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Research Article

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Knowledge Graph: A Survey

Abiola Akinnubi[1*] and Jeremiah Ajiboye[2]

[1]*University of Arkansas at Little Rock, Information Science Department, Little Rock, 72204, United States of America*

[2]*Information Security Researcher, London, United Kingdom*

[*]**Corresponding Author**
Abiola Akinnubi, Information Science Department, University of Arkansas at Little Rock, United States of America.

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Abstract

This survey discusses the concept of knowledge graphs, including their construction, extraction, and applications. Various tools such as Zotero, Web of Science, Google Scholar, EndNote, and VosViewer are used to analyze and visualize collected data. A Boolean query mechanism ensures the gathered material is relevant to the study. The discussion includes studies on relation extraction using graph neural networks, the application of knowledge graphs in biomedical research, and the use of knowledge graph embedding in healthcare. These studies highlight the growing importance of knowledge graphs in managing and representing complex information. Notable studies discussed include the role of knowledge graphs in connecting related medical information, the application of knowledge graph technology in healthcare, and the potential benefits and limitations of using knowledge graph embedding in biomedical data analysis. This survey paper provides valuable insights into the growing importance of knowledge graphs in managing and representing complex information and how they can help provide new insights into various fields. It suggests potential future directions for research in this area, highlighting the importance of continued exploration and innovation to realize the potential of knowledge graphs fully.

1. Introduction

Information and data representation has received attention in recent years; the introduction of the semantic web principle to modeling information and data in graph format using the lexical relationship and various available statements of facts in building relationships between entities is not left out. Entities are usually persons or things of interest to information scientists. Hence the adoption of a se- mantic framework in building and developing knowledge graphs for new and existing data. Since machine learning and artificial intelligence frameworks have been inculcated into various walks of life, knowledge graphs have since received research contributions utilising machine learning workflow in modeling relationships or extracting a representative relationship between data. This survey closely examines three key aspects of knowledge graphs: extraction, application, and construction. It further surveys various important literature that has contributed meaningfully to this domain, especially authors who have received citations in recent years whose article on knowledge graph addresses the extraction, application and construction of knowledge graphs. The survey then provides a brief analysis like publication trend keyword word cloud and network visualization of related bibliography to help readers understand the impacts of researchers working on knowledge graphs and the new emerging research by these authors.

2. Methodology

This survey utilizes several tools, including Zotero, Web of Science, Google Scholar, EndNote, and VosViewer, to manage, analyze, and visualize collected data. The survey involved collecting various publications and sorting them. These publications were stored in a reference manager library as a database. The collected articles were divided into three main themes: application of knowledge graph, construction of knowledge graph, and extraction of knowl- edge graph. A Boolean query mechanism was primarily used to ensure that the gathered material was not overburdened with unrelated pub- lications and to help maintain data consistency. Figure 1 below provides concise information for readers on collecting, sorting, and analyzing the data used in this study. This survey primarily focused on recent publications and included a few historical ones. Its main purpose was to give readers an idea of recent innovations and ad- vancements in the knowledge graph. Historical publication trends and other important network visualizations of author networks were generated.

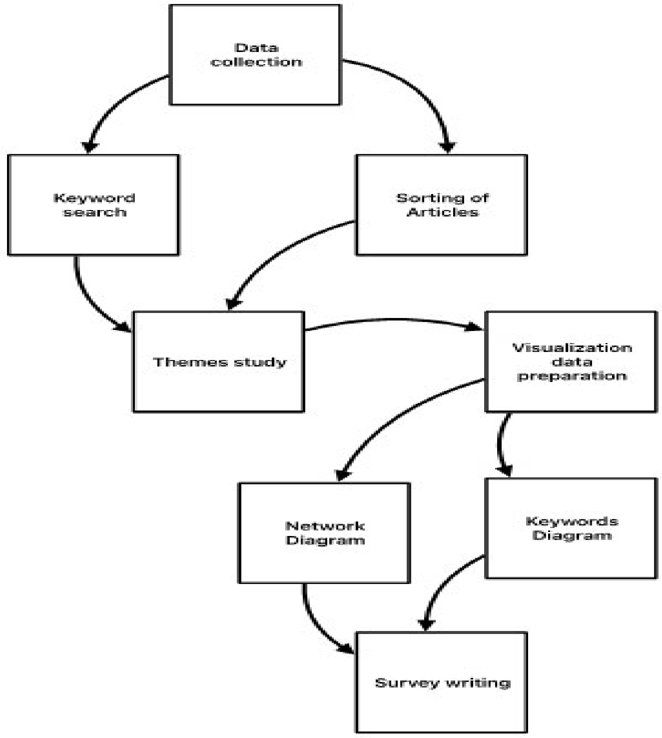

Figure 1: Step-Wise Approach to This Survey Research

3. Main Body

3.1 Extraction of Knowledge Graph

The extraction of knowledge graphs is a task that involves developing and mining knowledge from an existing corpus. This step is crucial in developing a knowledge graph, and it relies on relation ex- traction to complete the extraction of the knowledge graph task [1]. Used a topic modeling approach to extract and develop a knowledge graph for learning resources. The algorithm of topic extraction for knowledge graphs has the capability to extract main topics from the text corpus using the extracted topics to link related resources and generate a dynamic knowledge graph. Wikipedia Miner, TextRank, and Genism were used in the topic modeling approach. Combining these three approaches for knowledge graph extraction improved the accuracy level for knowledge graph extraction. Another information extraction mechanism uses graph convo- lution network (GCN), combined event trigger and GCN in mapping related information using the shortest path between an entity and related aggregated data [2]. The GCN approach involves tokenizing a sentence as a set of entries and passing sentence to a Bi-LSTM layer for classification. An entity type embedding was used to capture events or related information with an entity type of either Time, Person, organization, or Job Title within the sen- tence. The GCN transfers syntactically related information along the shortest paths between argument candidates that capture and aggregate the latent associations between arguments which is useful in developing a knowledge graph. Linking information syntactically is also like relations which models the edge in a graph. Hence, relation extraction is an important step in knowledge graph; uses the relation extraction approach on New York Times published news article to develop a knowledge graph [3].

