Research on Performance Evaluation and Optimization Strategy of Open-Domain Dialogue System Based on Knowledge Graph

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Abstract: With the development of artificial intelligence technology, open-domain dialogue systems are attracting more and more attention as a means of intelligent interaction. An open-domain dialogue system aims to create a natural, fluid, and enjoyable dialogue with the user. As a structured representation, a knowledge graph can provide rich semantic information and background knowledge for dialog systems. This paper mainly studies the performance evaluation and optimization strategy of open-domain dialogue systems based on a knowledge graph. First, the knowledge graph network model and the dialogue system protocol specification are introduced. Second, an open-domain dialogue system based on the knowledge graph is designed, which includes a knowledge graph collection module, a conversation preprocessing module, and a conversation recognition module. We introduced the optimization process of the structure, training, and dialogue model parameters. Third, the effectiveness of open-domain dialogue systems based on a knowledge graph is verified by experiments, and various evaluation indicators and methods are used to analyze the results. Finally, this paper's main contributions and innovations are summarized, and future research directions are pointed out. This paper concludes that open-domain dialogue systems based on knowledge graphs improve semantic understanding and logical consistency of dialogue, increase dialogue diversity and fun, achieve high-quality dialogue partners, promote the application of artificial intelligence technology in many fields, and meet the conversational needs of users.

1. Introduction

Open-domain dialogue systems are one of the essential applications of artificial intelligence technology and a general term for intelligent interaction. It can be divided into basic and non-basic dialogue systems, composed of answering and chat systems. To improve the intelligence of the dialogue system, the dialogue system entrusts the knowledge graph to acquire and represent knowledge. Since deep learning, knowledge graph has become the key to the dialogue system, and the quality of dialogue has become an evaluation index. Unlike the traditional dialogue system based on rules or templates, the dialogue system based on a knowledge graph places more emphasis on understanding semantics, logical consistency, and diversity. Therefore, we propose the topic of open-domain dialogue systems based on a knowledge graph, and performance evaluation and optimization strategies provide new solutions for pen-domain dialogue systems.

Knowledge graph originates from artificial intelligence with semantic network as the core. The network model contains triples. It is also a tool of the dialogue system. From the perspective of network structure, the knowledge graph pursues completeness and realizes knowledge modernization through the combination of entities, relationships, and attributes [1]. However, this is only on the static level. Today, the knowledge graph has opened up a path of dynamic updating. The advancement of knowledge graphs not only changes how knowledge is acquired and represented, reflecting the up-to-date knowledge of knowledge, but also rewrites the performance of the dialogue system and improves its quality. Therefore, the discussion of open-domain dialogue systems based on a knowledge graph must have a dynamic and global perspective. Therefore, we propose a performance evaluation and optimization strategy proposition in open-domain dialogue systems. In short, open-

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domain dialogue systems based on knowledge graphs are the necessary conditions and guarantees for intelligent interaction. The existing research shows that open-domain dialogue systems based on knowledge graphs have progressed, but there are also shortcomings. Researchers have yet to find ways to use knowledge graphs to effectively improve the quality of dialogue and continue to explore. Therefore, performance evaluation and optimization strategies need to be improved, contributing to theoretical innovation and practical needs.

Based on the above background analysis, this paper proposes a strategy to evaluate and optimize the performance of an open-domain dialogue system based on the knowledge graph to improve the semantic understanding and logical consistency of the dialogue system. The diversity and interest are improved through deep learning theory and neural networks. The main content is to design open-domain dialogue systems, including a knowledge graph collection module, dialogue preprocessing module, and dialogue recognition module. Experiments have verified its effectiveness and superiority and dealt with risks such as data sparsity and noise interference, so this study has theoretical significance and practical value [2].

