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Machine Learning, Optimization, and Data Science

11th International Conference, LOD 2025
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Revised Selected Papers, Part I

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Preface

LOD is the international conference embracing the fields of artificial intelligence, machine learning, deep learning, optimization and data science. The 11th edition, LOD 2025, was organized on September 21–24, 2025, in Riva del Sole Resort & Spa (Castiglione della Pescaia - Grosseto), Tuscany, Italy.

The review process of papers submitted to LOD 2025 was double blind, performed rigorously by an international program committee consisting of leading experts in the field.

Since 2015, the LOD conference brings academics, researchers and industrial researchers together in a unique *pandisciplinary community* to discuss the state of the art and the latest advances in the integration of machine learning, deep learning, nonlinear optimization and data science to provide and support the scientific and technological foundations for interpretable, explainable and trustworthy AI. In 2017, LOD adopted the *Asilomar AI Principles*.

The annual conference on machine Learning, Optimization and Data science - LOD is an international conference on machine learning, deep learning, AI, computational optimization and big data that includes invited talks, tutorial talks, special sessions, industrial tracks, demonstrations and oral and poster presentations of refereed papers.

LOD has established itself as a premier interdisciplinary conference in machine learning, computational optimization and data science. It provides an international forum for presentation of original multidisciplinary research results, as well as exchange and dissemination of innovative and practical development experiences.

LOD attracts leading experts from industry and the academic world with the aim of strengthening the connection between these institutions. The 2025 edition of LOD represented a great opportunity for professors, scientists, industry experts and research students to learn about recent developments in their own research areas and to learn about research in contiguous research areas, with the aim of creating an environment to share ideas and trigger new collaborations.

As chairs, it was an honour to organize a premier conference in these areas and to have received a large variety of innovative and original scientific contributions.

LOD 2025 received 180 submissions from 64 countries on five continents, and each manuscript was independently reviewed by a committee formed by at least five members. These two proceedings volumes contain 58 research articles written by leading scientists in the fields of machine learning, artificial intelligence, reinforcement learning, computational optimization, neuroscience and data science presenting a substantial array of ideas, technologies, algorithms, methods and applications.

This conference could not have been organized without the contributions of exceptional researchers and visionary industry experts, so we thank them all for participating. A sincere thank you goes also to the 30 sub-reviewers and to the Program Committee of more than 250 scientists from academia and industry, for their valuable and essential work of selecting the scientific contributions.

Finally, we would like to express our appreciation to the keynote speakers who accepted our invitation, and to all the authors who submitted their research papers to LOD 2025.

October 2025

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Semantic Services for Knowledge Graphs Exploration in Event-Based Epidemic Surveillance

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Abstract. The healthcare sector is currently undergoing a remarkable transformation due to rapid advancements in digital technology. In particular, the integration of digital tools into public health systems enhances epidemic forecasting and response, aiding policymakers and researchers in making informed decisions swiftly. However, current event-based monitoring tools often struggle to capture the complex dynamics of outbreaks. In response, this ongoing work aims to employ semantic technologies and knowledge graphs to improve the exploration of epidemiological information extracted from curated news and reports. By using knowledge graphs, we aim to offer machine-readable and interpretable information, thereby enhancing the analysis and understanding of epidemic surveillance. This work includes the development of semantic services and interactive visualization dashboards to facilitate the exploration of knowledge graphs, providing insights into the trends and dynamics of event-based epidemic surveillance over time and across regions.

Keywords: Epidemiology · Information Extraction · Visualization · Knowledge Graphs · Digital Health · Event-Based Surveillance

1 Introduction and Background

In recent years, the healthcare sector has experienced a significant transformation driven by rapid progress in digital technology. The incorporation of digital tools and innovative solutions into conventional healthcare systems has initiated a new era marked by extraordinary opportunities and challenges [5]. This shift,

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commonly known as the digital transformation of healthcare, includes a broad spectrum of technologies such as electronic health records, telemedicine, artificial intelligence (AI), and wearable devices.

These technologies are of particular importance in fields like public health intelligence because they enable real-time data collection and analysis, which are crucial for effective epidemic forecasting and response [18]. By integrating digital tools such as AI and wearable devices into public health systems, policymakers and researchers can enhance their ability to monitor and predict health trends, thus facilitating faster and more informed decision-making in times of crisis [4]. This synergy between digital transformation and public health intelligence not only improves the accuracy of epidemic forecasting but also strengthens the overall resilience of healthcare systems in managing societal challenges [4,18].