The relation extraction designed by authors in is called RECON; this uses WikiData and Freebase ontologies for developing their contextual neural network knowledge graph. RECON leverages neural networks to learn and optimize the knowledge graph [4]. Developed an extraction model which can be represented as $R = (r_i \mid i \in (1, N]\}$ R is relation, an event is represented as $E = (e_i \mid i \in (1, N]\}$. The model predicts each instance of relation and event in the corresponding corpus. This approach allows a knowledge graph extraction that uses the correlation of events and the traditional relation extracted to achieve a knowledge graph. Authors in published an interesting methodology for ex- tracting topics from learning resources and representing them as interactive knowledge graphs [1]. The study aims to help learners understand and navigate complex learning materials, leading to more effective learning outcomes. The approach has many poten- tial applications, including education, health, and environmental sustainability. By utilizing interactive knowledge graphs, learners can gain a deeper understanding of the subject matter and improve retention of the information. The study highlights the importance of presenting information engagingly and interactively and suggests that this approach can lead to better learning outcomes.

Overall, the study presents a promising new approach to learning that has the potential to revolutionize the way we educate ourselves and others [2]. Introduced a novel method for joint event extraction using graph convolutional networks. Their approach involves ex- tracting events along the shortest dependency paths, which has been shown to improve the accuracy of event extraction. To evaluate their method's effectiveness, the authors conducted experiments on three different datasets and reported state-of-the-art results in event extraction. Their findings suggest the proposed method is highly effective for extracting events from text data. This research is partic- ularly relevant in natural language processing, as event extraction is crucial in many applications, such as information retrieval and question-answering. By improving the accuracy of event extractions method can significantly enhance the performance of these applications. Overall, paper makes a valuable contribution to natural language processing, and their proposed method is a promising avenue for future research in event extraction.

Authors in presented RECON, a relation extraction model that utilizes knowledge graph context in a graph neural network [3]. The model incorporates knowledge graph embedding, entity embed- ding, and contextualized embedding to extract relations between entities. The authors evaluated the RECON model on the TACRED dataset and achieved state-of-the-art performance in relation extrac- tion. This work presents a promising approach to relation extraction using graph neural networks and knowledge graph context. It has the potential to advance the field of natural language processing further and contribute to applications such as question-answering and information extraction. There has been growing interest in exploring the intersection between neural symbolic reasoning and knowledge graphs in re- cent years [4]. Contributed to this ongoing conversation through their article titled ”Neural symbolic reasoning with knowledge graphs: Knowledge extraction, relational reasoning, and incon- sistency checking.” The authors delve into knowledge graphs for knowledge extraction, relational reasoning, and inconsistency check- ing and argue that these techniques can be combined with neural networks for improved performance. They provide a comprehen- sive overview of the state of the art in this area and offer insights into potential future directions for research. The article’s central argument is that combining neural networks and knowledge graphs can provide a powerful tool for reasoning over complex, structured data. The authors highlight the potential benefits of this approach, including increased accuracy, interpretability, and scalability.

Furthermore, the authors explore the challenges of working with knowledge graphs, such as the need for efficient algorithms to manage large-scale data and the difficulty of dealing with inconsistent or incomplete data. They also discuss the potential for incorporating human knowledge into the reasoning process, which could help to address some of these challenges. This article offers valuable insights into using neural symbolic reasoning and knowledge graphs for knowledge extraction, relational reasoning, and inconsistency checking. It provides a foundation for future research and highlights the potential for new and innovative data analysis and reasoning approaches. Knowledge graphs have become an increasingly valuable tool in managing and representing complex information in a structured format. They are used in various applications, such as search en- gines, recommendation systems, and natural language processing. However, creating and maintaining knowledge graphs can be diffi- cult and time-consuming, especially when dealing with enormous amounts of unstructured data.

In their article proposed a novel framework for populat- ing knowledge graphs through relation extraction and validation [5]. This framework solves the challenge of identifying and extracting relevant relationships between entities from a large amount of unstructured data. The authors introduced a distant supervision tech- nique that leverages existing knowledge graphs to generate training data for relation extraction models automatically. This approach is particularly useful when manually labelled training data is scarce or expensive. By exploiting the relationships between entities in knowledge graphs, this technique can effectively generate training data for relation extraction models, reducing the need for manual labelling. Furthermore, the authors introduced a validation step that lever- ages the structure of knowledge graphs to identify and correct erroneous relations. This step is crucial for ensuring the accuracy of the populated knowledge graph, as it helps to eliminate noisy or incon- sistent data. Using this validation step, the framework can effectively identify and eliminate errors in the populated knowledge graph, re- sulting in a more accurate representation of relationships between entities. The proposed framework was evaluated on two large-scale knowledge graphs, and the results showed that it outperformed ex- isting methods in terms of precision and recall. The authors’ work highlights the importance of leveraging existing knowledge graphs to generate labelled training data and using validation techniques to ensure the accuracy of the populated graph.

Overall, the framework proposed by has the potential to significantly improve the scalability and accuracy of the knowledge graph population, making it a valuable tool for a wide range of applications [5]. Future research can build upon this work by exploring how the proposed framework can be extended to different domains and types of data and by investigating other techniques for relation extraction and validation. In conclusion, the work by represents a significant contribution to the field of knowledge graph population, providing a practical and effective solution to the challenge of iden- tifying and extracting relevant relationships between entities from unstructured data. The proposed framework has the potential to significantly improve the accuracy and scalability of the knowledge graph population, making it a valuable tool for a wide range of applications.

In biomedical research, natural language processing (NLP) techniques have been increasingly utilized to extract and analyze copious amounts of information from various sources, such as scientific pub- lications and clinical notes. The application of NLP techniques in this field has allowed for constructing knowledge graphs, which can provide new insights into complex medical issues. Con-ducted one notable study in this area [6]. They developed a method for extracting a knowledge graph of Covid-19 through the mining of unstructured biomedical corpora. Using NLP techniques, they extracted relevant information from scientific publications and constructed a knowledge graph that can be used for further analysis and exploration. This study demonstrates the potential of knowl- edge graphs to provide a comprehensive understanding of complex medical problems, particularly in the ongoing Covid-19 pandemic.

Conducted another study using NLP techniques to construct knowledge graphs [7]. They developed a BERT-based method for clinical knowledge extraction, which can be used to construct and analyze biomedical knowledge graphs. Their approach involves training a BERT model on a large corpus of clinical texts and then using this model to extract relevant information and construct a knowledge graph. This study highlights the importance of using advanced techniques to construct knowledge graphs, which can offer new insights into complex medical issues. Both studies demonstrate the potential of NLP techniques for ex- tracting and analyzing information from biomedical corpora. By uti- lizing these techniques to construct knowledge graphs, researchers can gain new insights into complex medical problems and develop more effective treatments and interventions. This approach has the potential to revolutionize medical research, as it allows for the utilization of technology to provide more accurate and effective treatments for patients. Using NLP techniques for constructing knowledge graphs in biomedical research is a promising study area. The potential benefits of this approach are significant, as it can provide new insights into complex medical issues and lead to the development of more effective treatments and interventions. As such, we will likely see further studies in this area.