2. The Background of Open-domain Dialogue Systems

2.1 Knowledge Graph Network Model

The knowledge graph is a concept developed in parallel with the semantic network. The knowledge graph highlights the concept of artificial intelligence and the structured orientation of knowledge, reflecting the innovative strategies of knowledge acquisition and representation since the 21st century. However, it is still challenging to be consistent when we use formal standards to construct the definition and nature of the knowledge graph. The network model of the knowledge graph refers to the use of nodes and edges in graph theory to represent entities and relationships in knowledge, thereby constructing a structured knowledge representation. The network model of a knowledge graph usually contains three essential elements: entity, relationship, and attribute. Entities refer to objects in the knowledge graph, such as people, places, events, etc. Relationship refers to the connection between entities, such as members, occurrences, causes, etc. Attributes are characteristics of an entity or relationship, such as name, age, color, etc. The network model of a knowledge graph can be represented by triples (entities, relations, entities) or quadruples (entities, relations, entities, attributes), thus forming a vast directed graph or directed hypergraph. The knowledge graph network model has the following advantages: First, it can efficiently organize and store large amounts of intellectual information. Second, it facilitates the query and retrieval of knowledge data. Third, it supports many types of reasoning and analysis [3].

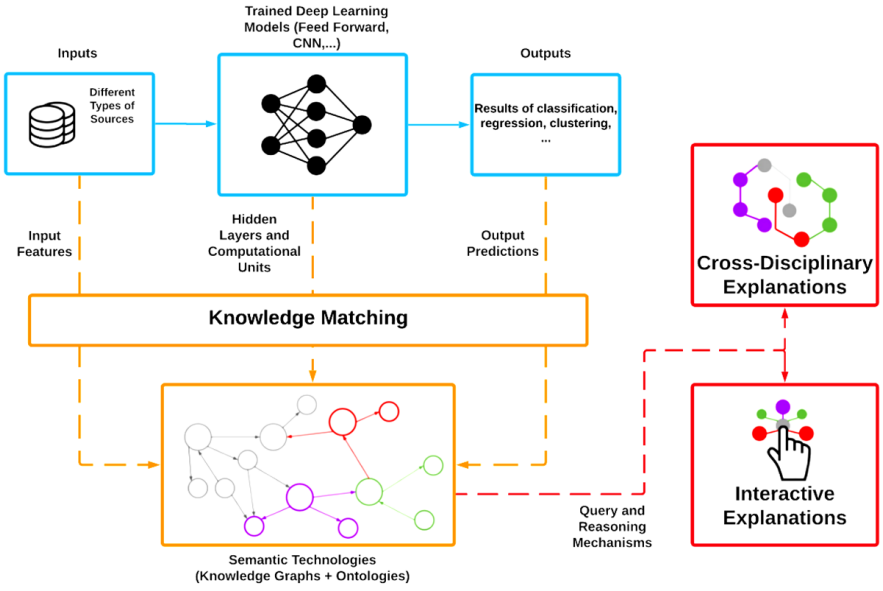

Figure 1 The knowledge graph network model

The knowledge graph network model is shown in Figure 1.

2.2 Dialogue System Protocol Specification

This paper proposes a dialogue system based on a knowledge graph. This method uses the structural and semantic capabilities of the knowledge graph to turn dialogues into knowledge retrieval and inference problems and trains neural network models to accurately identify and respond to user intent. To verify the effectiveness of the method, this paper uses the dialogue system protocol specification as the simulation platform to generate data with different themes, contexts, and complexity. We use it as the input of the neural network model. Simulation results show that this method realizes intelligent dialogue in many fields and scenarios and has good robustness and generalization ability. The knowledge graph is a structured representation used to store and organize a large amount of domain knowledge. The function of the knowledge graph is expressed as follows:

$$f(e_1, r, e_2) = \sigma(\mathbf{W}[\mathbf{e}_1; \mathbf{r}; \mathbf{e}_2] + \mathbf{b}) \tag{1}$$

Among them, e_1 and e_2 represent entities in the knowledge graph, r represents the relationship between entities; $\mathbf{e}_1$, $\mathbf{r}$ and $\mathbf{e}_2$ represent the vector representations of entities and relations, respectively, $\mathbf{W}$ and $\mathbf{b}$ are model parameters, σ is the activation function, and $f(e_1, r, e_2)$ represents the correlation score between entities and relationships.