When a public health outbreak occurs, policymakers need to act quickly to mitigate economic and societal impacts. Consequently, real-time forecasting of the outbreak's severity becomes crucial [13]. Therefore, researchers and policymakers are increasingly seeking alternative datasets to address the delays inherent in the release of official public health statistics [19]. The opportunities and challenges present in infectious disease epidemiology [15] are driving some of the activities of the Joint Research Centre (JRC)[1] of the European Commission (EC), as it pursues research initiatives and connects with other ongoing efforts in the field[2]. Current efforts are focused on monitoring outbreaks within the EU by utilizing datasets that are regarded as unconventional in traditional epidemiological modeling, such as (curated) social media and news [11,16]. Social media documents serve as a real-time reflection of societal attitudes, technological innovations, and policy developments, offering a unique lens through which to explore the multifaceted dimensions of digital transformation in public health. By analyzing social media articles, curated reports, and commentaries, we can glean insights into emerging public health events, public perceptions, experts' opinions, and evolving patterns related to disease outbreaks [14].

In the present day, there are several event-based monitoring tools available globally for epidemics, each providing a variety of analytical capabilities for analysis [17]. However, the majority of the existing systems have limitations in effectively capturing the complex dynamics of an outbreak. While they are capable of identifying specific tags, keywords, or entities in news articles, they typically fall short in extracting the relationships between these elements and supporting advanced queries. Recent work [6] has harnessed the extensive capabilities of Generative Pre-trained Large Language Models (LLMs) [3,23] to extract valuable epidemic information from curated news and reports, with the ultimate goal of improving response efforts [6].

While this work has explored several LLMs for the task, assessing their capabilities and main features in extracting valuable epidemic information, in the present contribution we want to show a currently ongoing effort aimed at utiliz-

[1] https://ec.europa.eu/info/departments/joint-research-centre_en.

[2] WHO EIOS: Epidemic Intelligence from Open Sources, https://www.who.int/initiatives/eios.

ing semantic technologies and knowledge graphs (KGs) [10,24] to allow for an improved exploration of the extracted epidemiological information and a more profound understanding of the conceptual structure of the specific domain by delineating categories of entities and their interrelationships.

KGs are extensive networks consisting of entities and relationships, offering machine-readable and interpretable information tailored to a specific domain and organized using formal semantics [8]. Recently, these graphs have become increasingly valued for their ability to structure data meaningfully, thereby enhancing the functionality of various AI systems [20]. Relationships between entities are usually expressed as triples in the format of <`subject, predicate, object`>, such as <`salmonella pullorum, country of infection, tanzania`> or <`salmonella pullorum, infected population cases, 1940`>. The structure of KGs is often defined by a domain ontology, and the development of large-scale KGs typically involves a semi-automated process that integrates both structured and unstructured data [7]. Approaches based on KGs and semantics can, for instance, facilitate the generation of novel scientific hypotheses by establishing connections among known entities in innovative ways [2].

In the remainder of this short contribution, we present the semantic services under current development enabling KGs exploration of the epidemiological information extracted from curated news and reports in event-based surveillance. We present several semantic data visualizations and show how these can potentially support insight gathering about trends and dynamics of event-based epidemic surveillance over time and in different geographical regions.

2 Dataset

The dataset under consideration encompasses curated epidemiological reports and news coming from the World Health Organization (WHO)'s Disease Outbreak News (DONs)[3]. The WHO DONs platform acts as an essential source of information on confirmed acute public health events or those that could potentially raise concerns. This publicly accessible platform has been delivering crucial updates since January 1996. The core mission of DONs is to disseminate information about confirmed or potential public health events. This includes incidents with unknown causes that pose or may pose significant international health concerns and could affect global travel or trade. It also covers diseases of known origins that have demonstrated the potential to cause serious public health impacts and spread internationally. Furthermore, it addresses events of significant public interest that could hinder essential public health interventions or disrupt international travel or trade. Since its launch, DONs has published over 3,000 curated pieces of epidemic news, from 1996-01-22 to the present.

