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Research Article

Mapping the Semantic Web with Bibliometric Analysis: An Intellectual, Conceptual, and Social Analysis

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ABSTRACT

The study investigates the evolution and likeness evolution of scientific foundations and core research themes in three domains Semantic web, linked data and open linked data. Bibliometric study of 3021 research papers is carried out using Scopus database data for 2004-2026. Using VOSviewer, which is a software tool used for the construction and visualisation of bibliometric networks, some analyses namely, bibliographic coupling, keyword co-occurrence and the co-authorship analysis were performed to characterise the intellectual, conceptual and social structures of the field Bibliographic coupling analysis shows not only one or few major core research areas, but also many more niche smaller areas co-exist. One major cluster created by experts a Core Linked Data Principles, Knowledge Graph Embeddings and Machine Learning, Core Semantic Web Theory. According to the data from keyword co-occurrence analysis, a hierarchical conceptual model for data science, comprising three clusters, namely, fundamental theory, facilitating technologies and practical applications, has been identified. The co-authorship study, reflecting an internationalisation of researches, indicates the presence of three sizeable European and North American hubs. The primary aim of this effort is to produce a detailed multi-layer 'science map' of the core Semantic Web research community. The analysed information indicates substantial progress into the field. The strong international cooperation can support a dynamic evolving diverse ecosystem of applied research owing to the robust theoretical framework. Researchers can benefit greatly from this map, especially those who wish to learn about the main research fronts, the most influential documents and the general structure of the field. Moreover, it also helps to identify the larger intellectual gaps and possible direction for future further works.

Keywords: Bibliographic Coupling, Bibliometric Analysis, Linked Data, Linked Open Data, Science Mapping, Semantic Web.

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INTRODUCTION

The semantic web has grown densely into interconnected research space shaped by various technical standards, knowledge representation and evolving interpretive practices. In order to understand the development of this field, it is necessary not only to analyze the documents and technologies but also to investigate the structures which regulate the movement of ideas, collaborations, and intellectual traditions. The "Semantic Web" which refers to the data on the web that can be understood by machines has been the focus of research in the area of information and computer sciences for the last two decades or so. The core of this notion is Linked Open Data (LOD), which refers to data that is open and publishable by anyone and frees to use and linking on a large scale follows certain standards of the web, and is sufficiently formally structured and machine-readable to be easy to link with other datasets (Avila-Garzon, 2020; Ronzhin *et al*., 2018). LOD combines the concept of public data (which is data that is open for anyone's use, reuse and redistribution) with the technical standards of Linked Data, which employs Unique Identifiers (URIs), standard formats (such as RDF), and links between datasets, in an effort to create a global "Web of Data" (Hogan, 2020; Ronzhin *et al*., 2018).

The LOD can boost innovation process by being an effective channel of data dissemination, while also enabling greater openness across various sectors like government, health care and business outfits. LOD allows the most heterogeneous datasets to come together by linking the data and not just opening it. Therefore, it is facilitating us to provide next-level operations, on-demand analytics and well-founded policymaking by collating dissimilar datasets. Thereby enabling the emergence of complex workflows, on-demand analytics, and sound policymaking. To better understand this critical field's intellectual structure, the present study deploys methods like bibliometric coupling,

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which is a quantitative method that measures the similarity between two documents on the basis of the references they share (Perianes-Rodriguez *et al*., 2016; Zhang *et al*., 2019). The method allows for the detection of themes and the emergence of new fronts with a high level of objectivity (Bretas and Alon, 2021; Linnenluecke *et al*., 2020). This effort to apply this method to the core literature where Semantic Web, Linked Data and Open Data occur together explicitly aims to obtain a fine intellectual and conceptual map of the community driving these developments.

This paper maps the Semantic Web as the next step in the development of the mapping of science framework of (Cobo *et al*., 2011), which recognizes the intellectual, conceptual, and social dimensions as the main indicators of the evolution of a research field. This study by combining bibliographic coupling, keyword co, occurrence and co, authorship network analysis sets out to chart the intellectual structure that underpins the field, the conceptual structure that delineates its cognitive boundaries and the social structure that connects the scholars who propel it further (Boyack *et al*., 2009). Work on cognitive and knowledge, evolution models is another argument for this multilayered design, as these models illustrate how scientific domains change through common foundations, changing themes, and collaborative networks. In sum, these frameworks enhance the interpretive reach of diplomatic analysis, thus enabling the positioning of Semantic Web research in its wider scholarly ecosystem.