With the rise of machine learning and natural language pro- cessing, relation extraction has become essential in text analysis. It involves identifying semantic relationships between entities in text, which can be used for various applications such as question answering, information retrieval, and knowledge base construction. However, extracting relations from the text can be challenging, es- pecially when dealing with long-tail relations with few occurrences in the data. In this context, propose a method for long-tail relation ex- traction using knowledge graph embedding and graph convolution networks [8]. The authors begin by constructing a knowledge graph, a structured representation of relationships between entities. They use this knowledge graph to learn a representation of the entities and their relationships, which is then used to score potential relations between entities in each text. The authors argue that this approach can capture the semantic meaning of relations beyond their surface forms and overcome the sparsity problem of long-tail relations.

The authors evaluated their method on several benchmark datasets, including the FewRel dataset, which contains relations with few examples and shows that it outperforms other state-of- the-art methods for long-tail relation extraction. Their method significantly improves accuracy for rare relations with less than five examples in the training data. The authors also analyze the effectiveness of different components of their method and provide insights into the challenges and opportunities of long-tail relation extraction. Overall, presents a promising approach for long-tail relation extraction, which can be applied to various domains and languages [8]. Their method combines the strengths of knowledge graph embed- ding and graph convolution networks and provides a scalable and interpretable solution for relation extraction.

3.2. Application

Knowledge graphs have seen applications in many walks of life. Biomedical and health sectors are sectors where knowledge graphs continue to receive contributions. For the Biomedical field, the role of the knowledge graph is important in connecting related medical information together. Authors in applied knowledge graphs on large-scale biomedical data, which uses labeled property graph per- sistent systems for context mining and knowledge discovery from PubMed and SCAIView data [9]. Also, authors in applied knowl- edge graphs in providing context on large-scale biomedical data [10]. Thereby encoding large medical corpus with knowledge and captur- ing relations between biomedical data that are related. The approach of using knowledge graph for Biomedical data allows scientists to encode and link related medical information, and knowledge graph provides the avenue to mine information from large data into concise information that can be queried by either the entity or relation.

In their recent study, investigated the application and evalu- ation of knowledge graph embedding in the context of biomedical data [11]. Provided valuable insights into the potential benefits and limitations of using knowledge graph embedding in biomedical data analysis. The authors explain how knowledge graph embedding can be applied to biomedical data. They also discuss the different methods used to evaluate the performance of knowledge graph embedding, including clustering and classification. The study then presents the authors' evaluation of several embedding methods, in- cluding TransE, DistMult, and ComplEx. Through their evaluation, the authors found that knowledge graph embedding can be valuable for biomedical data analysis. Specifically, they found that embed- ding can improve the accuracy of predictive models, which is crucial for many applications in biomedical research.

However, the authors also acknowledge the limitations of their study and the potential challenges associated with using knowledge graph embedding in practice. For example, the authors note that the embedding method can significantly impact performance and that more research is needed to determine the optimal approach for diverse types of biomedical data. Overall, the study by provides valuable insights into applying and evaluating knowledge graph embedding in biomedical data. The authors have provided a foundation for future research in this area by highlighting this approach's potential benefits and limitations. The healthcare industry has been revolutionized by the invention of Knowledge Graph technology, which has been increasingly ap- plied in this field in recent years. Provides a comprehensive and detailed review of the application of knowledge graph technology in healthcare, discussing the potential benefits and challenges of the technology, as well as identifying key use cases [12]. One of the most significant benefits of knowledge graphs in healthcare is improved data integration. Knowledge graphs can help integrate diverse data types, such as clinical and genomic data, leading to a more com- prehensive understanding of a patient's health status. Integrating these disparate data sets can also facilitate knowledge discovery by enabling researchers to identify new relationships between different data elements.

However, there are also several challenges associated with the use of knowledge graphs in healthcare. One of the key challenges is ensuring data quality and privacy, particularly given the sensitive nature of medical data. Another challenge is the need for sophisticated algorithms and tools to effectively analyze the copious amounts of data generated by knowledge graphs. Despite these challenges, there are several key use cases for knowledge graphs in healthcare. One such use case is clinical decision support, where knowledge graphs can help clinicians make more informed decisions by provid- ing them with relevant information about a patient's health status. Knowledge graphs can also be used for drug discovery, where they can help researchers identify new drug targets and predict drug interactions. Finally, knowledge graphs can be used for disease diagnosis, where they can help identify patterns and relationships in medical data that may not be immediately apparent to human analysts. Concludes that knowledge graph technology has enormous potential to transform the healthcare industry [12]. However, continued research and development is needed to realize its benefits fully. This technology can help healthcare professionals perform their duties more precisely and accurately, resulting in better patient outcomes.

The application of knowledge graphs is a growing field of research, with many industries exploring the potential benefits of utilizing this technology. conducted a survey on the application of knowledge graphs, exploring how knowledge graphs have been used in different industries, including healthcare, e-commerce, and social media [13]. The study found that knowledge graphs have effec- tively improved search results, recommendation systems, and data integration. Knowledge graphs have been used in the healthcare industry to improve patient care by providing more accurate diagnoses and treatment recommendations. E-commerce companies have utilized knowledge graphs to personalize recommendations and improve product search functionality. Social media platforms have applied knowledge graphs to enhance the user experience by providing more relevant content and better ad targeting. Despite the many benefits of knowledge graphs, there are still opportunities for further research. Discusses the potential for developing more sophisticated algorithms and integrating diverse types of data sources [13]. Knowledge graphs will likely become an in- creasingly valuable tool for improving search and recommendation systems and data integration across industries as the field evolves.

With the ever-increasing amount of information available on the internet, search engines have become a vital tool for accessing and processing this information. However, traditional keyword-based search approaches have limitations in providing accurate and rele- vant results to users. Researchers have developed knowledge graphs to address this issue, a structured representation of knowledge that captures the relationships between different concepts. review discusses the construction and applications of knowl- edge graphs for web search and beyond. They examined the meth- ods for constructing knowledge graphs, their applications beyond web search, and the challenges associated with their construction and maintenance. Provided an overview of the methods used for constructing knowledge graphs, including entity recognition, relation extraction, and ontology construction [14]. Entity recognition in- volves identifying entities such as people, organizations, and events from a text corpus. Relation extraction involves identifying and extracting the relationships between these entities. Ontology con- struction involves creating a formal representation of the entities the challenges associated with their construction and maintenance. Knowledge graphs can transform how we interact with information and provide more personalized and effective user experiences.

