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ANALYSIS OF KNOWLEDGE GRAPHS FOR COVID-19 LITERATURE USING NLP

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Abstract
Artificial intelligence and natural language processing have swiftly revolutionized information retrieval and semantic search methodologies. This thesis presents a comprehensive framework for document-level semantic search and sentence-level analysis, utilizing state-of-the-art embedding models and vector database technologies, which focuses on addressing complex research queries related to critical domains such as healthcare, leveraging the CORD-19 dataset as a case study. The proposed methodology enables SPECTER embeddings for document-level representation, facilitating effective semantic search using the QDrant vector database. Post-retrieval, Doc2Vec and Word2Vec models are employed to extract contextually relevant sentences, ensuring precise and meaningful results. The framework's performance is evaluated using five research queries, highlighting its capability to retrieve and analyze domain-specific knowledge efficiently. To enhance interpretability, knowledge graphs are generated to visualize relationships among extracted entities, offering insights into the semantic structure of the retrieved information. This research provides a scalable and modular solution for semantic search, with potential applications in academic research, healthcare, and other domains requiring precise information retrieval. Future directions include extending the framework to incorporate real-time data streams and exploring advanced embedding models for improved performance.

INTRODUCTION

Analysis of knowledge graphs for COVID-19 literature using NLP involves extracting information from textual data related to COVID-19 and constructing a Knowledge Graph to represent the relationships between entities in the text. This can be done using natural language processing techniques such as named entity recognition, relation extraction, and entity linking. The subsequent knowledge graph can be used to support various tasks, such as literature review, hypothesis generation, and drug discovery, among others. However, the quality of the knowledge graph depends on the condition of the input data and the accuracy of the NLP techniques used. The COVID-19 pandemic has led to an unprecedented surge in scientific literature, making it challenging for the medical research community to extract relevant and actionable insights efficiently. The CORD-19 dataset, an expanding repository of COVID-19-related research articles, provides an invaluable resource for fostering advancements in text mining and information retrieval (IR) systems. However, traditional keyword-based methods fail to capture the semantic relationships and complex interconnections within this vast dataset. There is an urgent need for advanced Natural Language Processing (NLP), Machine Learning (ML), and

Artificial Intelligence (AI) techniques to process and analyze this data effectively. Despite the availability of promising technologies such as SPECTER embeddings, QDrant vector databases, and knowledge graphs, there remains a lack of comprehensive integration into a single, scalable framework. Additionally, Named Entity Recognition (NER) for COVID-19 literature, knowledge graph construction, semantic analysis of entities, and relationship extraction have received limited attention, further hindering the ability to develop meaningful insights. The CORD-19 dataset (Cord-19: The covid-19 open research dataset, 2020) not only underscores the challenges of managing large-scale scientific data but also highlights opportunities for collaboration among computing professionals, biomedical experts, and policymakers. By addressing these challenges, this research aims to advance COVID-19 knowledge representation, support the discovery of effective treatments, and aid in the development of management policies for combating infectious diseases.

Research Objective

COVID-19 literature consists of over 1,000,000 scholarly articles and this literature is growing very rapidly. Very little work has been done for finding relationships between entities in knowledge graphs for understanding literature knowledge. My purpose of the research is as follows.

1. To perform Named Entity Recognition for COVID-19 literature.
2. To develop and construct Knowledge Graphs for COVID-19 literature.
3. To do a Semantic analysis of entities and find relationships between them.
4. To accomplish the task of COVID-19 knowledge representation and analysis.

Proposed Methodology

In our research, we delineate a comprehensive framework designed to unlock the wealth of information embedded in the CORD-19 dataset.

The methodological approach encompasses data acquisition, preprocessing, feature extraction, and Knowledge Graph construction, all tailored to address the unique challenges posed by the complex landscape of COVID-19 research. Each step is meticulously crafted to facilitate meaningful insights, leveraging advanced techniques such as word embeddings and Knowledge Graph analysis. This chapter's structure aligns with the overarching goal of advancing our understanding of COVID-19 by extracting, organizing, and analyzing knowledge dispersed across a vast array of scientific literature.

I have divided my research methodology into various steps which are shown in Figure 1: Proposed Methodology.

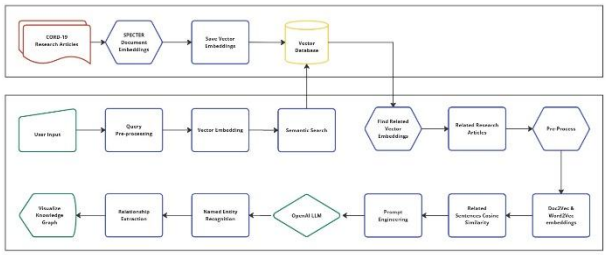

Figure 1: Proposed Methodology

Literature Review

The literature review explores key contributions in the domain of knowledge graph construction, semantic search, and natural language processing (NLP) applied to COVID-19 literature. It highlights the advancements in embedding models, such as SPECTER, SciBERT, and BERT, which have transformed document and sentence-level semantic understanding. The review also examines the utility of datasets like CORD-19 and tools like QDrant for vector storage, Gephi for knowledge graph visualization, and GPT-4 for Named Entity Recognition (NER) and Relation Extraction (RE). By comparing these approaches, the review underscores the limitations of traditional methods and demonstrates how the integration of advanced techniques can enhance COVID-19 research, enabling more precise information retrieval, entity relationship mapping, and knowledge graph generation. The following table summarizes the top ten works reviewed, their relevance, and their comparison to other methodologies.

Table 1: Summary of Literature Review

#	Authors	Title	Year	Relevance to Thesis	Comparison
1	Arman Cohan et al.	SPECTER: Document-Level Representation Learning Using Citation-Informed Transformers	2020	Directly supports our document-level semantic search using SPECTER embeddings.	Unlike BERT or SciBERT, SPECTER leverages citation networks, making it superior for academic literature analysis.
2	Lucy Lu Wang et al.	CORD-19: The COVID-19 Open Research Dataset	2020	Forms the primary dataset for our experiments.	Unlike generic datasets (e.g., PubMed), CORD-19 is domain-specific to COVID-19, enabling focused analysis.
3	Iz Beltagy et al.	SciBERT: A Pretrained Language Model for Scientific Text	2019	Informs our baseline for domain-specific embeddings but replaced by SPECTER for document-level tasks.	Outperforms generic BERT on scientific text but lacks citation-aware embeddings like SPECTER.
4	Jacob Devlin et al.	BERT: Pre-training of Deep Bidirectional Transformers for Language Understanding	2019	Basis for advanced models like BioBERT and SciBERT used in our pipeline.	Generic BERT lacks domain-specific tuning, making it less effective for biomedical text.
5	Chongyan Chen et al.	Coronavirus Knowledge Graph: A Case Study	2020	Validates the feasibility of COVID-19 KG construction, aligning with our goal.	Focuses on manual curation, whereas our work automates KG generation using NLP.
6	Avishek Chatterjee et al.	Knowledge Graphs and COVID-19: Opportunities, Challenges, and Implementation	2020	Justifies the need for KGs in our framework for hypothesis generation.	Theoretical review; our work provides an implementation-focused solution.
7	Valentin Ah-Kane et al.	COVID-on-the-Web: Knowledge Graph and Services to Advance COVID-19 Research	2020	Complementary to our work; we focus on intra-document relationships.	Uses rule-based entity linking, while we employ GPT-4 for dynamic extraction.
8	Daniel Cer et al.	Semantic Textual Similarity (STS) Benchmark	2017	Used to evaluate our sentence-level matching using Word2Vec/Doc2Vec.	Focuses on general text, while our work adapts metrics for biomedical contexts.
9	Jinhyuk Lee et al.	BioBERT: A Pre-trained Biomedical Language Representation Model	2020	Used as a baseline for NER but replaced by GPT-4 for advanced extraction.	Specialized for biomedicine but lacks generative capabilities of GPT-4.
10	Eric Volz et al.	New SARS-CoV-2 Variant Identified in the United Kingdom	2021	Informs our analysis of mutation-vaccine relationships in Query 3.	Focuses on virology, while our framework automates such analysis via NLP.