This study aims to answer the following research questions:

- What are the main intellectual clusters and research fronts at the core of Semantic Web and Linked Data research?
- What are the core concepts that define these research fronts?
- How do these clusters relate to one another, and what does this structure reveal about the field's most central conversations?

LITERATURE REVIEW

Methodological Advances in Bibliometric Coupling

One of the most important techniques of a modern bibliometric analysis is bibliometric coupling, which is a very basic instrumental technique. Its mechanism is straightforward: create a link between two documents that both cite the same third one, and the strength of this link will be directly proportional to the number of shared references, i.e. the more references they have in common, the stronger their relationship will be (Perianes-Rodriguez *et al*., 2016). The networks that demonstrate how research fields are interconnected and which areas are the most densely connected can be created by scientists through mapping these links in a large document set (Tsilika, 2023; Zhang *et al*., 2024).

The method has been instrumental in mapping the existing knowledge base of a scientific field and also in figuring out the new and trending research topics by locating the clusters of the latest papers that share the same references (Bernatović *et al*., 2022; Capolupo, 2024). In order to get a full view, bibliographic coupling is additionally merged with co-citation and co-word analyses which together provide a deeper insight into the research field's past, its current state, and the development of its themes (Abdelwahab *et al*., 2025; Zupic and Čater, 2015).

The Importance and Application of Open Linked Data

Linked Open Data has been a great helper in different domains as the researches had demonstrated. The significant change its role has caused in public sector innovation and consequently the emergence of "smart cities" is probably the most visible impact of data, driven services, transparency enhanced, and citizen empowerment through the availability of data that have been made possible (Hitz-Gamper *et al*., 2019; Janssen *et al*., 2017). Besides that, the LOD standards are very important for enhanced data integration and interoperability since they make it possible for the data from vastly different and heterogeneous sources to be blended without any restraint (Hogan, 2020; Ronzhin *et al*., 2018). This unique feature, in particular, is of a great help for the biomedical field, which uses LOD to web-scale implement and data integration as a means to promote sciences (Kamdar *et al*., 2019).

Mapping the Open Linked Data Research Landscape

Earlier bibliometric analyses of Open Data and LOD illustrate that the area is very dynamic and it keeps expanding and diversifying rapidly. Thematic mapping has been consistently highlighting not only the major themes like the semantic web, open government, and data sharing, but also the theme that are emerging such as big data analytics and recommender systems (Velez-Estevez *et al*., 2023; Zhang *et al*., 2018; Zou *et al*., 2025). Analyses of scientific mapping and performance have pinpointed the UK, USA, and China as the biggest contributors, with thematic clusters covering both the theoretical and practical aspects of research (Zhang *et al*., 2018). These bibliometric and scientometric studies demonstrate the firm direction towards data-driven innovation and digital transformation.

METHODOLOGY

This research presents a bibliometric analysis that includes bibliographic coupling, keyword co-occurrence and Co-authorship analysis to delineate the structure of the core 'Semantic Web' and 'Linked Data' research field.

Data Source and Corpus Creation

The bibliographic data for the research were obtained from the Scopus database on September 24, 2025. A precise search query was created to focus the corpus on documents that explain the three core concepts in detail. The final query used was: (TITLE-ABS-KEY ("linked open data") AND TITLE-ABS-KEY ("semantic web") AND TITLE-ABS-KEY ("linked data")) AND PUBYEAR > 2004 AND PUBYEAR < 2026

Using this query, the final dataset consisting of 3,021 documents were saved in CSV format with full bibliographic information and cited references.

Analysis Tool and Process

The bibliometric analyses and network visualizations were done using VOSviewer version 1.6.20. Three separate sets of analyses were done:

- **Bibliometric Coupling:** The type of analysis was set to "Bibliometric coupling," with "Documents" as the unit of analysis. A threshold was set to include only documents with a minimum of 5 citations, resulting in a map of 1,000 documents.
- **Keyword Co-occurrence:** A second analysis was performed for "co-occurrences," using "All keywords" as the unit of analysis. A minimum occurrence threshold of 15 was set, resulting in a network of 250 keywords. This adjustment allowed for more clarity in the conceptual map.
- **Co-authorship:** A third analysis was run for "Co-authorship," with "Countries" as the unit of analysis to map the global collaboration network.