Have explored the topic of Semantic web tools for drug discovery in their article, which is published in the Expert Opinion on Drug Discovery journal. They discuss the potential of Semantic web technologies to improve the integration and interpretation of data across different domains and describe several innovative tools that utilize Semantic web technologies to aid in drug discovery. One such tool is the ChemMaps system, which provides a visual representation of chemical space to aid in identifying potential drug candidates. This tool can help researchers identify new drug targets and find innovative approaches to target specific diseases. Another tool that the authors discuss is CLEVER, which uses Semantic web technologies to integrate data from multiple sources to improve drug target identification. This tool can help researchers identify existing drugs that can be repurposed for new diseases. The authors note that the use of Semantic web technologies in drug discovery is still in its initial stages but have the potential to significantly improve the efficiency and effectiveness of the drug discovery process. They suggest that Semantic web technologies can help identify new drug targets, repurpose existing drugs, and improve clinical trial efficiency. Furthermore, the authors suggest that Semantic web technolo- gies can help manage and analyse large and complex datasets, a com- mon challenge in drug discovery. These technologies can also facil- itate data sharing and knowledge across different research groups and organizations, leading to more collaborative and productive drug discovery efforts.

In conclusion, article highlights the potential of Semantic web technologies in drug discovery and provides examples of inno- vative tools that utilize these technologies [15]. Their work suggests that Semantic web technologies can significantly improve the efficiency and effectiveness of the drug discovery process and help identify new drug targets, repurpose existing drugs, and manag and analyse complex data.

The authors also discuss the challenges of constructing and maintaining knowledge graphs, such as scalability, accuracy, and completeness. Scalability is the ability to scale knowledge graphs to accommodate copious amounts of data. Accuracy ensures that the knowledge graph accurately represents real-world entities and rela- tionships. Completeness ensures that the knowledge graph includes all relevant entities and relationships. Knowledge graphs have numerous applications beyond web search. explored some of these applications, such as question- answering systems, recommendation engines, and natural language processing. Question-answering systems use knowledge graphs to answer user queries precisely and accurately. Recommendation engines use knowledge graphs to provide personalized user rec- ommendations based on their preferences and behaviours. Natural language processing uses knowledge graphs to understand the mean- ing of natural language text and generate appropriate responses.

In conclusion, knowledge graphs offer a promising approach to improving search engines' accuracy and relevance. Study pro- vides a comprehensive overview of the methods used for construct- ing knowledge graphs, their applications beyond web search, and

3.3. Construction

Presented an analysis of COVID-19 Knowledge Graph con- struction and applications [16]. The study reviewed various methods and techniques for constructing knowledge graphs, including rule-based systems, machine-learning algorithms, and hybrid approaches. The authors discussed the significance of knowledge graphs in COVID- 19, highlighting how they can facilitate data integration, knowl- edge discovery, and decision-making. The study also evaluated the performance of different knowledge graph construction methods, highlighting their strengths and weaknesses. Overall, the study pro- vides insights into constructing knowledge graphs and their potential applications in COVID-19. In the study by, the authors discussed the construction of knowledge graphs in the context of COVID-19. The study evalu- ated various methods and techniques for constructing knowledge graphs, including rule-based systems, machine-learning algorithms, and hybrid approaches. The authors emphasized the importance of knowledge graphs in facilitating data integration, knowledge discovery, and decision-making in COVID-19.

The study highlighted the strengths and weaknesses of different knowledge graph construction methods. Rule-based systems were found to be useful for constructing knowledge graphs with a small number of concepts and relationships. At the same time, machine learning algorithms were more suited for larger and more complex knowledge graphs. Hybrid approaches that combine the strengths of rule-based systems and machine learning algorithms were effective for constructing knowledge graphs with many concepts and relationships. Overall, the study by provides valuable insights into constructing knowledge graphs and their potential applications in COVID-19 [16]. The study emphasizes the importance of selecting the appropriate method for constructing knowledge graphs based on the size and complexity of the knowledge graph. This can help researchers and practitioners to effectively use knowledge graphs for data integration, knowledge discovery, and decision-making in the context of COVID-19. Proposed a knowledge graph construction approach for the legal domain. The authors discussed the importance of constructing a knowledge graph to organise and connect information in the legal domain. They described their approach, which involves using natu- ral language processing techniques to extract entities and relations from legal documents and then constructing a graph based on these entities and relations. The authors also discussed the challenges and future directions of knowledge graph construction in the legal domain.

The approach proposed by for constructing knowledge graphs in the legal domain significantly contributes to legal infor- mation management [17]. The authors highlighted the importance of knowledge graphs in enabling the efficient organization and connection of legal information. They also demonstrated the practical application of their approach in knowledge graph construction, which involved natural language processing techniques for entity and relation extraction from legal documents. The use of natural language processing techniques in knowledge graph construction is not new, but the authors' approach demon- strates its effectiveness in the legal domain. However, the authors acknowledged that there are still challenges in constructing knowl- edge graphs in the legal domain, such as the complexity of legal language and the need for expert knowledge for validation. Address- ing these challenges will require further research and innovation. In conclusion, the approach proposed by is a promising step to- wards efficient and effective legal information management through knowledge graph construction [17]. Further research will undoubtedly contribute to developing knowledge management systems that fa- cilitate better access to legal information and improved decision- making.

Discuss the construction and application of a knowledge graph. Using remote sensing data, the authors create a knowledge graph that can be used to identify patterns and relationships between different data points. The authors also discuss the potential applica- tions of knowledge graphs in healthcare, finance, and transportation. Overall, the article provides important insights into the importance of knowledge graphs for data analysis and decision-making. In their study, explain how they constructed their knowl- edge graph by extracting data from sources such as satellite imagery and social media [18]. They then used natural language processing and machine learning algorithms to identify relationships between the different data points and construct a comprehensive knowledge graph. The authors also discuss the potential applications of knowl- edge graphs in various fields, such as urban planning, disaster man- agement, and environmental monitoring.