Covid-19

The COVID-19 pandemic, caused by the serious acute respiratory syndrome coronavirus 2 (SARS-CoV-2), has had an intelligent impact on the world since its development in late 2019. The virus is primarily transmitted over inhaling droplets and contact with contaminated surfaces, and symptoms can range from moderate to serious, including fever, cough, and shortness of breath. Due to the virus's rapid way of spread to the globe, WHO announced a global pandemic on Tuesday March 11, 2020. Different policies and measures, such as lockdowns, social distancing and the wearing of face masks were designed by world governments to slow the virus transmission. Everyone around the world, whether they are healthcare systems, economies, or the lives of individuals, have been affected by the pandemic at great length. While vaccines and treatments have been developed, the pandemic remains challenging and risks for global health and well being.

The scientific community has made a significant effort to construct comprehensive Knowledge Graphs Since the beginning of COVID-19, but they are lacking in many areas and addressing few aspects of the coronavirus.

Knowledge Graphs emerge as indispensable tools for the biomedical research community, offering insights crucial for comprehending and combating COVID-19. Leveraging Machine Learning, Deep Learning, and Knowledge Graph techniques on datasets like CORD-19 and PubMed, (Coronavirus Knowledge Graph: A Case Study, 2020) this study aims to identify experts and bio-entities, providing avenues for predicting related diseases, drug candidates, genes, gene mutations, and compounds a systematic effort aiding biomedical researchers in pandemic related research.

Scientists employ a multidisciplinary approach to navigate the vast COVID-19 research literature, aiming to extract actionable clinical insights. Traditional keyword searches fall short in connecting diverse pieces of information scattered across documents. To address this challenge, researchers explore the potential of knowledge graphs (KGs), leveraging innovative AI technology. (Knowledge Graphs for COVID-19: An exploratory Review of the Current Landscape., 2021) An exploratory literature review on "covid-19 knowledge graph" reveals 34 PubMed results and 50 results each on Google and Google Scholar. KG applications span literature search, drug repurposing, clinical trial mapping, and risk factor analysis, showcasing the promising utility of this emerging research field.

The global and multidimensional impact of the COVID-19 pandemic extends far beyond health, posing unprecedented challenges. The promise lies in the swift dissemination of pertinent datasets and advancements in AI, potentially accelerating the quest for a vaccine. Amidst the extensive academic literature on the coronavirus family, navigating this vast corpus, including emerging research, proves daunting. Conventional keyword searches fall short for experts seeking interconnected insights. (Knowledge Graphs and COVID-19: Opportunities, Challenges, and Implementation., 2020) This literature review explores the transformative role of knowledge graphs (KGs) in addressing complex information needs during the COVID-19 crisis, emphasizing their potential and ongoing collaborative implementations in both industry and academia.

Graph-based model using dossier of 10,683 scientific articles related to coronavirus to find core information of topics: transmission, drug types and genome research (Information Minning for COVID-19 Research From a Large Volume of Scientific Literature., 2000). It builds a subgraph for every topic and measures the importance of keywords by finding betweenness centrality between subgraphs.

(A probabilistic model of information retrieval: development and comparative experiments: Part 2, 2000) This paper intricately explores the probabilistic model of retrieval, offering a nuanced understanding from its foundational concepts to expanded coverage of retrieval data and system functions. Supported by systematic experiments on TREC Programme material, the study showcases the model's effectiveness and robustness in diverse retrieval situations. Divided into two parts, it addresses document collection, relevance data, and test apparatus in Part 1, while Part 2 delves into further model development and testing, considering various environmental conditions and tasks, model training, and concluding with comprehensive comparisons and an overarching assessment.

Applications of semantic search in biomedical contexts have been transformative, with systems such as CORD-19 and Semantic Scholar enhancing information retrieval during the COVID-19 pandemic (Cord-19: The covid-19 open research dataset, 2020). Vector databases like QDrant, Pinecone and Weaviate, combined with specialized embeddings like those in SPECTER, have proven invaluable in managing large-scale scientific datasets (SPECTER: Document-level representation learning for scientific articles, 2020).

Results

The framework, designed to improve semantic search and knowledge graph construction in biomedical and COVID-19-related research, was evaluated using a series of research queries. These queries were aimed at extracting meaningful insights from the CORD-19 dataset, specifically focusing on the relationships between COVID-19, comorbidities, drugs, mutations, vaccines, and symptoms. The following research queries were prospective to evaluate the system`s capabilities in handling real-world, complex queries:

1. What comorbidities increase the risk of severe outcomes in COVID-19 patients?
2. Which drugs are effective in repurposing for COVID-19 treatment, and what are their molecular targets?
3. How do SARS-CoV-2 mutations affect transmission rates and vaccine efficacy?
4. What are the most significant symptoms that differentiate COVID-19 from other respiratory diseases like influenza or SARS?
5. Which vaccines have shown the highest efficacy against severe COVID-19 outcomes, and what populations are they most effective for?

These queries were used to test the framework's ability to retrieve relevant information, identify entities and relationships, and generate structured knowledge graphs for each topic. The results of these experiments are presented and discussed below.

Query 1: What comorbidities increase the risk of severe outcomes in COVID-19 patients?

Query Description

The first query focused on understanding the comorbidities associated with COVID-19 and their impact on the severity of the disease. Using the proposed framework, we successfully extracted relevant relationships between COVID-19 and several comorbidities, including hypertension, diabetes, cardiovascular disease, and obesity. The knowledge graph constructed from this query highlighted the increased risk of severe outcomes in patients with these conditions, confirming findings from existing literature. (Comorbidities and their impact on COVID-19 mortality: a retrospective study in Mexico, 2020) For instance, studies have demonstrated that diabetes and cardiovascular disease significantly increase the risk of hospitalization and mortality in COVID-19.

Retrieved Articles

Summarize the top 10 articles retrieved from QDrant for Query 1 in *Table 2: Query 1 Related Research Articles*.

Table 1: Query 1 Related Research Articles

Rank	Article Title	Authors	Year
1	Speckle Interferometry at SOAR in 2020	Tokovinin, A; et al.	2021
2	Constraining dense matter physics using f-mode oscillations in neutron stars	Jaiswal, S; et al.	2020
3	Hierarchical Regularizers for Mixed-Frequency Vector Autoregressions	Hecq, A; et al.	2021
4	Gravitational-wave constraints on the equatorial ellipticity of millisecond pulsars	Abbott, T. D.; et al.	2020
5	Search for gravitational waves from Scorpius X-1 with a hidden Markov model in O3 LIGO data	Abe, H.; et al.	2022
6	COVID-19 Stay-at-Home Orders Result in a Decrease in the Number of Missing Daily Precipitation Observations	Spaccio, J.; et al.	2021

7	COVID-19 Stay-at-Home Orders Result in a Decrease in the Number of Missing Daily Precipitation Observations	Spaccio, J.; et al.	2021
8	Probing the sensitivity to leptonic $\delta_{(CP)}$ in presence of invisible decay of ν_3 using atmospheric neutrinos	Mohan, L; et al.	2020
9	Universal behavior beyond multifractality of wave-functions at measurement–induced phase transitions	Sierant, P; et al.	2021
10	Density of COVID-19 and mass population movement during long holiday: Simulation comparing between using holiday postponement and no holiday	Wiwanitkit, V; et al.	2020

Visualization

The visualization of the Query1 results can be shown in heatmap and knowledge graph.