Leveraging the work in [6], we have used the epidemiological information extracted from DONs and mapped it to a knowledge graph in RDF/OWL [1],

[3] https://www.who.int/emergencies/disease-outbreak-news/.

using the Infectious Disease Ontology (IDO)[4] and GeoNames[5] for geo-location mapping, obtaining roughly 45K distinct (non-reified) triples which connect 2.9K unique entities via a total of 3.6K generalized relations. As the deployed methodology has been evaluated and proven to have reliable performance [6], the extracted epidemiological information from DONS and the knowledge graph have been made publicly available, respectively in CSV, RDF/XML[6] and Turtle[7] formats, within the European Data Portal [12] at the following permanent location:
Repository name: European Data Portal
Data identification number:
https://data.europa.eu/data/datasets/89056048-7f5d-4d7c-96ad-f99d1c0f6601
Data are freely available to the public and can be downloaded without any login details by selecting the appropriate URL in one of the repositories above. We enable the interested community to use the extracted data under Creative Commons Attribution 4.0 International (CC BY 4.0) license[8].

3 Knowledge Graph Exploration Services

The knowledge graph of epidemiological information can be loaded within any triplestore supporting it, such as Openlink Virtuoso[9], Blazegraph[10], GraphDB[11], and Neo4j[12], enabling access and exploration of the contained epidemiological data. In particular, we have set up a Virtuoso SPARQL endpoint for this purpose[13], where the KG can be queried, and analytical information on target entities, attributes, and relations can be retrieved in user-specified data formats. Practically, the SPARQL queries can be edited in the text area available in the Virtuoso interface for the SPARQL query language, which is the standard reference language and a W3C [9] recommendation for querying RDF/OWL data. The SPARQL endpoint is also accessible as a dedicated REST web service. It requires as input of an API request a user-defined SPARQL query and produces as output the query result in one of the following formats: *text/html*, *text/rdf +n3*, *application/xml*, *application/json*, or *application/rdf+xml*.
Queries such as `CONSTRUCT`, `ASK`, `DESCRIBE`, and `SELECT` can be executed to retrieve data from the KG. A `CONSTRUCT` query yields an RDF graph created by replacing variables within the query. An `ASK` query produces a boolean value, either true or false, signifying if the query pattern has any matches. A `SELECT` query outputs the values of variables that are successfully matched within the

4 https://www.ebi.ac.uk/ols4/ontologies/ido.
5 https://www.geonames.org/.
6 https://www.w3.org/RDF/.
7 https://www.w3.org/TR/turtle/.
8 CCBY 4.0, https://creativecommons.org/licenses/by/4.0/.
9 OpenLink Virtuoso: https://virtuoso.openlinksw.com/.
10 Blazegraph: https://blazegraph.com/.
11 GraphDB: https://www.ontotext.com/products/graphdb/.
12 Neo4j: https://neo4j.com/.
13 https://api-vast.jrc.service.ec.europa.eu/sparql/.

query pattern. Typically, this kind of query is structured into three main sections:
1. PREFIX is used to define shorthand prefixes for URIs in the query.
2. SELECT specifies which variables will be included in the outcome of the query.
3. FROM indicates to which named-graph is requested to restrict the query.
4. WHERE sets out the graph pattern that the data must correspond to.

As an example, consider the Nipah virus - India report, having id: `don-record2740` and namespace: `http://data.jrc.ec.europa.eu/dataset/89056048-7f5d-4d7c-96ad-f99d1c0f6601`; the RDF information related to this individual can be obtained from the endpoint with the SPARQL query:

```
SELECT *
WHERE {
<http://data.jrc.ec.europa.eu/dataset/
         89056048-7f5d-4d7c-96ad-f99d1c0f6601/don-record2740>>
   ?p ?o}
```

Simply put, this query selects all data triples with properties ?p and objects ?o, matching the resource "Nipah virus - India" where `don-record2740` id is the subject. For each result statement, a link to its corresponding URL in a Virtuoso Faceted Browser[14] is also returned, allowing further navigation. The Faceted Browser allows the exploration of the KG by querying the endpoint with free text search patterns. This returns a list of literal property values or labels that match the text pattern specified as input. The result set can then be narrowed down by

Fig. 1. Faceted Browser showing the extracted Nipah virus - India information.

[14] https://api-vast.jrc.service.ec.europa.eu/fct/.

