactive agent needs much more complex procedural knowledge (knowledge that makes it possible to distinguish a goldfinch from a canary).

Thus, the diagrammatic formula for the knowledge-*that* of a reactive agent shown in Fig. 1, in the general case, is incomplete and must be supplemented by a question, the answer to which is knowledge-*that* of the reactive agent. Figure 2 shows a refined formula for the knowledge-*that*.

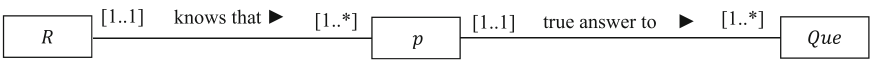

Fig. 2. A refined formula for the knowledge-that of a reactive agent

In Fig. 2, *Que* denotes a class of questions. The class diagram shown in Fig. 2 differs from the class diagram shown in Fig. 1 in that it contains one more relation of the association type between the class of propositions *p* and the class of questions *Que*. The multiplicity [1..*] of the pole of the association adjacent to the class *Que* means that one or more objects of the class *Que* participate in the association. In other words, the same proposition can be the answer to several different questions.

3 Interrogative Formula of the "Search Instruction" Type Question

The logical connection between the question of the "search instruction" type and the answer to this question can be revealed by explicating the question formula proposed by Belnap and Steel [4]. The question formula, which Belnap and Steel consider, and which they call the interrogative formula, defines a question as a composition of two logical components: the request of the question and the subject of the question. In Fig. 3, the interrogative formula is presented in the form of a UML class diagram.

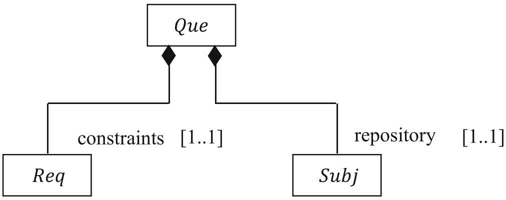

Fig. 3. The interrogative formula in the form of a UML class diagram

The class diagram in Fig. 3 represents the class of questions *Que* as a composite of two classes: the class of question's requirements *Req* and the class of question's subjects *Subj*. The multiplicity [1..1] of poles adjacent to the *Req* and *Subj* classes means that exactly one object of each of these classes participates in the composition. The names of the poles reflect the roles of objects of these classes in the composition. The pole adjacent to the *Subj* class is named "repository", since the subject of the question points to that part of the reactive agent's memory where the knowledge that includes the answer to the question is located. The pole adjacent to the *Req* class is named "constraints" since the requirement of the question sets constraints that the reactive agent must take into account when forming an answer.

Belnap and Steel's theory assumes that the knowledge determined by the subject of the question is propositions that are represented by sentences in natural language, and the requirement of the question may, for example, require that these sentences be considered as an alternative.

Questions are classified with the cardinality of the subject of the question. The subject of the question can be: (1) a finite and small number of propositions; (2) an infinite or very large number of propositions. In the first case, the relevant questions are called whether-questions, and in the second case – which-questions.

An example of a whether-question is the question of tobacco smoking, which was, allegedly, formulated by the English king James the first [4]:

«Tobacco smoking: a vice, a virtue, a vagary, an extravagance, a cure for all ills?»

The subject of this question consists of exactly five elements: "tobacco smoking is a vice"; "tobacco smoking is a virtue"; "tobacco smoking is a vagary"; "tobacco smoking is an extravagance"; "tobacco smoking is a cure for all ills".

An example of a which-question is the following question:

«Which positive integer is the smallest prime greater than 45?»

The subject of this question consists of an infinite number of elements and can be represented by two clauses with one variable.

x is the smallest prime greater than 45.
x is a positive integer.

It is clear that whether-question is a special case of which-question, and whether-subject is a special case of which-subject. Belnap and Steel propose a notation for whether-subject, according to which whether-subject is represented by a clause with variables (such a clause is called the subject matrix) and a set of constraints that define the values of variables in the matrix (such constraints are called category conditions).

Both the subject matrix and category conditions are represented by means of natural language.

The answer to whether-question or which-question is part of the subject of the question that the reactive agent separates from the whole subject of the question in accordance with the constraints set by the requirement of the question. The subject of whether-question or which-question contains the answer to the question, therefore the subject of a question of the type "search instruction" can be understood as an indefinite answer, or an answer with some (often significant) degree of indefiniteness.

4 Knowledge Structure in Question-Answer Transactions

The concept of "proposition" is not identical to the concept of "sentence" in natural language. A proposition can be represented by a natural language sentence. Representation of propositions in the form of sentences in natural language is convenient when writing articles on the interpretation and modeling of knowledge-*that*, but, from the author's point of view, it limits the developers of artificial reactive agents using such kinds of models.