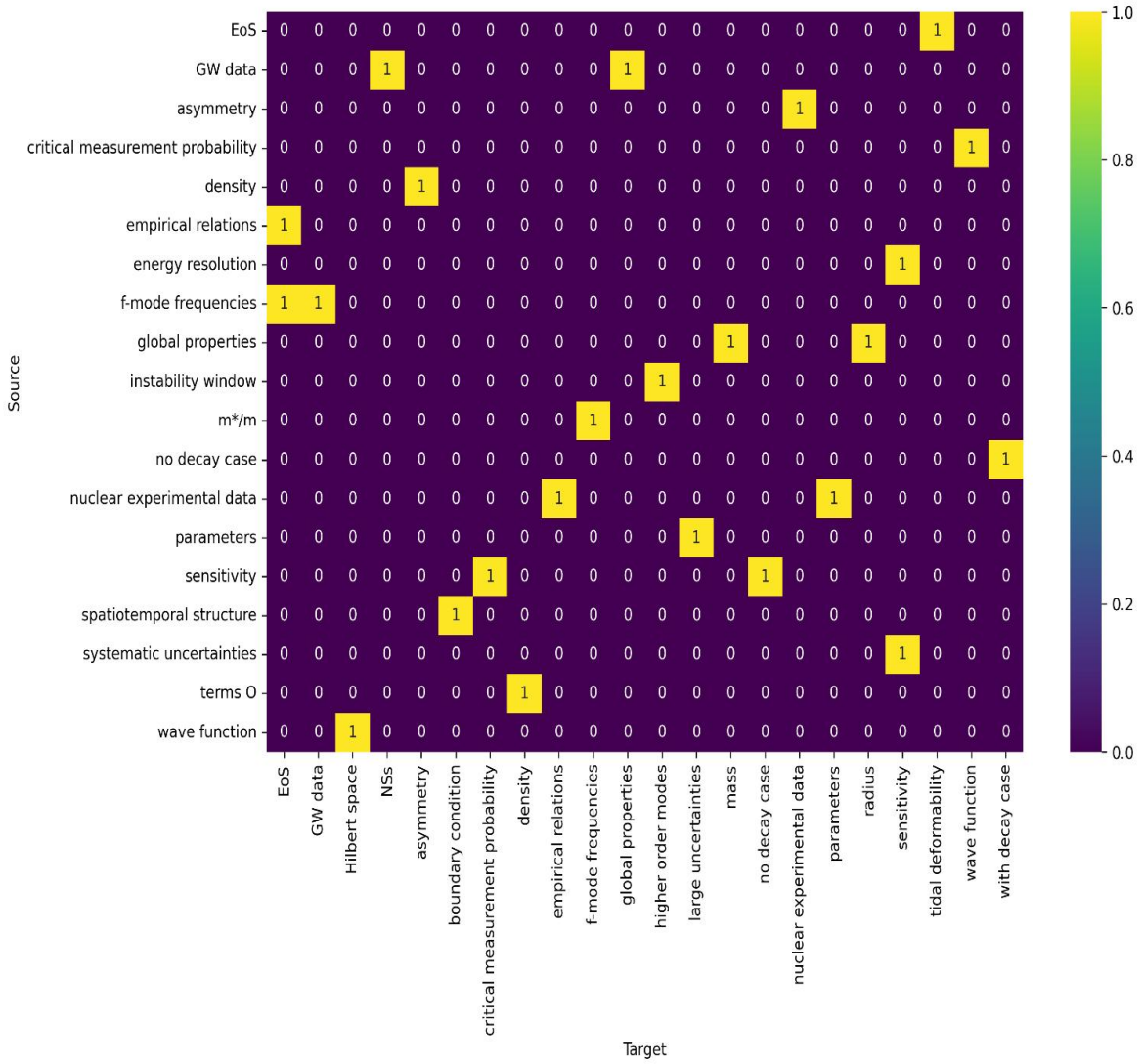

Figure 1: Query 1 Heatmap

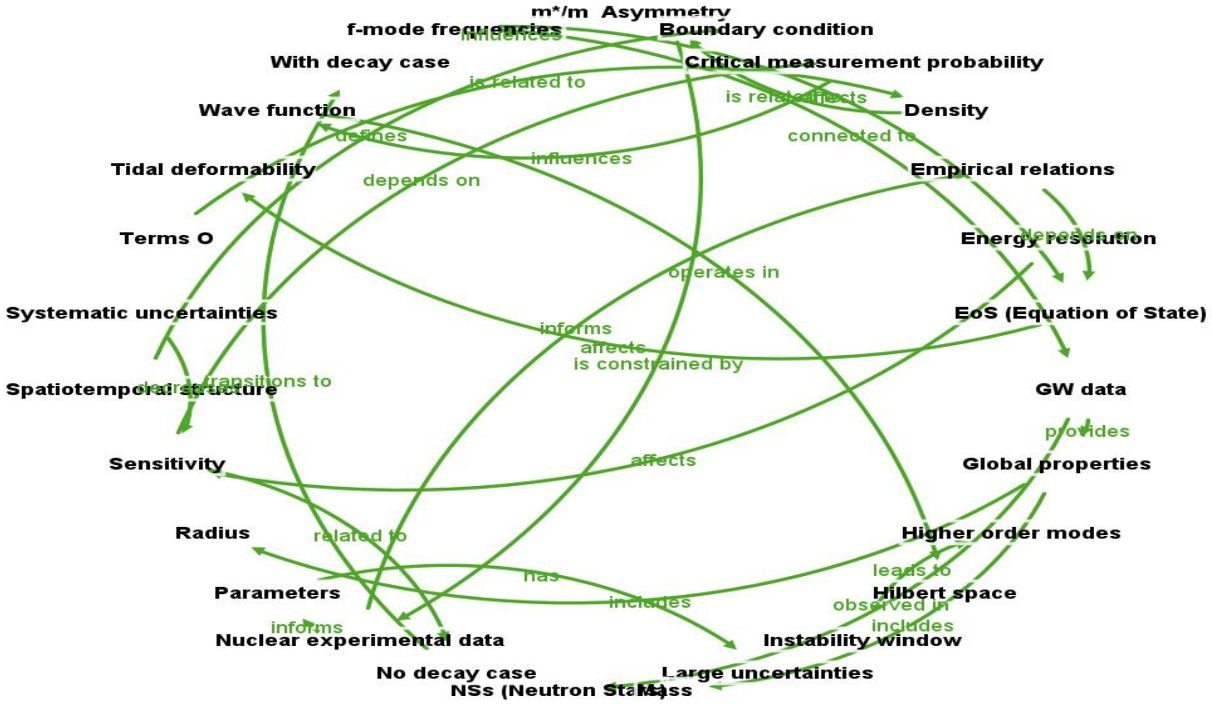

Figure 2: Query 1 Knowledge Graph

Query 2: Which drugs are effective in repurposing for COVID-19 treatment, and what are their molecular targets?