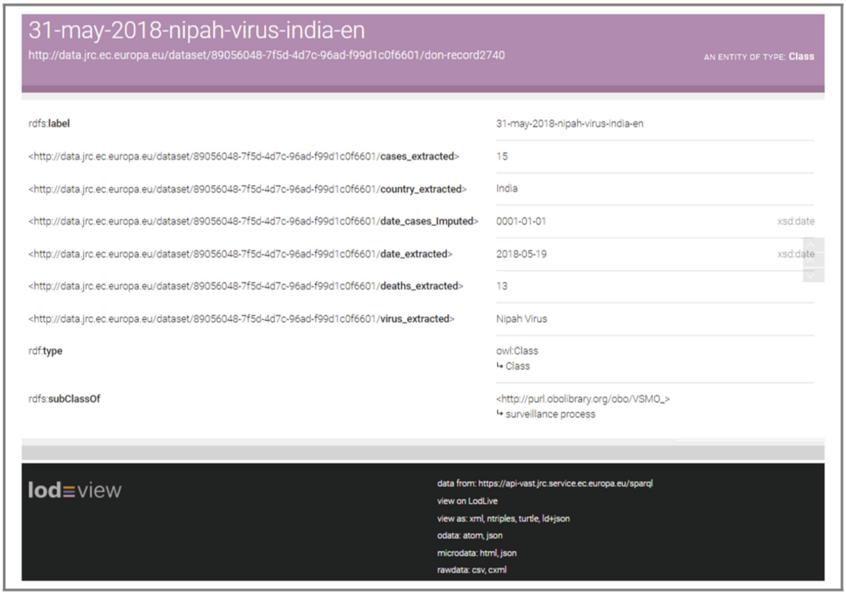

Fig. 2. Content negotiation of the Nipah virus - India report with LodView.

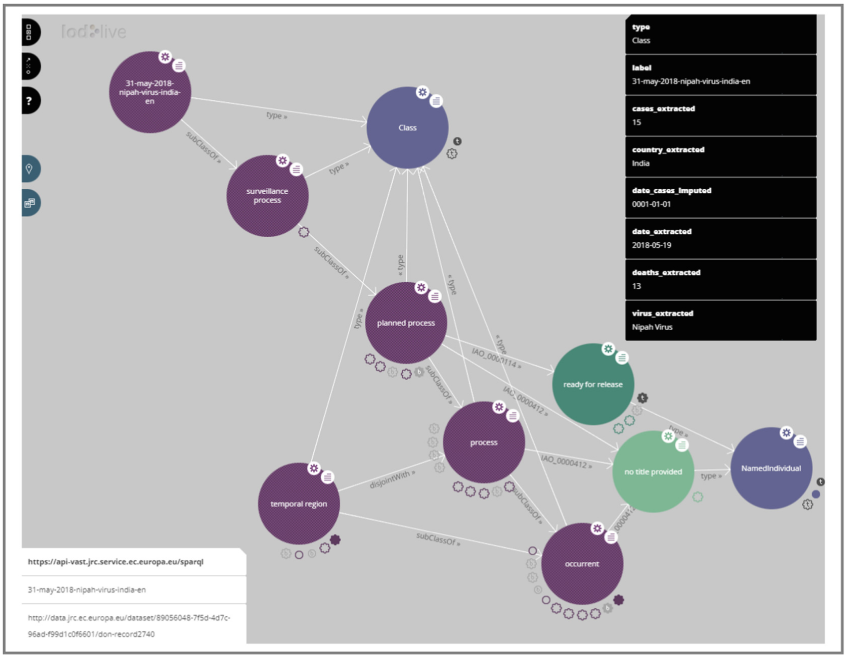

Fig. 3. Graph visualization of Nipah virus - India in LodLive.

filtering for specific entity types or property values, allowing for navigation of the target sub-graph structure. For example, the `don-record2740` can be visualized with the Faceted Browser[15] as illustrated in Fig. 1, where users can explore the RDF information of the Nipah virus - India report in a structured and intuitive way, providing a classification of the data in various dimensions. In Fig. 2, it is also reported its LodView representation where one can exploit and navigate the DON entity, seeing for example the related outbreak information, the report categorisation as `IDO:surveillance_process` and `OWL:Class`, and downloading the raw data in one of the available formats, e.g. rdf+xml or ld+json, among others. Finally, Fig. 3 shows the LodLive graph representation of the RDF data of the `don-record2740` report relatively to the other outbreak events present in the KG. For instance, this allows the user to automatically expand the relations of a selected resource, calculate inverse and `owl:sameAs` relations, store images during navigation, and eventually geo-localize the browsed data as points on a map.