Furthermore, the article highlights the importance of knowledge graphs for data analysis and decision-making. The authors note that knowledge graphs can help to identify patterns and insights that may be missed through traditional data analysis methods. This can lead to more informed decision-making and better outcomes in various fields. Overall, provide an informative and insightful discussion on the construction and application of knowledge graphs. Their study highlights the potential of knowledge graphs for data analysis and decision-making in various fields [18]. It provides important insights into the construction and application of knowledge graphs. The article by focuses on constructing a disease-symptom knowledge graph from web-board documents. The study aims to extract relevant information from user-generated content on web boards and construct a knowledge graph that can be used for disease diagnosis and treatment [19]. The authors used natural language pro- cessing techniques and graph analysis to extract disease-symptom associations from web-board documents. The resulting knowledge graph effectively identified disease-symptom associations and could be used for disease diagnosis and treatment. Overall, the study high- lights the potential of knowledge graph construction for improving healthcare outcomes.

Knowledge graph construction is a rapidly growing field, and this study by is a valuable contribution to the literature. The authors use advanced natural language processing techniques and graph analysis to extract disease-symptom associations from web- board documents. The resulting knowledge graph is a powerful tool for disease diagnosis and treatment and could potentially be used to improve healthcare outcomes. The study highlights the potential of knowledge graph construction for improving healthcare outcomes and suggests that this approach could be used to develop similar tools for other domains [19]. Overall, the article by provides a valuable contribution to the field of knowledge graph construction. The study demonstrates the potential of this approach for improving healthcare outcomes and suggests that knowledge graph construc- tion could be used for other applications as well. Further research in this area is needed to fully understand the potential of knowledge graph construction. Still, the results of this study are promising and suggest that this approach could significantly impact a wide range of domains. Knowledge graphs have gained popularity in recent years as an effective method of structuring and managing large amounts of data. Provide a case study on constructing software knowledge graphs, outlining a methodology for acquiring, preprocessing, and constructing knowledge graphs [20]. The authors highlight the impor- tance of evaluating the quality of the knowledge graph through metrics such as precision, recall, and F1 score. They also discuss the challenges of constructing knowledge graphs, including data quality, scalability, and performance, and provide recommendations for addressing them.

The study by provides valuable insights into constructing software knowledge graphs and offers practical guidance for re- searchers and practitioners [20]. By outlining a clear methodology for constructing knowledge graphs, the authors provide a framework for structuring and managing copious amounts of data more efficiently and effectively. Additionally, the study emphasizes the importance of evaluating the quality of the knowledge graph, which is crucial for ensuring accurate and reliable results. One of the key contributions of the study is its discussion of the challenges of constructing knowledge graphs. As the authors note, data quality, scalability, and performance are all major challenges that must be addressed when constructing knowledge graphs. By providing recommendations for addressing these challenges, the authors offer practical guidance for researchers and practitioners interested in constructing their own knowledge graphs. Overall, the study by is an important contri- bution to the field of knowledge graph construction [20]. By outlining a clear methodology for constructing software knowledge graphs and discussing the challenges and recommendations for addressing them, the authors provide valuable insights and practical guidance for researchers and practitioners.

Knowledge graphs are a powerful way to represent and organize information, and they have become increasingly important in fields such as web search, natural language processing, and data analyt- Ontology-based methods involve predefined concepts and relationships, while machine learning-based methods use statistical models to infer relationships from data. Hybrid approaches combine these two methods to generate high-quality knowledge graphs. The article by also covers the challenges and limitations of knowledge graph construction, such as data quality issues and the need for scalable and efficient algorithms. Data quality issues can arise due to incomplete or inconsistent data sources, while efficient algorithms are necessary to manage copious amounts of data and ensure scalability. Moreover, the authors highlight the potential applications of knowledge graphs beyond web search, including natural language processing, data analytics, and the semantic web. Knowledge graphs can be used to improve information retrieval, entity recognition, and relationship extraction, among other things. They can also integrate heterogeneous data sources and provide a unified view of data. Overall, this article provides valuable insights into the current state of knowledge graph construction and its potential applications beyond web search. Researchers and practitioners in various fields can benefit from this comprehensive overview of knowledge graph construction and its applications.

4. Analysis

This section is dedicated to discussing analytical results obtained from the collected literature. The rest of this section is in the following order: 4.1 is dedicated to publication volume analysis, where the impact of each publication type and how they increased over the years are addressed. 4.2 discusses how author titles are converted into keywords and analyse the keywords' impacts. 4.3 discusses the various network-generated results obtained from the bibliography.

4.1. Publication Volume Analysis

A total of 48 research articles were used to generate the publication volume analysis after carefully filtering and sorting out the collected publications. Publications that fall into this category were screened according to the theme discussed in section 3 of this paper. This allows this work to focus on papers closely matched with edicated themes. Figure 2 shows the categories of the papers collected. There are four categories journals, onference papers, documents, and book chapters. Journals have the highest count of the collected paper; this may be inferred as a matured field now receiving improved articles that have gone beyond the ideation stage. Book sections were least published due to the book and book sections requiring more content and dedication to complete. The publication trend in Figure 3 shows growth in research articles from 2012 to date; knowledge graph publication gains peak in 2021 while this number is expected to increase in the coming years. Knowledge graph adoption is expected to increase in the coming years as data gets more connected in the web and other enterprise industries. Researchers are expected to focus more on Journal publications since the field is more mature than early adoption fields [21-46].