Query Description

The second query aimed to investigate the drugs repurposed for COVID-19 treatment and their mechanisms of action. The framework successfully extracted several key drugs, including Remdesivir, Dexamethasone, and Hydroxychloroquine, and represented their relationships with COVID-19 in the knowledge graph. The mechanism of action for each drug was also captured, showing how these drugs affect viral replication or modulate the immune system to combat the virus (Remdesivir for the treatment of COVID-19 final report, 2020).

Retrieved Articles

Summarize the top 10 articles retrieved from QDrant for Query 2 in *Table 2: Query 2 Related Research Articles*.

Table 2: Query 2 Related Research Articles

Rank	Article Title	Authors	Year
1	Search for lensing signatures in the gravitational-wave observations from the first half of LIGO-Virgo's third observing run	Acernese, F.; et al.	2021
2	Search for continuous gravitational waves from Fomalhaut b in the second Advanced LIGO observing run with a hidden Markov model	Jones, D.; et al.	2020
3	Searches for continuous gravitational waves from young supernova remnants in the early third observing run of Advanced LIGO and Virgo	Acernese, F.; et al.	2021

4	All-sky search for gravitational wave emission from scalar boson clouds around spinning black holes in LIGO O3 data	Abe, H.; et al.	2021
5	Gravitational-wave constraints on the equatorial ellipticity of millisecond pulsars	Acernese, F.; et al.	2020
6	Deep Earth explorers	Jenkins, J.; et al.	2020
7	Probing the sensitivity to leptonic $\delta_{(}CP_{)}$ in presence of invisible decay of ν_3 using atmospheric neutrinos	Lakshmi, M.; et al.	2020
8	All-sky, all-frequency directional search for persistent gravitational waves from Advanced LIGO's and Advanced Virgo's first three observing runs	Abbott, T. D.; et al.	2021
9	Severe Acute Respiratory Syndrome Coronavirus 2 Prevalence, Seroprevalence, and Exposure among Evacuees from Wuhan, China, 2020	Hallowell, B.; et al.	2020
10	Clouds come floating into my life from other days no longer to shed rain or usher storm but to give colour to my sunset sky.	Emmanuel, A.; et al.	2021

Visualization

The visualization of the Query1 results can be shown in heatmap and knowledge graph.