In the following boxes, we showcase some further examples of queries for developers and researchers that can be run on the knowledge graph of epidemiology information. To avoid repetitions, consider all the following SPARQL queries to be prefaced with the following standard headers:

```
PREFIX data:
<http://data.jrc.ec.europa.eu/dataset/89056048-7f5d-4d7c-96ad-
                                                 f99d1c0f6601/>
   PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX dcterm: <http://purl.org/dc/terms/>
PREFIX dc: <http://purl.org/dc/elements/1.1/>
PREFIX owl: <http://www.w3.org/2002/07/owl#>
PREFIX xml: <http://www.w3.org/XML/1998/namespace>
PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>
PREFIX obo: <http://purl.obolibrary.org/obo/>
PREFIX skos: <http://www.w3.org/2004/02/skos/core#>
```

Suppose one wants to know all the events related to “Nipah virus” outbreak:

```
SELECT ?event
WHERE {?event data:virus_extracted ?label .
        FILTER (?label = ‘‘Nipah Virus’’)}
```

The same but with a more flexible regular expression in the SPARQL query:

```
SELECT ?event
WHERE {?event data:virus_extracted ?label .
        FILTER regex(str(?label), ‘‘nipah’’, ‘‘i’’)}
```

[15] https://api-vast.jrc.service.ec.europa.eu/describe//?url=http://data.jrc.ec.europa.eu/dataset/89056048-7f5d-4d7c-96ad-f99d1c0f6601/don-record2740.

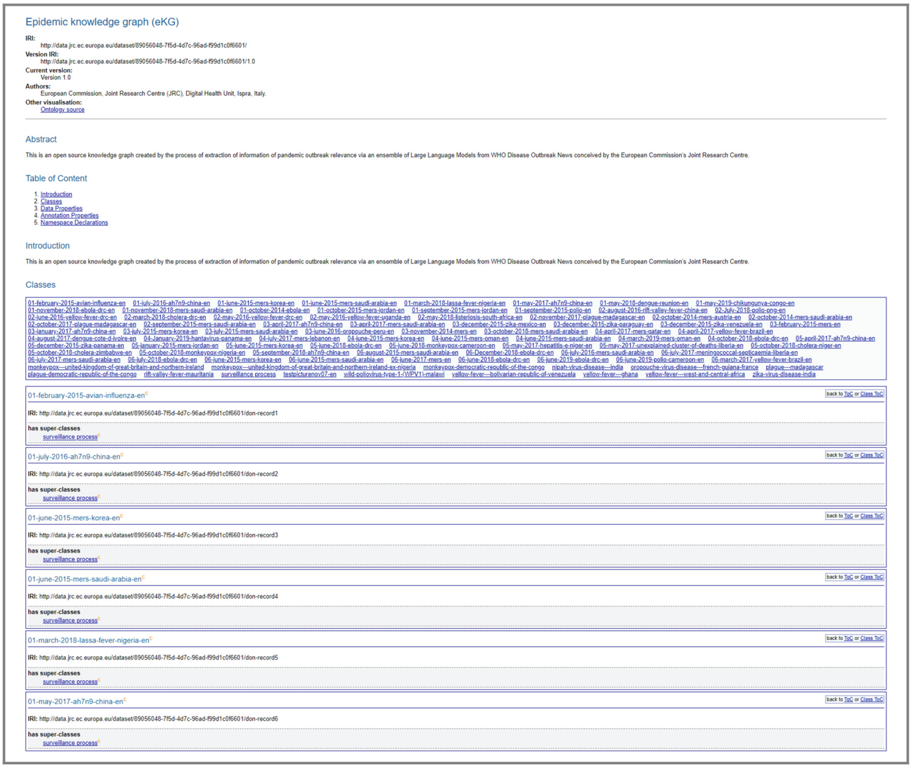

Fig. 4. An extract from the knowledge graph representation in LODE.