RESULTS: THE INTELLECTUAL AND CONCEPTUAL LANDSCAPE

Descriptive Overview and Geographic Distribution

The compilation of 3,021 final documents indicates worldwide scientific communication; nevertheless, the continents and countries where most of the production took place can be easily identified (Figure 1). Demonstrates how the world of research is a playground for the major European players and in particular, the most productive countries are undoubtedly Germany (471 documents), Italy (344), France (239), and Spain (225). Apart from Europe, the United States (341 documents) stands as the main source of research innovation and the most influential non-European center.

Intellectual Structure: Thematic Research Fronts

The analysis of bibliographic coupling led to the generation of a network of 1,000 connected documents grouped in 12 clusters of themes by an algorithm. The core intellectual structure weighted by total citations is showed at Figure 2. Different colour stands for thematic clusters. The size of each node is based on total citation count. The diameter of each node is indicative of the total number of citations the paper has received. The nodes in this case represent an individual document. An attribute selected, specifically total citations, weights these and functions as a yardstick of influence. As an example, a paper that has been cited more times will be displayed as a bigger, and thus more visible, circle. While on the other hand, a paper that has been cited fewer times will be displayed as a much smaller circle. This will allow you to identify the biggest influential work in every theme without digging through the depth of the visualization, simply by noticing the biggest nodes. The map shows a multipolar configuration consisting of several large clusters, the main research fronts, connected with small groups. The size of every node depends on its total count of citations, which denotes the key papers that anchor the field.

The analysis finds several dominant research fronts, representing the primary "schools of thought" within the field. The most outstanding documents for each major cluster are presented in Table 1.

Based on the landmark papers in Table 1, one can fathom the following thematic interpretations for the most significant clusters:

Cluster 2 (Core Linked Data Principles and DBpedia)

This is arguably the most fundamental and basic cluster, relying heavily on the landmark work by Heath (2011) which provides the four basic principles that characterize Linked Data in a clear way, and the notable paper by Bizer (2008) that shows the first widespread application of these principles for the extraction of structured data from Wikipedia for integration into the DBpedia knowledge base. Basically, these works represent the core of the cluster both in terms of theory and practice.

Cluster 6 (Core Semantic Web Theory and Standards)

This cluster, defined by the influential and comprehensive survey paper Hogan *et al*., (2011), consists of the theoretical foundations of the entire field. The paper under review is a comprehensive introduction to the specifications, technologies and formalizations (like RDF, OWL, and SPARQL) that allow the Web of Data to exist, serving as a canonical reference for the technical community.

Clusters 3 and 9 (Machine Learning and Recommender Systems)

These groups are closely and tightly interrelated. Moreover, they represent significant research. This mainly concerns the application of machine learning techniques to knowledge graphs. Nickel *et al*., (2012) paper is a landmark and a trailblazing piece of work in knowledge graphs and embedding models. According to Ristoski *et al*., (2016), it uses micro studies of linked data which gives insights into generic issues and difficulties faced while developing linked data applications. It is clear from the document that there is a focus on the use of linked data structure to power predictive models.

Cluster 5 (Ontology Engineering and Data Integration)

This cluster, corresponding to the work of Vandenbussche *et al.*, (2017), is primarily concerned with the various techniques and methods involved in the generation, management, and integration of data by means of formal ontologies, thus representing the essential scientific investigation of the data lifecycle management.

Conceptual Structure: The Field's Core Concepts

To confirm and expand on these themes, a keyword co-occurrence analysis was conducted. The network in Figure 3 resulting from this work represents the key concepts and their connections, thus revealing the conceptual framework that very closely reflects the cognitive framework derived from analysis of the document. Here, every node represents a keyword, and different colours indicate different conceptual clusters. Each node in the keyword co- occurrence represents an author keyword, and the node's size reflects the number of times the keyword is used in the documents. The colours represent conceptual clusters formed by