3. Open-Domain Dialogue Systems Based on Knowledge Graph

3.1 Knowledge Graph Collection Module and Dialogue Preprocessing Module

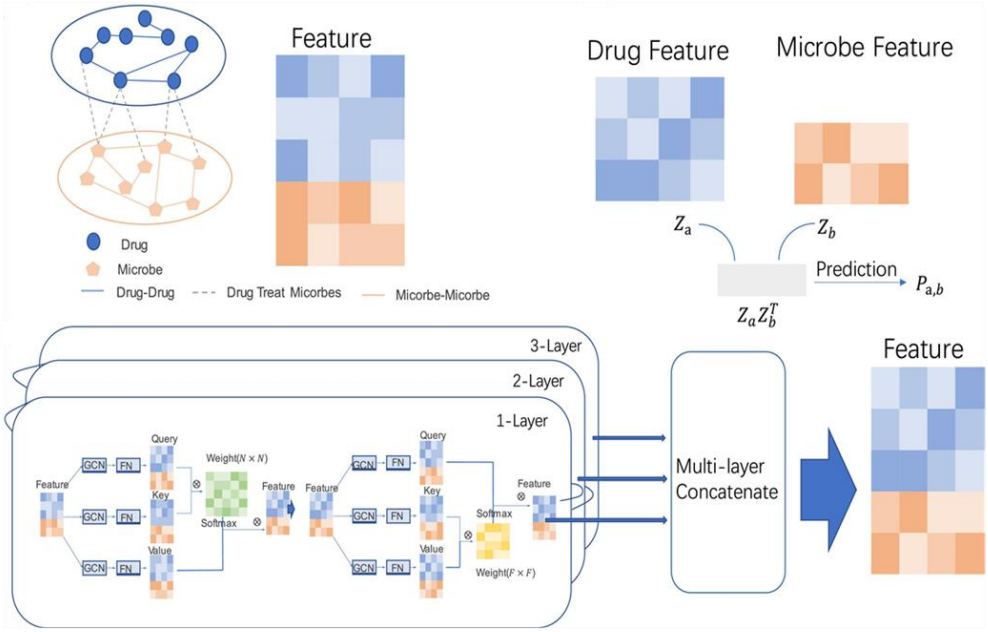

Figure 2 Knowledge graph collection module and dialogue preprocessing module

The knowledge graph collection module and the dialog preprocessing module are important components of an open-domain dialog system based on the knowledge graph. They are the expression of knowledge support and input processing of the dialogue system. The knowledge graph collection module and the dialogue preprocessing module discuss methods of building knowledge graphs from the perspective of data source, data quality, and data scale. In addition, some scholars believe that a knowledge graph is a form of knowledge representation or knowledge base. Because the knowledge graph is more structured and semantic to some extent, it belongs to information science for the purpose of intelligence. The research history of knowledge graph can be traced back to the semantic network, and its main activities include knowledge extraction, fusion, and reasoning. The concept

and technology of dialogue preprocessing modules are closely related to the development of natural language processing [4]. Thanks to the dialog preprocessing module, user input becomes an important source of information for the dialog system. The main contribution of the dialogue preprocessing module theory in modern times is the introduction of deep learning and attention mechanisms. Therefore, the concept of dialogue preprocessing module initially focused on text analysis based on linguistic feature attributes. The knowledge graph collection module and dialogue preprocessing module are shown in Figure 2.

3.2 Dialogue Identification

3.2.1 Dialogue Model Structure

Compared to traditional dialogue systems based on rules and templates, knowledge graph-based dialogue systems emphasize the relationship between dialogue content and knowledge graphs and emphasize semantic understanding and reasoning. Although some scholars have questioned that the dialogue system may not be directly related to the knowledge graph, most scholars argue that the knowledge graph can effectively support the dialogue system. Liu et al. proposed a classical architecture model of a dialogue system including three elements: language understanding, dialogue management, and language generation. Since then, the model has become a typical tool for dialogue systems and developed a concept called dialogue system based on a knowledge graph [5]. Scientists believe that dialogue systems are interactive and "multi-round." A conversation ends only when the user and system reach a common goal. Thus, dialogue management is the core of the dialogue system. In addition, scientists have summarized dialogue management into two models: the state-based dialogue management model and the intention-based dialogue management model. The former focuses on tracking and updating the status of the conversation, and the latter focuses on identifying and executing user intent, also called user requests. Although knowledge graph-based dialogue systems have some technical challenges, they are more natural and flexible from an intelligence point of view. As a result, the concept of a dialogue system based on a knowledge graph has gradually become the consensus of dialogue system research and practice.