If the knowledge-*that* used by an artificial reactive agent is tied to a specific natural language, then the agent can maintain a dialogue only in a specific language and is monolingual. In the case when the representation of the knowledge-that of a reactive agent is carried out in categories that are not related to a specific natural language, then there is a potential opportunity to design an artificial reactive agent that can support a dialogue in several languages and be multilingual. It is very important to be multilingual, especially for an artificial dialogue agent "dwelling" on the Internet.

4.1 The Language of Ternary Description

It is advisable to represent declarative knowledge in a question-answer transaction by means, of the ontology which is based on non-linguistic entities. One of these means is the Language of Ternary Description (LTD), proposed by Uyemov [5–8].

The initial entity in LTD is an object, in the most general sense of the word. An object, depending on its place in the structure of knowledge, can exist in one of three forms: object-thing, object-property, and object-relation.

The categories "thing" and "property" have the traditional meaning in the LTD, which is accepted in classical logic, and the meaning of the category "relation" differs from the traditional one. It is generally accepted to use the concept of "relation" to denote the mutual influence of several things, or the relationship between things. In the context of the LTD, a relation is understood as what constitutes a thing, or the relationship that takes place in a thing. In other words, the relation in LTD is, in some sense, another name for the internal logical organization of a thing.

The binary association of an object-thing with an object-property generates two prototypes for representing entities in LTD.

1) The name of the first prototype is "a thing, which possesses a property", and the formal notation is: $(*)*$.

2) The name of the second prototype is: “a property, which attributed to a thing”, and the formal notation is: $(*))*$.

The binary association of an object-thing with an object-relation generates two more prototypes for representing entities in LTD.

3) The name of the third prototype is: “a thing, in which a relation takes place”, and the formal notation is: $*(*)$.
4) The name of the fourth prototype is “a relation, which takes place in a thing”, and the formal notation is: $*((*)$.

The object-thing symbol is written inside the brackets, the object-property symbol is written to the right of the brackets, and the object-relation symbol is written to the left of the brackets.

The association of an object-thing with an object-property or with an object-relation has a direction. If the symbol of an object-thing is enclosed in ordinary (single) parentheses, then this means that the association is directed from the object-thing to the object-property or object-relation. In words, this is expressed as: “a thing, which possesses a property “, or “a thing in which a relation takes place.” An asymmetric (double) parenthesis means that the association is directed from an object-property or an object-relation to an object-thing. Verbal formulation: “a property, which attributed to a thing “, or “a relation, which takes place in a thing.”

An object, depending on the degree of indefiniteness of knowledge about it, exists in one of three forms:

1) a definite object (the asterisk in the prototype substitutes by symbol t),
2) an indefinite object (the asterisk in the prototype substitutes by symbol a),
3) an arbitrary object (the asterisk in the prototype substitutes by symbol A).

The categories “thing, property and relation”, as well as “definiteness, indefiniteness, and arbitrariness” are independent and form nine classes of objects: (1) a definite object-thing, (2) an indefinite object-thing, (3) an arbitrary object-thing, (4) a definite object-property, (5) an indefinite object-property, (6) an arbitrary object-property, (7) a definite object-relation, (8) an indefinite object-relation, (9) an arbitrary object-relation.

Substituting into prototypes for representing entities in LTD instead of the asterisk one of the symbols t, a or A, we get a set of possible models of knowledge-*that* represent in the ontological basis of LTD. Since there are four prototypes, in each of which we can substitute two symbols of the object, and the total number of object symbols is three, there are 24 possible models of knowledge-that.

4.2 Representation of Declarative Knowledge in Question and Answer

The question-answer transaction, in the context of the LTD-representation of declarative knowledge, will be considered as a development of the idea of the interrogative formula, shown in Fig. 3.

The subject of the question is the key element of the question-answer transaction. The reactive agent, when constructing an answer, is essentially engaged in transforming the indefinite knowledge pointed to by the subject of the question into definite knowledge-*that* of the answer.

When modeling the knowledge pointed to by the subject of the question, we will restrict ourselves to only the following four alternative models.

$$K_{subj} = (t)a \tag{1}$$

$$K_{subj} = (a)t \tag{2}$$

$$K_{subj} = (t))a \tag{3}$$

$$K_{subj} = (a))t \tag{4}$$

There are several reasons for choosing models (1)–(4) to represent the knowledge of the subject of the question. First, the subjects of most of the examples of questions described in works devoted to the logic of questions and answers can be represented by one of the models (1)–(4) [4, 10, 11]. Secondly, these are exactly the models that correspond to the idea that a reactive agent, when constructing an answer, transforms the indefinite knowledge of the subject of the question into definite knowledge-that of the answer. One of the objects in models (1)–(4) is indefinite, and the active agent expects to receive more specific knowledge about it from the reactive agent.