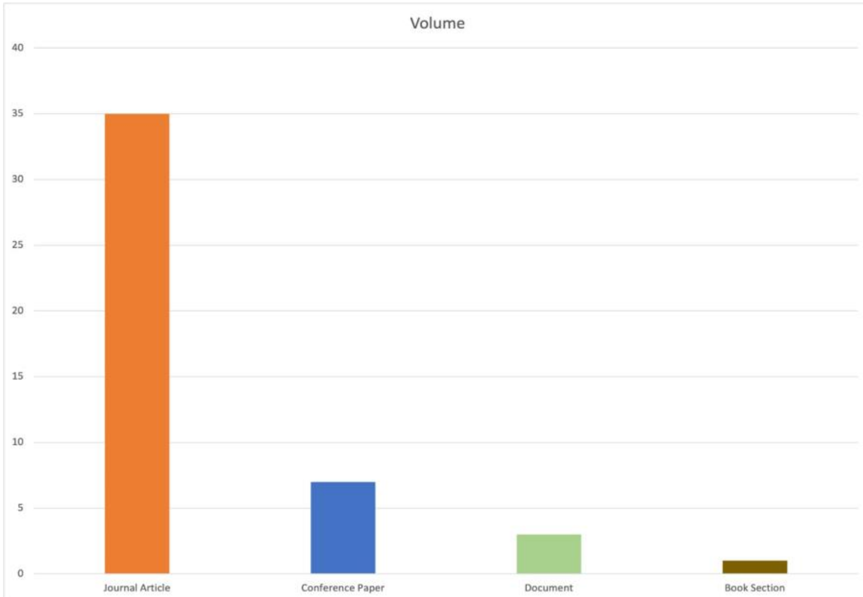

Figure 2: Grouped Publication Statistics for Various Article Types

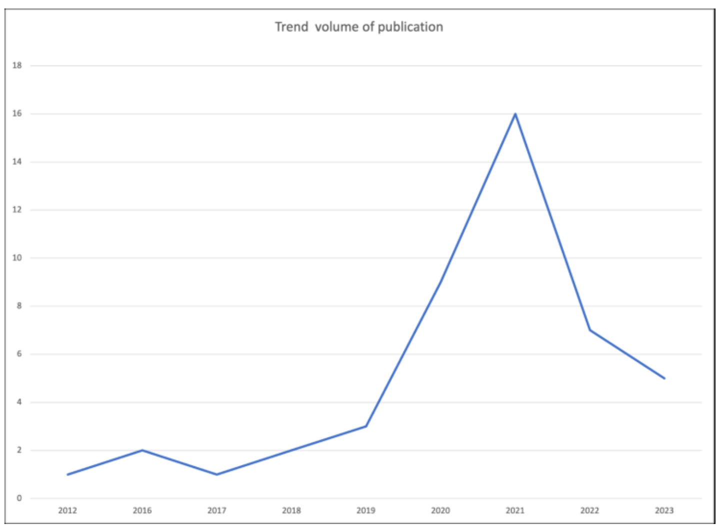

Figure 3: Volume of the Publication for the Selected Bibliography

4.2. Published Article Title Keyword

This section discusses the various keyword that shaped the narratives of the authors title and helps readers understand the topic and title of choice by various authors. The keyword from the word cloud in Figure 4 shows that many authors used "knowledge graph" in their title. With the other import keyword making the context of the titles centered around the construction of knowledge graphs, relation extraction is a precursor task in building a knowledge graph. Also, the convolution network mentioned in these keywords showed that machine learning is now one of the required additional tasks in making knowledge graphs more knowledgeable and enhanced to handle the modern-day web and complex data tasks.

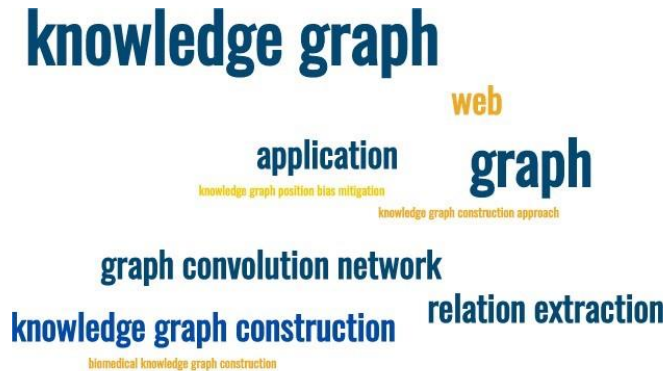

Figure 4: Keyword Wordcloud for Selected Author's Title

Also, for journals contributing content to existing fields in knowledge graphs, their titles have these highlighted keywords since the author is contributing to an existing field, often accompanied by a new suggested framework or approach.

4.3. Network Analysis

In this section, an explanation is provided for various generated network diagrams. This diagram has 5 types: a similar work network diagram shows work like the selected 48 literature used in this survey. Others are the earlier work network diagram, later work diagram, authors network or co-authorship networks, and suggested authors whose work either share similarities or can contribute to the advancement of the selected literature.

4.3.1. Similar Works Network

This network representation helps identify authors with similar research contributions to the selected authors in the bibliography of this work. It then shows the interconnected relationship of the authors under this category and their collaboration or co-authorship with one another. This can help future researchers and readers of this work identify collaboration opportunities or important authors whose contribution is growing and advancing the knowledge graph. The network visualization shows 2 closely clustered communities; however, there is some sparse network clusters Figure 5 around the 2 communities. Also, similar works contain 1473 published articles that are related.

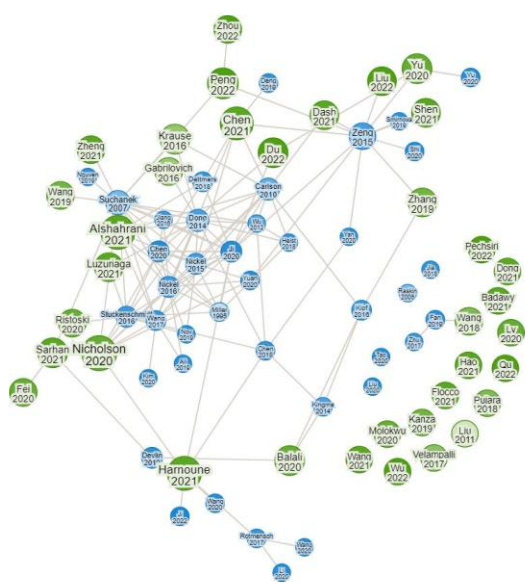

Figure 5: Similar Works Authors Network Diagram

4.3.2. Earlier Work Network

The earlier work consists of 92 published articles with 2 community clusters like a similar network; however, there were little to no sparse nodes or disconnected networks as the two communities have interrelationships in collaborations Figure 6. This can be interpreted as regular collaboration in works by earlier researchers in this field, as fewer authors allowed for more collaboration in advancing the knowledge graph.

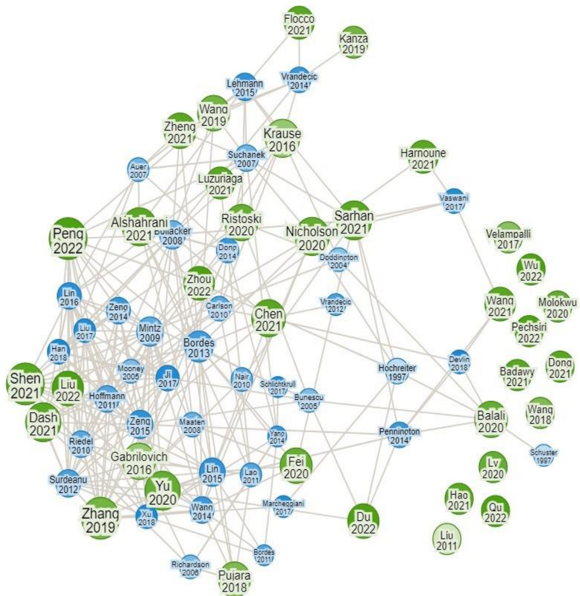

Figure 6: Earlier Work Network Diagram

4.3.3. Later Work Network

The later work consists of authors producing research that succeeds the selected bibliography or can be described as works published after the selected bibliography. Figure 7 shows author "Wang" is a dominant node in the later work network diagram. This means this author, despite previous work, has continued to research and advance knowledge graphs more than the initial contribution to the field of knowledge graphs. Another important node (author) contributing to the later work is "Nicholson" with other authors collaborating with "Nicholson" in advancing the knowledge graph.