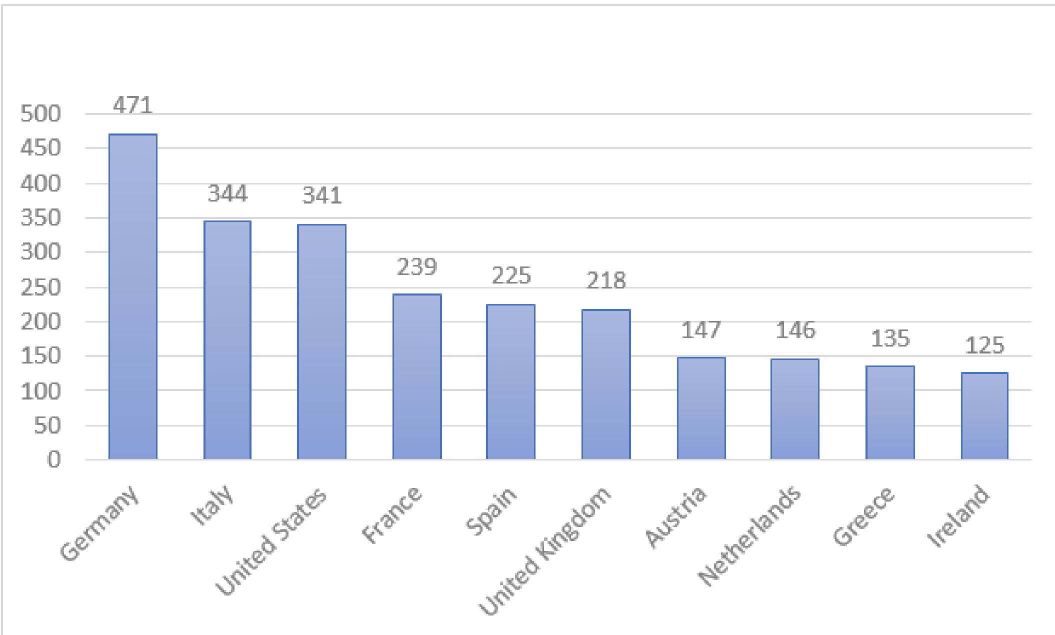

Figure 1: Top 15 Most Productive Countries/Territories in the Research Corpus.

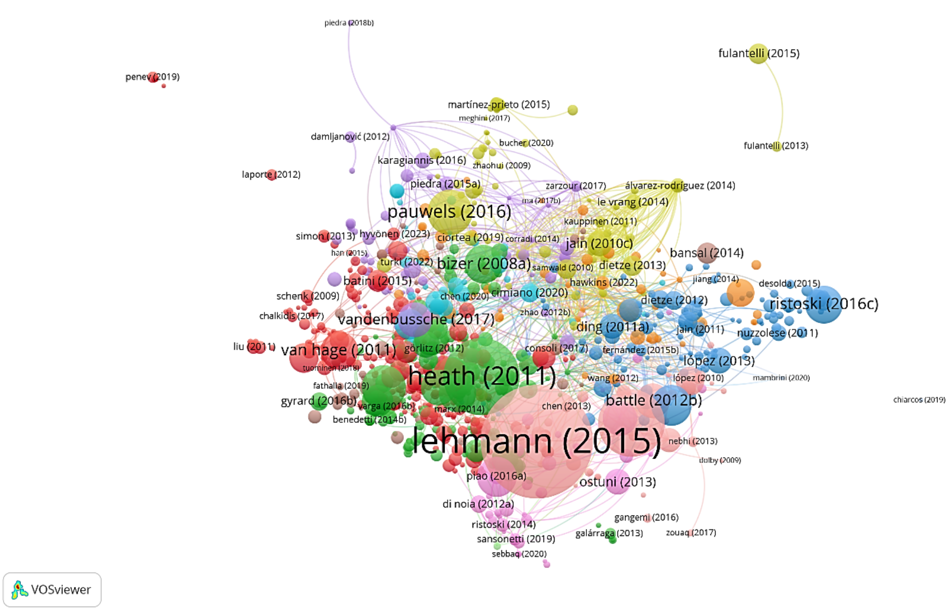

Figure 2: Bibliometric Coupling Network of Core Semantic Web and Linked Data Research.

Table 1: Top Cited Documents for the Main Thematic Clusters.