3.2.2 Dialogue Model Training and Parameter Optimization Process

In researching dialogue systems based on knowledge graphs, previous studies considered the semantic understanding of dialogue content. They should have addressed the context of dialogue history, resulting in inconsistent responses or poor optimization effects. Based on the above problems, we have improved the dialogue model training and parameter optimization process, mainly combining the attention mechanism and the recurrent neural network model. We have deeply optimized the structure of the neural network to make the dialogue system more responsive. Specifically, the attention mechanism technology is used to extract the critical information in the dialogue history and assign different weights to that information. Second, using the recurrent neural network model, the vector of the attention mechanism's output and the input's vector are fused to generate a new hidden state vector. This vector is input to the language generation module to generate the final response text. Finally, the cross-entropy loss function and gradient descent algorithm are used to calculate and optimize the model parameters. Attention mechanisms are techniques that mimic human visual attention. Its job is to select and focus on essential parts of the input sequence. The function of the attention mechanism is expressed as follows:

$$\alpha_{t,i} = \frac{\exp(e_{t,i})}{\sum_{j=1}^{T} \exp(e_{t,j})} \tag{2}$$

Among them, $\alpha_{t,i}$ represents the attention weight of the i-th input element at the t-th time step; $e_{t,i}$ represents the similarity score between the i-th input element and the hidden state at the t-th time step; T represents the input sequence length. The dialogue model training and parameter

optimization process is shown in Figure 3.