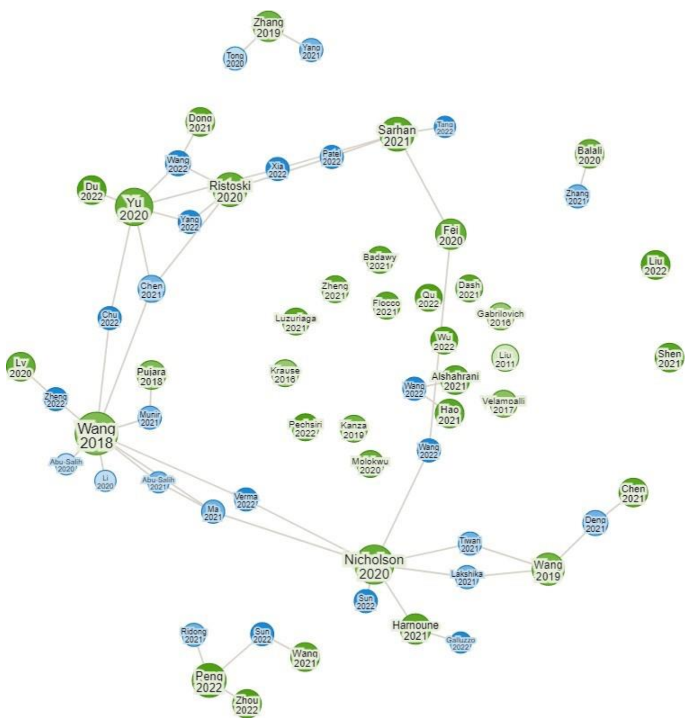

Figure 7: Later work Network Diagram

5. Conclusion and Future Works

Knowledge graph researchers have a significant task in modelling and representing the ever-changing data generated daily, requiring continuous knowledge completion. In the last 10 years, researchers have contributed immensely to advancing knowledge graphs and developing various knowledge extraction frameworks. These frame- works have also used natural language processing (NLP) to extract meaningful semantics from a corpus, thus aiding in knowledge graph relation development. This survey highlights various contri- butions to knowledge graph extraction, application, and construction by various literature and the growth in research interest in knowl- edge graphs. Future work will involve dynamic and recurrent knowledge extraction and completion, taking the advancement of knowledge graphs to the next level. This is due to the advent of large language models (LLMs) like ChatGPT and other prompt LLM frameworks now available to end-users. This survey paper would benefit from more literature in the future, particularly on how ChatGPT-generated text can be modelled in the form of a knowledge graph.

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References

1. Badawy, A., Fisteus, J. A., Mahmoud, T. M., & El-Hafeez, A. (2022). Topic extraction d interactive knowledge graphs for learning resources. Sustainability, 14(1), 226.
2. Balali, A., Asadpour, M., Campos, R., & Jatowt, A. (2020). Joint event extraction along shortest dependency paths using graph convolutional networks. Knowledge-Based Systems, 210, 106492.
3. Bastos, A., Nadgeri, A., Singh, K., Mulang, I. O., Shekarpour, S., Hoffart, J., & Kaul, M. (2021, April). RECON: relation extraction using knowledge graph context in a graph neural network. In Proceedings of the Web Conference 2021 (pp. 1673-1685).
4. Du, K., Yang, B., Wang, S., Chang, Y., Li, S., & Yi, G. (2022). Relation extraction for manufacturing knowledge graphs based on feature fusion of attention mechanism and graph convolution network. Knowledge-Based Systems, 255, 109703.
5. Flocco, D., Palmer-Toy, B., Wang, R., Zhu, H., Sonthalia, R., Lin, J., ... & Brantingham, P. J. (2021, December). An Analysis of COVID-19 Knowledge Graph Construction and Applications. In 2021 IEEE International Conference on Big Data (Big Data) (pp. 2631-2640). IEEE.
6. Kanza, S., & Frey, J. G. (2019). A new wave of innovation in Semantic web tools for drug discovery. Expert Opinion on Drug Discovery, 14(5), 433-444.
7. Dash, S., Glass, M. R., Gliozzo, A., Canim, M., & Rossiello, G. (2021). Populating Web-Scale Knowledge Graphs Using Distantly Supervised Relation Extraction and alidation. Information, 12(8), 316.
8. Yu, H., & Li, H. (2021). A knowledge graph construction approach for legal domain. Tehnički vjesnik, 28(2), 357-362.
9. Alshahrani, M., Thafar, M. A., & Essack, M. (2021). Application and evaluation of knowledge graph embeddings in biomedical data. PeerJ Computer Science, 7, e341.
10. Harnoune, A., Rhanoui, M., Mikram, M., Yousfi, S., Elkaimbillah, Z., & El Asri, B. (2021). BERT based clinical knowledge extraction for biomedical knowledge graph construction and analysis. Computer Methods and Programs in Biomedicine Update, 1, 100042.
11. Kanza, S., & Frey, J. G. (2019). A new wave of innovation in Semantic web tools for drug discovery. Expert Opinion on Drug Discovery, 14(5), 433-444.
12. Ter Horst, H., Brazda, N., Schira-Heinen, J., Krebbers, J., Müller, H. W., & Cimiano, P. (2023). Automatic knowledge graph population with model-complete text comprehension for pre-clinical outcomes in the field of spinal cord injury. Artificial Intelligence in Medicine, 137, 102491.
13. Gabrilovich, E., & Usunier, N. (2016, July). Constructing and mining web-scale knowledge graphs. In Proceedings of the 39th International ACM SIGIR conference on Research and Development in Information Retrieval (pp. 1195-1197).
14. Dörpinghaus, J., Stefan, A., Schultz, B., & Jacobs, M. (2020). Towards context in large scale biomedical knowledge graphs. arXiv preprint arXiv:2001.08392.
15. Chen, H., Deng, S., Zhang, W., Xu, Z., Li, J., & Kharlamov, E. (2021). Neural symbolic reasoning with knowledge graphs: Knowledge extraction, relational reasoning, and inconsistency checking. Fundamental Research, 1(5), 565-573.
16. Fei, H., Ren, Y., Zhang, Y., Ji, D., & Liang, X. (2021). Enriching contextualized language model from knowledge graph for biomedical information extraction. Briefings in bioinformatics, 22(3), bbaa110.
17. Hao, X., Ji, Z., Li, X., Yin, L., Liu, L., Sun, M., ... & Yang, R. (2021). Construction and application of a knowledge graph. Remote Sensing, 13(13), 2511.
18. Gajendran, S., Manjula, D., Sugumaran, V., & Hema, R. (2023). Extraction of Knowledge Graph of Covid-19 Through Mining of Unstructured Biomedical Corpora. Computational Biology and Chemistry, 107808.
19. Bastos, A., Nadgeri, A., Singh, K., Mulang, I. O., Shekarpour, S., Hoffart, J., & Kaul, M. (2021, April). RECON: relation extraction using knowledge graph context in a graph neural network. In Proceedings of the Web Conference 2021 (pp. 1673-1685).
20. Peng, T., Han, R., Cui, H., Yue, L., Han, J., & Liu, L. (2022). Distantly supervised relation extraction using global hierarchy embeddings and local probability constraints. Knowledge-Based Systems, 235, 107637.
21. Lv, W., Liao, Z., Zhang, Y., Kuang, L., Chen, Y., & Bi, S. (2020, October). How to construct software knowledge graph: A case study. In 2020 IEEE World Congress on Services (SERVICES) (pp. 145-150). IEEE.
22. Wang, C., Ma, X., Chen, J., & Chen, J. (2018). Information extraction and knowledge graph construction from geoscience literature. Computers & geosciences, 112, 112-120.
23. Pechsiri, C., & Piriyakul, R. (2022). Construction of Disease-Symptom Knowledge Graph from Web-Board Documents. Applied Sciences, 12(13), 6615.
24. Zhang, N., Deng, S., Sun, Z., Wang, G., Chen, X., Zhang, W., & Chen, H. (2019). Long-tail relation extraction via knowledge graph embeddings and graph convolution networks. arXiv preprint arXiv:1903.01306.
25. Velampalli, S., & Jonnalagedda, M. V. (2017). Graph based