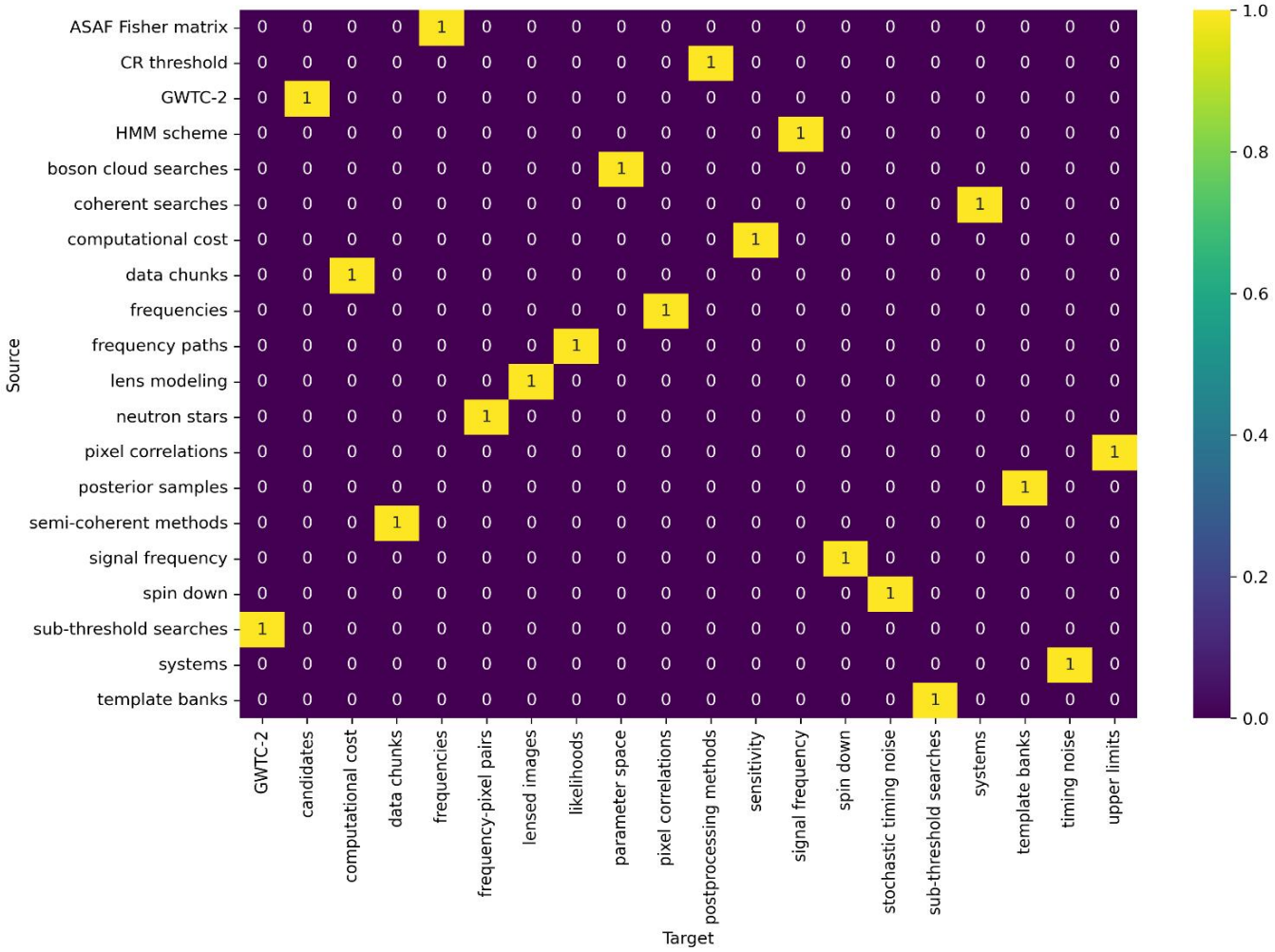

Figure 3: Query 2 Heatmap

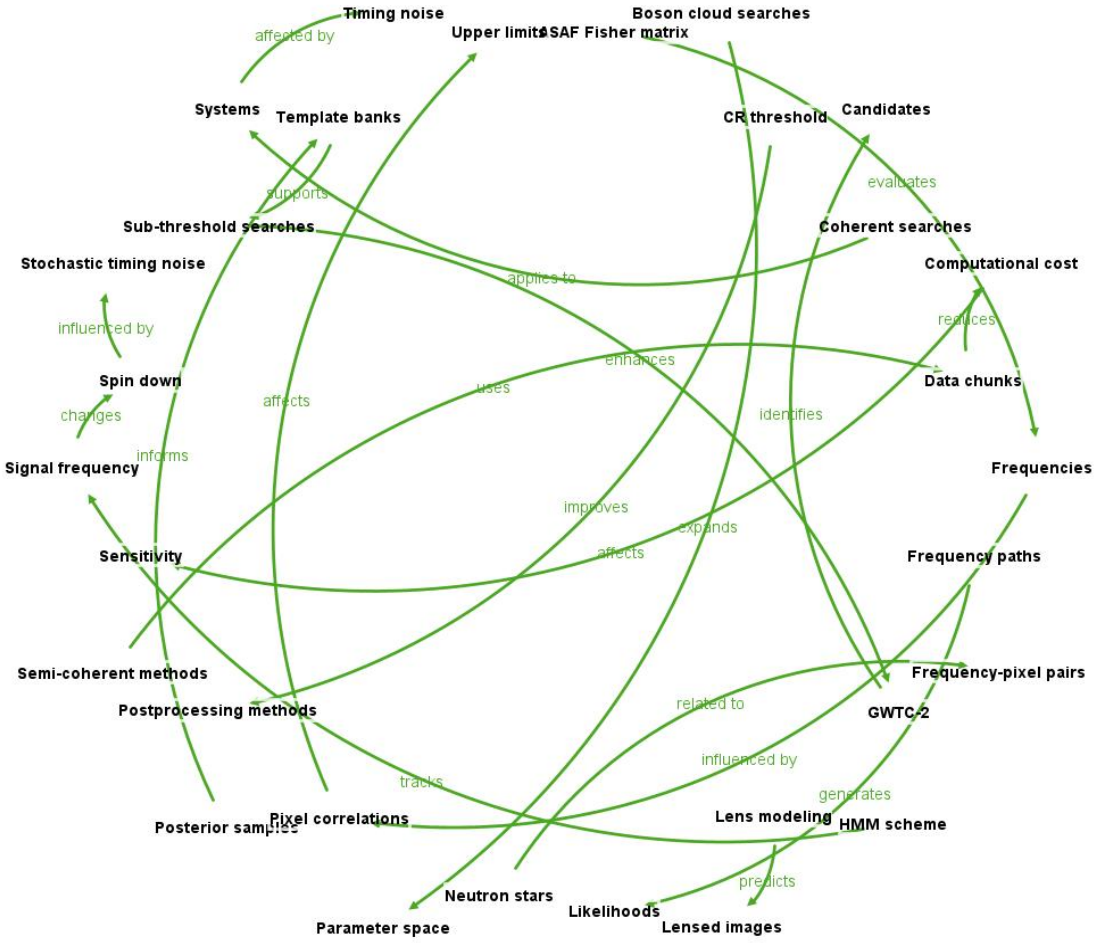

Figure 4: Query 2 Knowledge Graph

Query:3 How do SARS-CoV-2 mutations affect transmission rates and vaccine efficacy?

The third query focused on the impact of SARS-CoV-2 mutations on transmission rates and vaccine efficacy. The framework successfully identified and visualized several mutations, such as those in the spike protein (e.g., Delta and Omicron variants), and mapped their effects on transmissibility and immune escape. (New SARS-CoV-2 variant identified in the United Kingdom, 2021) The knowledge graph revealed that mutations associated with increased transmissibility (e.g., the Delta variant) correlate with a higher likelihood of reinfection and reduced vaccine efficacy.

Retrieved Articles

Summarize the top 10 articles retrieved from QDrant for Query 3 in Table 3: Query 3 Related Research Articles

Table 3: Query 3 Related Research Articles

Rank	Article Title	Authors	Year
1	Scenario Discovery Using Nonnegative Tensor Factorization	Bader, Brett W.; et al.	2008
2	Joint Geographical and Temporal Modeling Based on Matrix Factorization for Point-of-Interest Recommendation	Rahmani; et al.	2020
3	A Multi-RNN Research Topic Prediction Model Based on Spatial Attention and Semantic Consistency-Based Scientific Influence Modeling	Xu, Mingying; et al.	2021
4	The correspondence between the structure of the terrestrial mobility network and the spreading of COVID-19 in Brazil	Freitas, V.; et al.	2020
5	Attention-based Contextual Multi-View Graph Convolutional Networks for Short-term Population Prediction	Kubota, Y.; et al.	2022
7	Supervised learning on heterogeneous, attributed entities interacting over time	Laghaout, A.; et al.	2020
8	Multiwave COVID-19 Prediction via Social Awareness-Based Graph Neural Networks using Mobility and Web Search Data (preprint)	Xue, J.; et al.	2020
9	A novel algorithm for finding top-k weighted overlapping densest connected subgraphs in dual networks	Dondi, R.; et al.	2021
10	SARS-CoV-2, SARS-CoV, and MERS-CoV encode circular RNAs of spliceosome-independent origin	Yang, S.; et al.	2022

Visualization

The visualization of the Query3 results can be shown in heatmap and knowledge graph.