The model $K_{subj} = (t)a$ represents knowledge about a specific definite thing, which possesses indefinite property. A question with such a subject is formed by an active agent in the case when he wants to know which properties a given thing possesses.

The model $K_{subj} = (a)t$ represents knowledge about an indefinite thing, which possesses specific definite property. A question with such a subject is formed by an active agent in the case when he wants to know which things possess a given property.

The model $K_{subj} = (t))a$ represents knowledge about an indefinite property, which is attributed to a specific definite thing. A question with such a subject is formed by an active agent in the case when he wants to know which specific property is attributed to a given thing.

The model $K_{subj} = (a))t$ represents knowledge about a definite property, which is attributed to some indefinite thing. A question with such a subject is formed by an active agent in the case when he wants to know to which things a given property is attributed.

The disadvantage of models (1)–(4), from the point of view of software engineering, is their poor adaptability for mapping into relevant data structures. These models could be useful for the development of software systems if we could find a way to transform them into types or data structures of modern programming systems. This is, first of all, about the datalogical interpretation of an indefinite object.

One of the possible datalogical interpretations of indefiniteness is multiplicity. An indefinite object can be understood as a set of definite objects, and the cardinality of this set as a measure of indefiniteness. Then a decrease in the degree of indefiniteness of an object is equivalent to a decrease in the cardinality of the corresponding set. An indefinite object turns into a definite one when the cardinality of a set becomes equal to one, or when the set is represented by one specific definite object.

Taking into account such interpretation of indefiniteness, we can replace indefinite objects with lists of specific objects and describe models (1)–(4) with the following patterns.

$$K_{subj} = (thing) \rightarrow list\ of\ properties \tag{5}$$

$$K_{subj} = (list\ of\ things) \rightarrow propery \tag{6}$$

$$K_{subj} = (thing)) \leftarrow list\ of\ properties \tag{7}$$

$$K_{subj} = (list\ of\ things)) \leftarrow property \tag{8}$$

Patterns (5)–(8) are datalogic analogs of models (1)–(4), which describe declarative knowledge that can be transferred to a reactive agent by means of the subject of the question.

Since the subject of the question is, in fact, an indefinite answer, and the reactive agent, when constructing the answer, reduces the degree of indefiniteness of the subject of the question to a level acceptable for the answer, then the knowledge-that patterns of the answer should be similar to patterns (5)–(8). The patterns of knowledge-that of the answer differ from the patterns of knowledge of the subject of the question by the cardinality of the set of objects-things or objects-properties. We may describe the knowledge-that of the answer with the following patterns.

$$K_{ans} = thing\ POSSESSES\ PROPERTIES\ list\ of\ properties \tag{9}$$

$$K_{ans} = list\ of\ things\ POSSESSES\ PROPERTY\ property \tag{10}$$

$$K_{ans} = list\ of\ properties\ ATTRIBUTED\ TO\ thing \tag{11}$$

$$K_{ans} = property\ ATTRIBUTED\ TO\ list\ of\ things \tag{12}$$

5 Conclusion

Chatbots are capable of maintaining long-term dialogue with a human. The dialogue protocol between a chatbot and a human can be represented as a sequence of transactions. The human partner forms the interrogative part of the transaction in order to receive from the chatbot a portion of the declarative knowledge necessary to continue the dialogue. The portion of declarative knowledge that is requested from the chatbot belongs to the class of knowledge-*that* that is a proposition. When forming an answer in the form of a proposition, the chatbot uses procedural knowledge, which depends on how the question is formulated. Thus, a chatbot is a knowledge-based system, and during its development, it is necessary to rely on one or another model of knowledge representation associated with a dialogue transaction. The logical connection between question and answer in a single transaction is modeled by Belnap and Steel's interrogative formula. The key component of the interrogative formula is the subject of the question, which for the question of "search instruction" type can be considered as knowledge-*that* of the answer, but with a significant degree of indefiniteness.

It is advisable to build models of knowledge on an ontological basis, which is not associated with linguistic categories but represents the semantic essence of knowledge. In this case, there is a potential opportunity to develop multilingual chatbots, which is especially important for chatbots operating on the Internet. The article illustrates the applicability of Uyemov's Ternary Description Language for representing portions of declarative knowledge associated with a question-answer transaction. The patterns for representing the knowledge of the subject of the question and the corresponding answer, represented by formulas (5)–(12), explain the internal logical essence of the question-answer transaction in the context of knowledge representation and are not associated with a specific natural language.

Further development of this work is supposed to be carried out in the direction of synthesizing a model of a dialogue knowledge base, which includes not only declarative knowledge associated with dialogue transactions but also procedural knowledge necessary for conducting a question-answer dialogue focused on solving problems.

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