knowledge discovery using MapReduce and SUBDUE algorithm. Data & Knowledge Engineering, 111, 103-113.
26. Wang, P., Jiang, H., Xu, J., & Zhang, Q. (2019). Knowledge graph construction and applications for Web search and beyond. Data Intelligence, 1(4), 333-349.
27. Wu, X., Li, Y., Wang, J., Qian, Q., & Guo, Y. (2022). UBAR: User Behavior-Aware Recommendation with knowledge graph. Knowledge-Based Systems, 254, 109661.
28. Krause, S., Hennig, L., Moro, A., Weissenborn, D., Xu, F., Uszkoreit, H., & Navigli, R. (2016). Sar-graphs: A language resource connecting linguistic knowledge with semantic relations from knowledge graphs. Journal of Web Semantics, 37, 112-131.
29. Pujara, J., & Singh, S. (2018, February). Mining knowledge graphs from text. In Proceedings of the Eleventh ACM International Conference on Web Search and Data Mining (pp. 789-790).
30. Nicholson, D. N., & Greene, C. S. (2020). Constructing knowledge graphs and their biomedical applications. Computational and structural biotechnology journal, 18, 1414-1428.
31. Zou, X. (2020, March). A survey on application of knowledge graph. In Journal of Physics: Conference Series (Vol. 1487, No. 1, p. 012016). IOP Publishing.
32. Yan, H., Gui, L., Pergola, G., & He, Y. (2021). Position bias mitigation: A knowledge-aware graph model for emotion cause extraction. arXiv preprint arXiv:2106.03518.
33. Wang, H., Qin, K., Lu, G., Yin, J., Zakari, R. Y., & Owusu, J. W. (2021). Document-level relation extraction using evidence reasoning on RST-GRAPH. Knowledge-Based Systems, 228, 107274.
34. Wang, X., & El-Gohary, N. (2023). Deep learning-based relation extraction and knowledge graph-based representation of construction safety requirements. Automation in Construction, 147, 104696.
35. Luzuriaga, J., Munoz, E., Rosales-Mendez, H., & Hogan, A. (2021). Merging web tables for relation extraction with knowledge graphs. IEEE Transactions on Knowledge and Data Engineering.
36. Ristoski, P., Gentile, A. L., Alba, A., Gruhl, D., & Welch, S. (2020). Large-scale relation extraction from web documents and knowledge graphs with human-in-the-loop. Journal of Web Semantics, 60, 100546.
37. Zheng, W., Yin, L., Chen, X., Ma, Z., Liu, S., & Yang, B. (2021). Knowledge base graph embedding module design for Visual question answering model. Pattern recognition, 120, 108153.
38. Sarhan, I., & Spruit, M. (2021). Open-cykg: An open cyber threat intelligence knowledge graph. Knowledge-Based Systems, 233, 107524.
39. Molokwu, B. C., Shuvo, S. B., Kar, N. C., & Kobti, Z. (2020, October). Link prediction in social graphs using representation learning via knowledge-graph embeddings and convnet (rlvecn). In 2020 IEEE International Conference on Systems, Man, and Cybernetics (SMC) (pp. 2173-2178). IEEE.
40. Liu, M., Zhou, F., He, J., & Yan, X. (2022). Knowledge graph attention mechanism for distant supervision neural relation extraction. Knowledge-Based Systems, 256, 109800.
41. Mao, N., Huang, W., & Zhong, H. (2021). KGGCN: Knowledge-guided graph convolutional networks for distantly supervised relation extraction. Applied Sciences, 11(16), 7734.
42. Liu, Z., & Sun, M. (2012). Can prior knowledge help graph-based methods for keyword extraction?. Frontiers of Electrical and Electronic Engineering, 7, 242-253.
43. Yu, H., Li, H., Mao, D., & Cai, Q. (2020). A relationship extraction method for domain knowledge graph construction. World Wide Web, 23, 735-753.
44. Qu, J. (2022). A Review on the Application of Knowledge Graph Technology in the Medical Field. Scientific Programming, 2022.
45. Shen, S., Duan, S., Gao, H., & Qi, G. (2021). Improved distant supervision relation extraction based on edge-reasoning hybrid graph model. Journal of Web Semantics, 70, 100656.
46. Zhou, Q., Zhang, Y., & Ji, D. (2023). Distantly supervised relation extraction with KB-enhanced reconstructed latent iterative graph networks. Knowledge-Based Systems, 260, 110108.