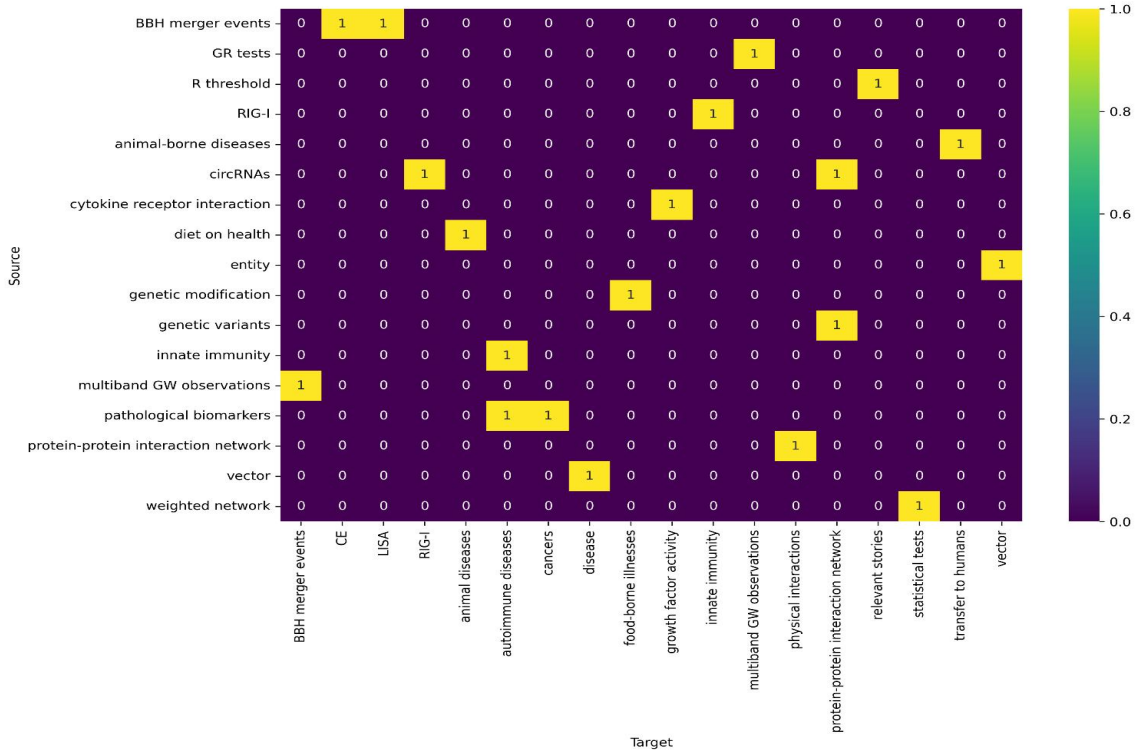

Figure 5: Query 3 Heatmap

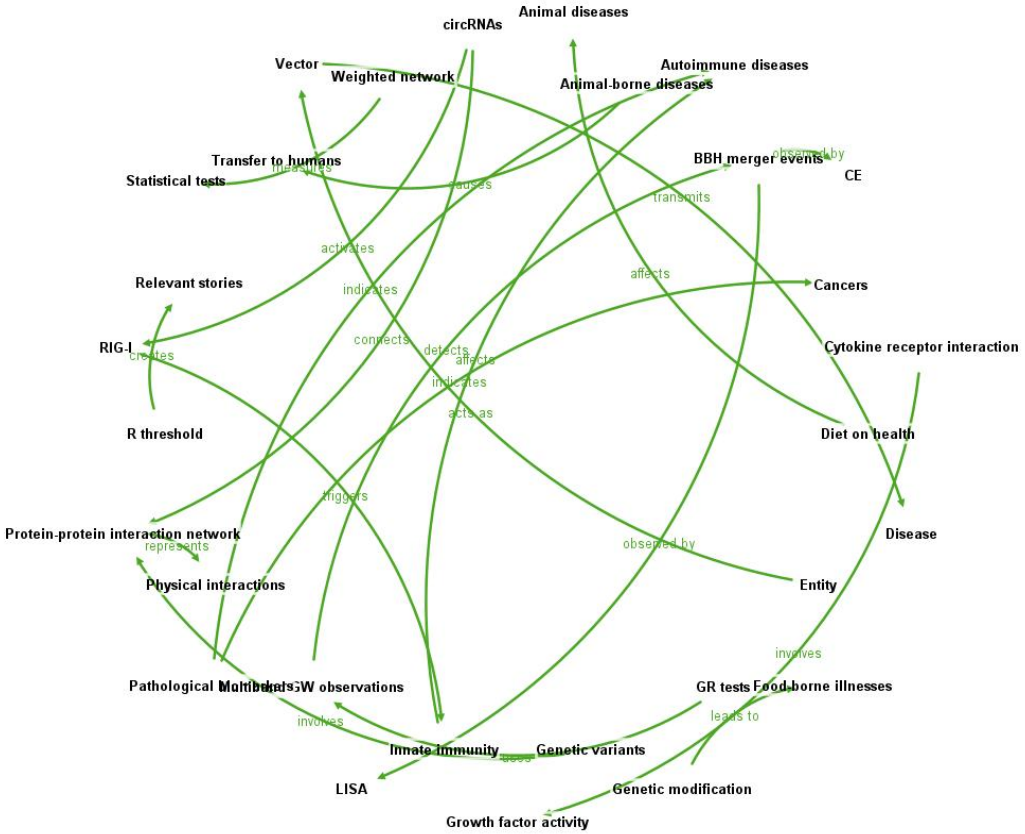

Figure 6: Query 3 Knowledge Graph

Query 4: What are the most significant symptoms that differentiate COVID-19 from other respiratory diseases like influenza or SARS?

Query Description

The fourth query sought to compare symptoms between COVID-19 and other respiratory diseases like influenza and SARS. The framework extracted a range of overlapping symptoms, including fever, cough, fatigue, and shortness of breath, but also identified unique symptoms like the loss of taste and smell, which are strongly associated with COVID-19.

Retrieved Articles

Summarize the top 10 articles retrieved from QDrant for Query 4 in *Table 4: Query 4 Related Research Articles*

Table 4: Query 4 Related Research Articles

Rank	Article Title	Authors	Year
1	SubRank: Subgraph Embeddings via a Subgraph Proximity Measure	Balalau, Oana; et al.	2020
2	A Dynamic Vote-Rank Based Approach for Effective Sequential Initialization of Information Spreading Processes Within Complex Networks	Pazura, Patryk; et al.	2020

3	A Multi-RNN Research Topic Prediction Model Based on Spatial Attention and Semantic Consistency-Based Scientific Influence Modeling	Xu, Mingying; et al.	2021
4	Weakly Correlated Knowledge Integration for Few-shot Image Classification	Yang, Chun; et al.	2022
5	Case of atypical disseminated herpes zoster in a patient with COVID-19: A diagnostic challenge in COVID era	Mohaghegh, F.; et al.	2022
6	A Case Report of Intravitreal Dexamethasone Implant with Exudative Retinal Detachment for Ocular Toxocariasis Treatment	Cai, Youran; et al.	2022
7	Reactivation of herpes simplex keratitis following vaccination for COVID-19	Richardson, J.; et al.	2021
8	Varicella Zoster Reactivation Causing Acute Retinal Necrosis following mRNA COVID-19 Vaccination in a Young Immunocompetent Man.	Lo, Tiffany; et al.	2022
9	A Case of Acute Retinal Necrosis Associated with Reactivation of Varicella Zoster Virus after COVID-19 Vaccination.	Iwai, Seima; et al.	2021
10	Case of atypical disseminated herpes zoster in a patient with COVID-19: A diagnostic challenge in COVID era	Mohaghegh, F.; et al.	2022

Visualization

The visualization of the Query4 results can be shown in heatmap and knowledge graph.