Cluster	Author(s) and Year	No. of Citations
1	van Hage (2011)	295
1	Fernández (2013)	243
1	Shaw (2009)	175
2	Heath (2011)	1204
2	Janowicz (2019)	406
2	Bizer (2008)	301
3	Nickel (2012)	340
3	Ristoski (2016)	290
3	López (2013)	134
4	Pauwels (2016)	420
4	Jain (2010)	133
4	Fulantelli (2015)	88
5	Vandenbussche (2017)	252
5	Latif (2009)	62
5	Karagiannis (2016)	53
6	Hogan (2011)	184
6	Willighagen (2013)	111
6	Cimiano (2020)	72
7	Caracciolo (2013)	163
7	Arenas (2011)	108
7	Zhao (2014)	49
8	Bansal (2014)	93
8	Camarda (2012)	90
8	Dling (2012)	66
9	Ristoski (2016)	328
9	di Noia (2012)	248
9	Ostuni (2013)	140
11	Usbeck (2018)	54
11	Diefenbach (2018)	13
12	Mambrini (2020)	5
12	Chiarcos (2019)	5

grouping those keywords which co-occur very frequently. Words having the same colour are from the same thematic area, while the different colours stand for different underlying topics.

The concept map reveals a layered structure of different but interconnected themes that are represented in Table 2. The analysis depicts a hierarchical structure of various themes, main concepts and theory, an intermediate layer of data handling principles, and a final layer geared towards the application of data science and web technologies.

To grasp the conceptual landscape very effectively, it is useful to observe how these seven clusters spawn each other and create an entire ecosystem. Clusters 1 and 4 serve as the conceptual and linguistic bedrock, giving the big picture of a machine-readable web as well as the common metadata language that every researcher can communicate using. Residing upon this base, Cluster 3 is focused on the philosophy and formal organization of shared knowledge in the form of ontologies whereas Cluster 5 is tasked with the handling and querying of such data using tools such as RDF and SPARQL. The other clusters concentrate on active deployment with the infrastructure installed. Cluster 6 describes how semantic technologies can be utilized in daily web services and applications. In the meantime, Clusters 2 and 7 are an intelligent form of the frontier of the field, demonstrating that researchers have gone beyond the data capture to the active extraction of information, via data mining, natural language processing and more sophisticated semantic recommenders.

DISCUSSION: STRUCTURE, EVOLUTION, AND FOUNDATIONS

The study of intellectual and conceptual structures portrays the core Semantic Web research community from different perspectives. The map of the bibliographic coupling shows how communication occurred and most recent research fronts. At the same time, a keyword co-occurrence map displays themes that determine core concepts. The logic of this organized pattern is evidently organised reality, a gigantic underlying research front in (Heath, 2011; Hogan, 2011) further expands core theories, principles and standards. Directly from this theoretical nucleus, distinct fields of applied research, especially in Machine Learning and Natural Language Processing, can be most clearly seen to be facilitated. This is evidenced by the strong intellectual clusters Nickel (2012) and Ristoski (2016) strongly leading. The keyword analysis is in line with the fact that these application areas may have their own specific vocabularies (e.g., 'recommender systems'), but they are all connected to the axis concepts of the Semantic Web and Linked Data.

The Evolution of the Field: From Foundational Landmarks to Rising Stars

The temporal overlay of the bibliographic coupling network overlay shows the growth of the field in a very vivid manner. Most of the foundational core, with the landmark papers in Table 1, can be dated back to the years between 2008 and 2015. Recently, most of the research is at the outskirts of the major clusters, i.e., the Machine Learning and NLP communities. It explicitly shows a shift of momentum from creating the core concepts to using them in data science contexts, which is further corroborated by normalized citations' analysis indicating newer papers as "rising stars." Here in Figure 4, the nodes show publications ranging from 2012 (dark blue) to 2020 (yellow).

The Social Structure: Global Collaboration Networks

By analysing the co-authorship network of countries, one can understand the social structure of the research community