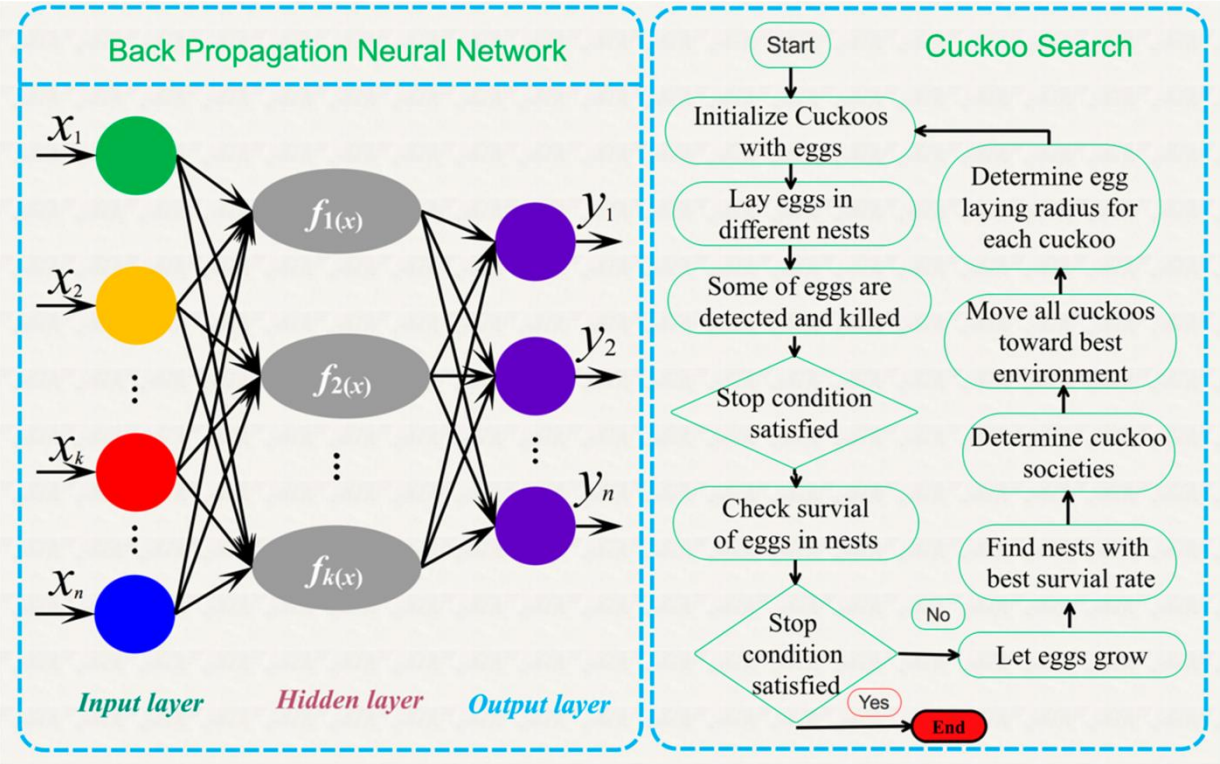

Figure 3 The dialogue model training and parameter optimization process

4. Analysis of Experimental Results of Open-Domain Dialogue Systems Based on Knowledge Graph

4.1 Dialogue System Experiment Process

The experimental process of the dialogue system is the main content of the research, which focuses on the performance and effect of the dialogue system and directly reflects the design and advantages and disadvantages of the dialogue system through the dialogue data and evaluation indicators. Some components of the experimental process of the dialogue system are gradually being formed, such as the collection and labeling of dialogue data, evaluation methods and standards, systematic comparison and analysis, etc. Moreover, various evaluation systems have gradually received attention. However, the practice of some dialogue systems remains in the stage of closed domain or specific task, contrary to the logical framework and generation mechanism of open-domain dialogue systems. So, the following problems occur:

- How can you effectively use the structured and semantic information in your knowledge graph to improve the intelligence of the dialogue system?
- How do you reconcile domain and common sense knowledge within your knowledge graph to improve the naturalness and flexibility of the dialogue system?
- How can multiple dimensions, such as user satisfaction, task completion, and ability to interact, be holistically considered to assess the overall effectiveness of a dialog system?

4.2 Dialogue System Evaluation Indicators and Methods

From an evaluation perspective, dialogue system evaluation metrics and methods are the fundamental link in dialogue system research and the central embodiment of dialogue system performance and impact. Therefore, evaluation metrics and evaluation methods for dialogue systems are mainly based on user satisfaction, task completion, and dialogue ability [6]. The purpose of designing a dialogue system is to improve user satisfaction, and the user is the beneficiary of the dialogue system. Currently, the dialogue system strengthens user satisfaction control from two

perspectives: subjective evaluation and objective evaluation. There are three primary forms: questionnaire survey, evaluation index, and internal optimization of the dialogue system. First, users are satisfied with the dialogue system's functionality, content, and form. Second, we will achieve quantitative user satisfaction management by formulating indicators such as accuracy, recall, and F1 score and disclosing the evaluation indicators to users. In recent years, dialogue systems based on knowledge graphs have improved the intelligence level of dialogue systems and increased user satisfaction through knowledge retrieval and reasoning. However, unlike traditional rule-based or template-based dialog systems, the naturalness and flexibility of current knowledge graph-based dialog systems need further improvement.

4.3 The Result Analysis of Dialogue System

The result analysis of the dialogue system is the application and verification of the evaluation metrics and method of the dialogue system. It is also the summary and feedback of the experimental process of the dialogue system. The analysis results of the dialogue system will show different effects. The criteria and selection of the evaluation indicators and methods of the dialogue system serve the performance and effectiveness of the dialogue system. The analysis results of the system are mainly reflected in the advantages and disadvantages of the system. In the evaluation framework of open-domain dialogue systems based on a knowledge graph, accurate recognition, effective response, intelligent reasoning, and natural interaction are the core values and the highest criteria for developing dialogue systems. The diversity of open-domain dialogue systems based on knowledge graphs and the difference in user requirements lead to a complex situation in the analysis of dialogue systems [7]. Systems have made some progress in semantic understanding and reasoning, but the knowledge graph is imperfect, and the dialogue system needs a flexible adaptation mechanism. Therefore, the shortcomings of open-domain dialogue systems based on knowledge graphs are generated, negatively affecting the analysis of dialogue system results. The result analysis of the dialogue system is shown in Figure 4.