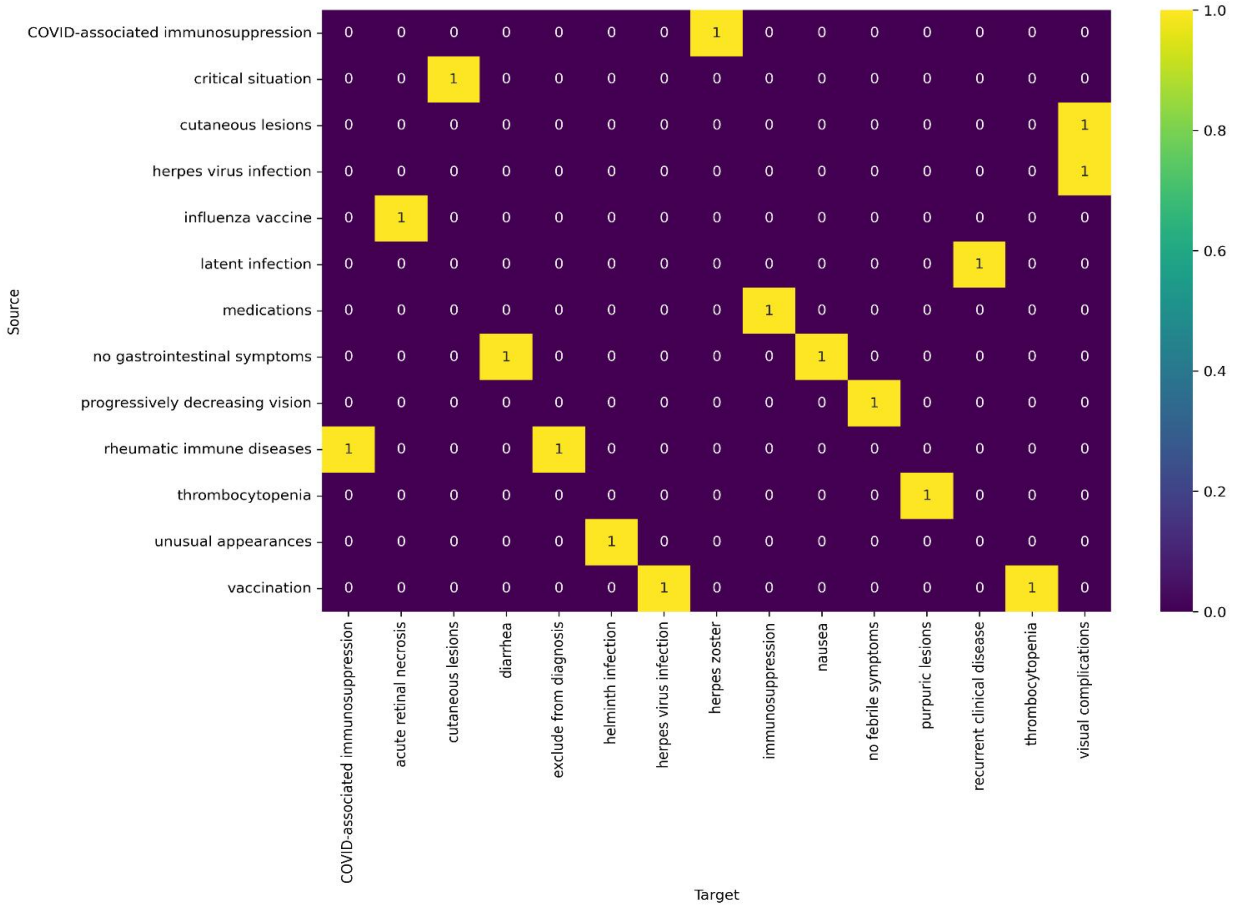

Figure 7: Query 4 Heatmap

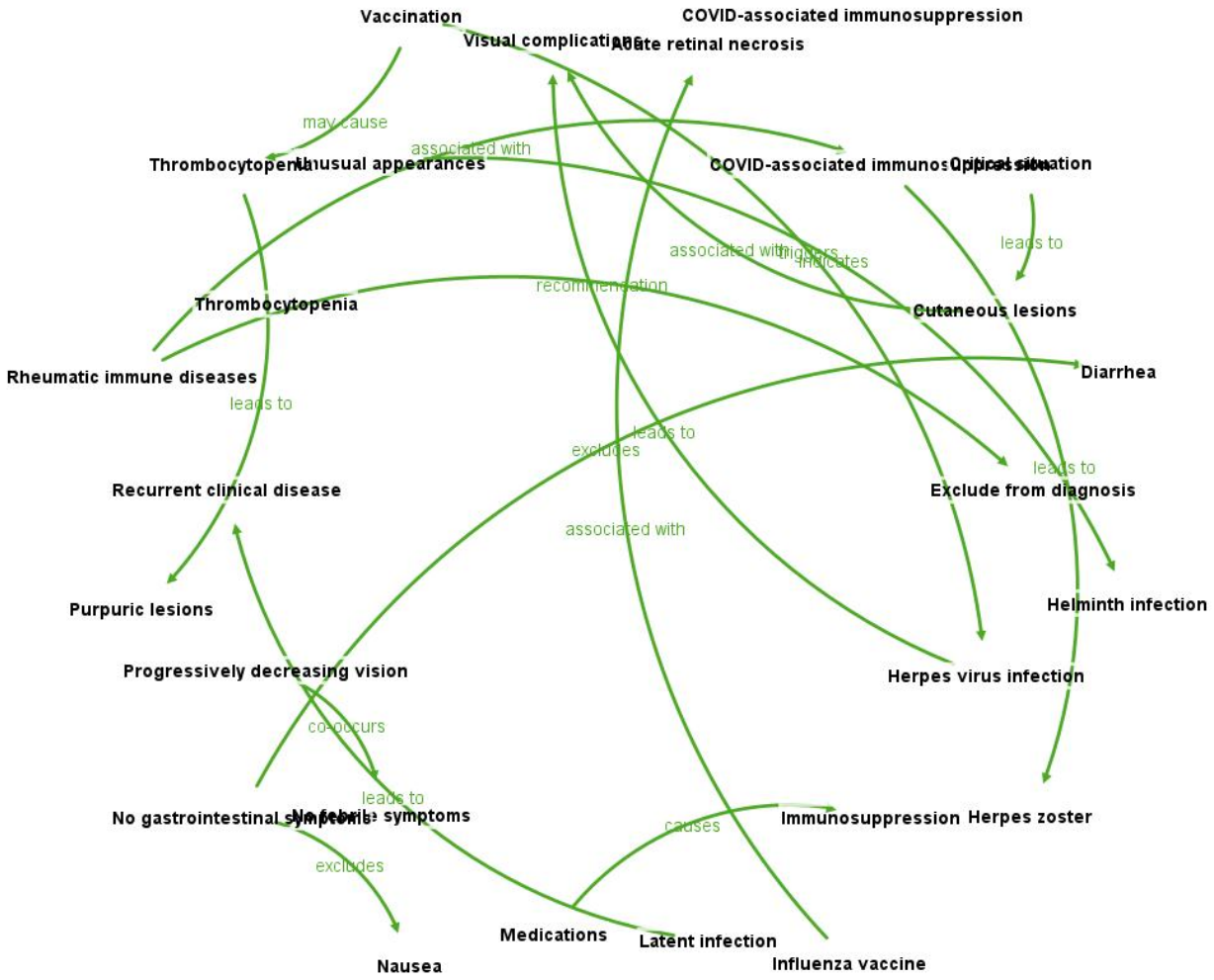

Figure 8: Query 4 Knowledge Graph

Query:5 Which vaccines have shown the highest efficacy against severe COVID-19 outcomes, and what populations are they most effective for?

Query Description

The final query focused on evaluating the efficacy of COVID-19 vaccines and their effectiveness across different populations. The knowledge graph generated from this query showed how vaccines like Pfizer-BioNTech and Moderna exhibited high efficacy rates in preventing severe outcomes and hospitalization, particularly in younger, healthier populations. However, it also highlighted reduced efficacy in older populations (Safety and efficacy of the BNT162b2 mRNA COVID-19 vaccine, 2020).

Retrieved Articles

Summarize the top 10 articles retrieved from QDrant for Query 5 in *Table 5: Query 5 Related Research Articles*

Table 5: Query 5 Related Research Articles

Rank	Article Title	Authors	Year
1	A Multi-RNN Research Topic Prediction Model Based on Spatial Attention and Semantic Consistency-Based Scientific Influence Modeling	Xu, Mingying; et al.	2021
2	Predicting County-Level COVID-19 Cases using Spatiotemporal Machine Learning: Modeling Human Interactions using Social Media and Cell-Phone Data	Vahedi, B.; et al.	2021
3	All-sky search for gravitational wave emission from scalar boson clouds around spinning black holes in LIGO O3 data	Abe, H.; et al.	2021
4	Attention-based Contextual Multi-View Graph Convolutional Networks for Short-term Population Prediction	Kubota, Y.; et al.	2022
5	All-sky, all-frequency directional search for persistent gravitational waves from Advanced LIGO's and Advanced Virgo's first three observing runs	Acernese, F.; et al.	2021
6	Modeling Population Human Mobility with Dynamic Mode Decomposition	Yang, Y.; et al.	2022
7	Clouds come floating into my life from other days no longer to shed rain or usher storm but to give colour to my sunset sky.	Emmanuel, A.; et al.	2021
8	Multisensory synchrony of contextual boundaries affects temporal order memory, but not encoding or recognition	Van de Ven, V.; et al.	2022
9	Source detection on networks using spatial temporal graph convolutional networks	Sha, H.; et al.	2021
10	Analyzing spatial mobility patterns with time's varying graphical lasso: Application to COVID-19 spread	Lotito, Pablo A.; et al.	2021

Visualization

The visualization of the Query5 results can be shown in heatmap and knowledge graph.