The following SPARQL query finds all the outbreaks that occurred in "Italy":

```
SELECT ?event
WHERE {?event data:country_extracted ?label .
        FILTER (?label = ''Italy'')}
```

Lastly, the following SPARQL query retrieves all the outbreaks occurring in "Italy" in the year "2017", specifying the name of the disease and the number of confirmed cases:

```
SELECT ?event ?outbreak ?cases
WHERE {?event data:country_extracted ?label .
?event data:date_extracted ?date .
        FILTER (?label = ''Italy'') .
        FILTER (year(?date) = 2017) .
        ?event data:virus_extracted ?outbreak .
        ?event data:cases_extracted ?cases . }
```

These queries represent only some basic examples and there might be various other use cases that can be addressed. For more complex queries, we refer the reader to various tutorials available on the web, and to technical articles in the literature [21,22] for a more intense deep dive into the SPARQL query language.

The knowledge graph of epidemiological information can also be browsed in a human-readable format using the *Live OWL Documentation Environment (LODE)*, which facilitates exploration for users. LODE provides an easy-to-use interface for viewing general axioms, namespace declarations, named individuals, classes, annotations, and object properties within intuitive HTML pages[16]. Figure 4 shows an extract from the KG representation in LODE. The KG can also be accessed through a holistic, force-directed graph layout using *WebVOWL*[17] as in Fig. 5. Interaction with these tools allows for customizable visualizations, offering a user-friendly description of the elements of the KG and enhancing the user's ability to leverage the epidemiological information within.

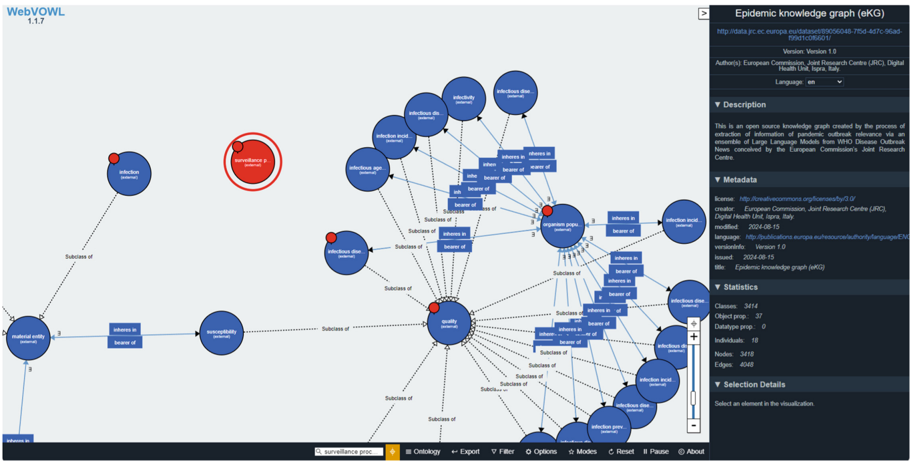

Fig. 5. A snapshot of the WebVOWL visualization.

16 http://wit.istc.cnr.it/arco/lode/extract?url=https://jeodpp.jrc.ec.europa.eu/ftp/jrc-opendata/ETOHA/ETOHA-OPEN/epidemicIE-DONs.rdf.

17 https://service.tib.eu/webvowl/#iri=https://jeodpp.jrc.ec.europa.eu/ftp/jrc-opendata/ETOHA/ETOHA-OPEN/epidemicIE-DONs.rdf.

4 Conclusions

In this short contribution, we have shown our currently ongoing work on employing semantic technologies and knowledge graphs to enhance the exploration and understanding of epidemiological information. The semantic services we are building allow the exploration of the knowledge graph of epidemiological information, offering an evolving landscape of the extracted outbreaks from DONS over the years through a collection of interactive visualization dashboards. By leveraging these tools, it becomes possible to improve real-time data collection and epidemic analysis, thus supporting more informed decision-making in public health. Future work will focus on further developing the epidemiological knowledge graph and conducting both quantitative and qualitative model evaluations. Efforts will be directed towards developing a dynamic pipeline to ensure the information is continuously updated. Additionally, we aim to implement entity linking to align the knowledge graph with popular standard biomedical ontologies, thereby facilitating metadata standardization and enhancing interoperability across datasets.

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