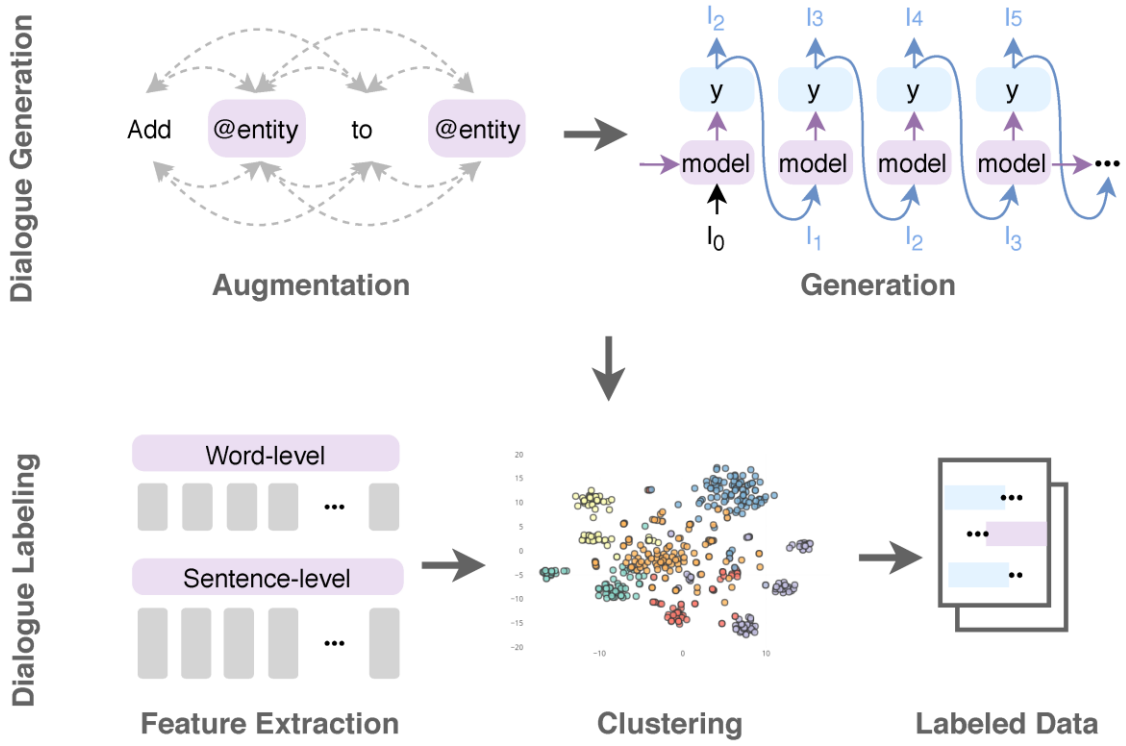

Figure 4 The result analysis of the dialogue system

5. Conclusion

The open-domain dialogue systems based on knowledge graphs have been at the forefront of

dialogue system research, posing challenges and requirements for designing and implementing dialogue systems. Dialogue systems are the epitome of artificial intelligence and an essential means of human-computer interaction. In addition, it meets the urgent needs of completing information acquisition and maintaining a knowledge graph and reflects the requirements of the knowledge graph. Under the influence of open-domain dialogue systems based on knowledge graphs, we construct the theoretical analysis framework and practical mechanism of dialogue systems. In recent years, the latest information technology, such as deep learning, has promoted the development of dialogue systems. By enhancing the dialogue system with technologies such as knowledge retrieval and reasoning and increasing its accuracy and scientificity, its value is equivalent to the internal logic of the knowledge graph. Therefore, the knowledge graph also provides a new path for the dialogue system. To sum up, the sustainable development and improvement of open-domain dialogue systems based on knowledge graphs will help to better serve user needs and promote the construction and application of knowledge graphs.

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