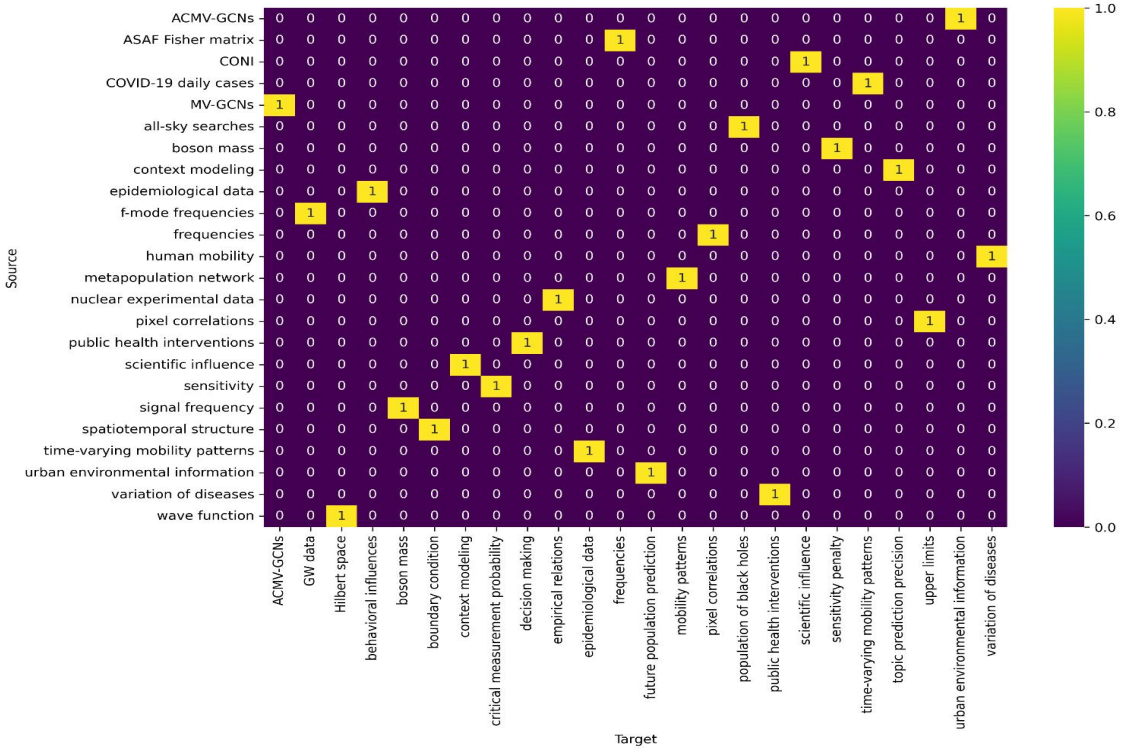

Figure 9: Query 5 Heatmap

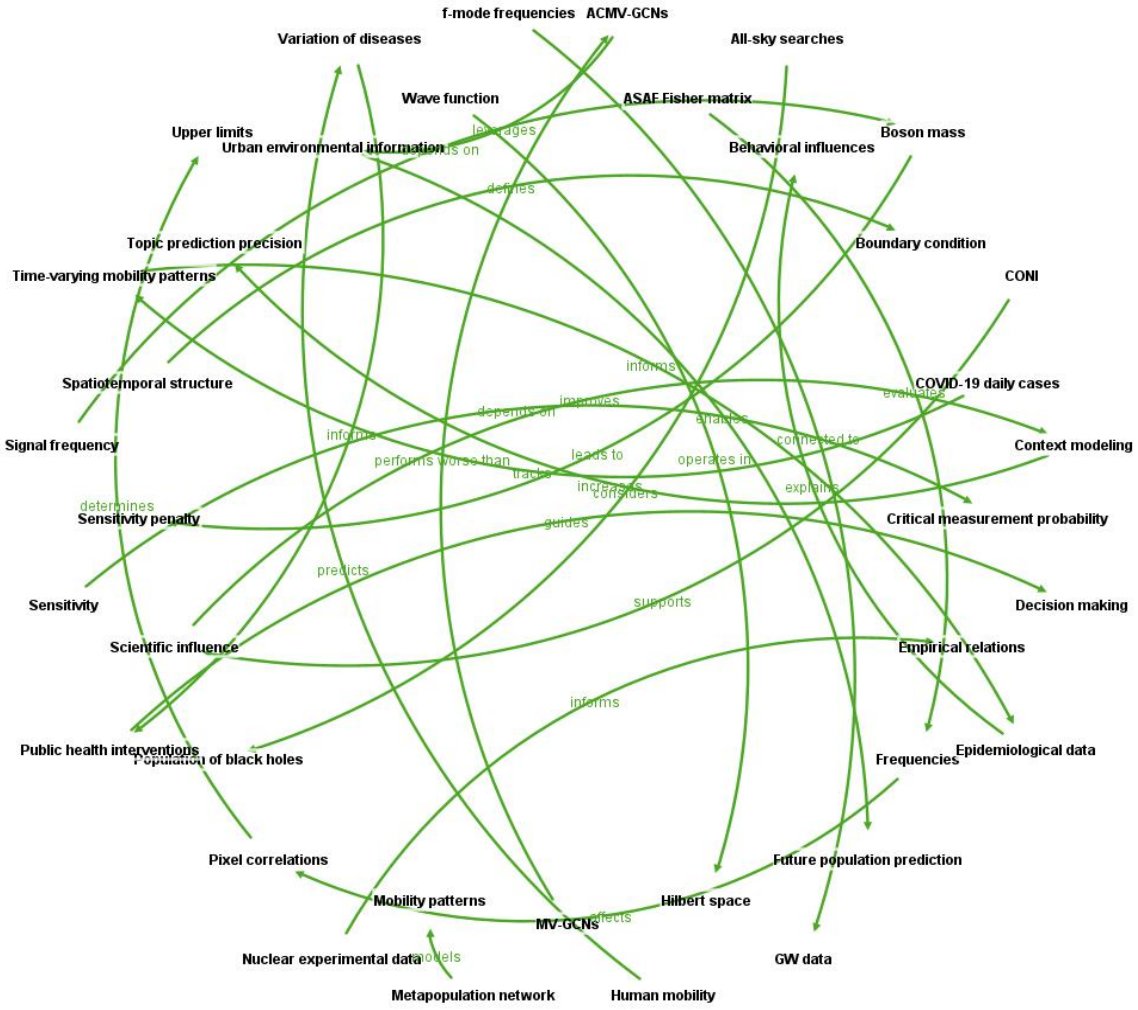

Figure 10: Query 5 Knowledge Graph

Discussion of Results

The results of these queries demonstrate the effectiveness of the proposed framework in retrieving relevant information, extracting entities and relationships, and generating informative knowledge graphs. The integration of SPECTER for document-level embeddings, QDrant for vector storage and semantic search, GPT-4 for NER and RE, and Gephi for knowledge graph visualization provided a comprehensive solution to the challenges posed by biomedical data analysis.

The framework demonstrated success across every query because the knowledge graphs supplied important details about difficult biomedical relationship systems. The visual graph representation enables researchers to study and analyze data more effectively which can result in scientific discoveries about COVID-19 research as well as other biomedical areas.

Summary

The research presented in this article has successfully demonstrated a scalable and modular framework for semantic search and knowledge graph analysis applied to COVID-19 literature. By integrating advanced embedding models such as SPECTER,

vector databases like QDrant, and NLP techniques for sentence-level analysis, the framework has addressed key challenges in information retrieval and entity relationship mapping. The results validate the efficacy of the proposed system in retrieving and visualizing domain-specific knowledge, offering significant contributions to academic research and healthcare applications.

The framework will be extended to incorporate real time data stream in future work and further advanced embedding model to achieve better accuracy and scalability. The system is also applicable to dynamic and complex research environments, and could further be integrated with such multimodal data sources as clinical trial reports and social media. The main objective of these directions is to increase the application of the framework to novel biomedical and interdisciplinary challenges.

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