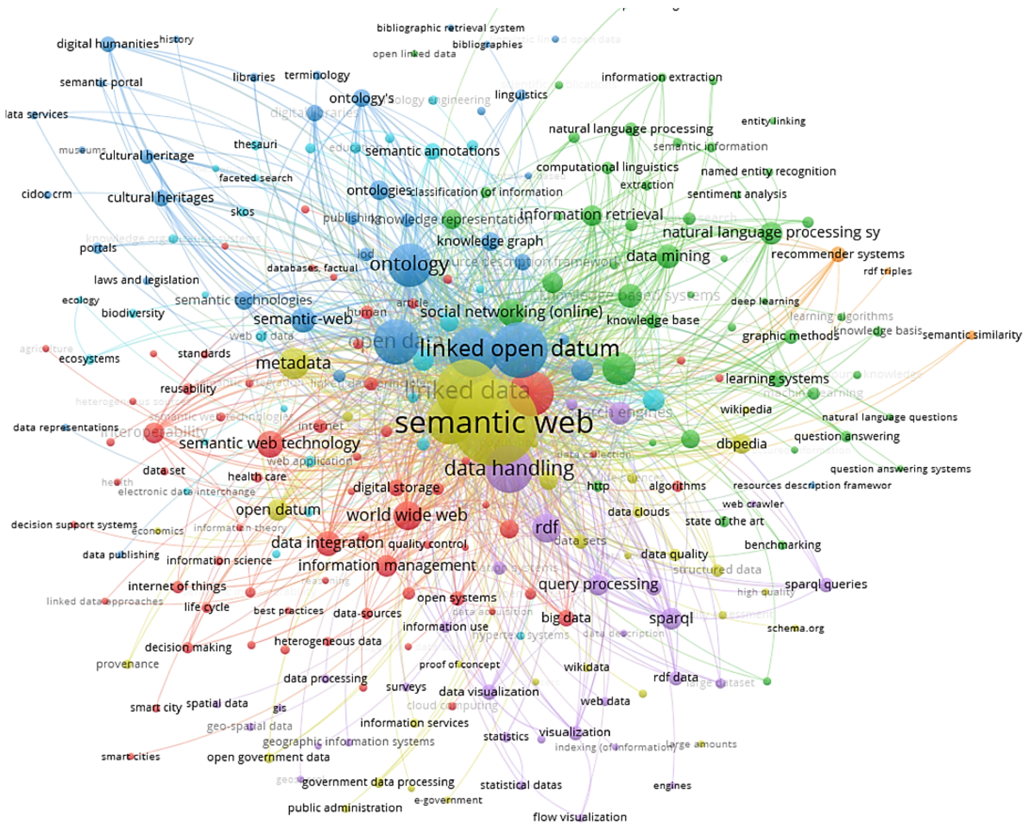

Figure 3: Keyword Co-occurrence Network.

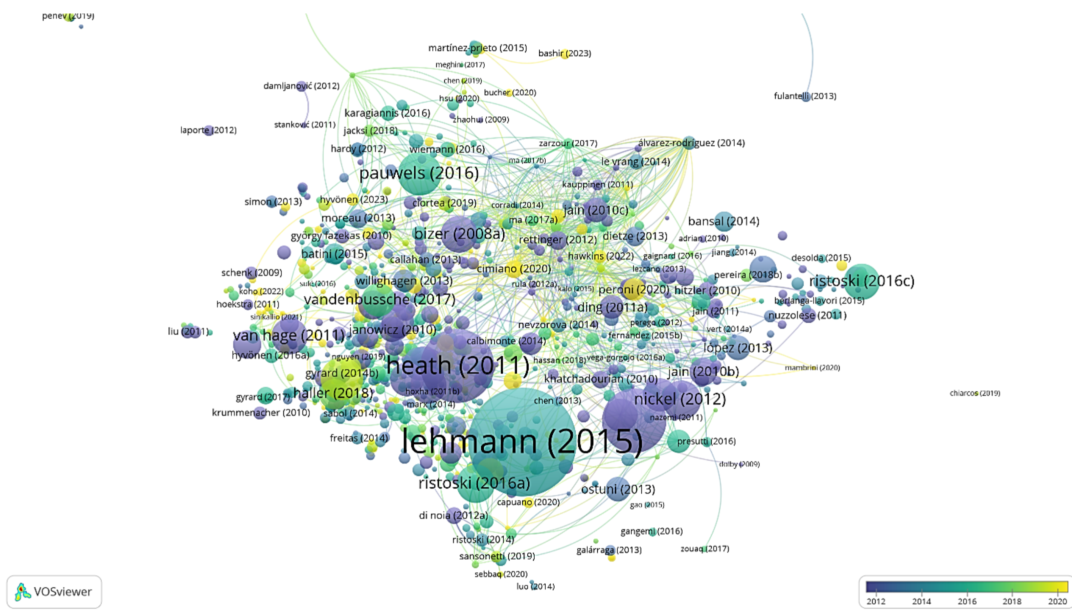

Figure 4: Temporal Overlay of the Bibliographic Coupling Network.

Figure 5. Apart from the intellectual map, this social map reveals the patterns of global collaboration that lead to the research field's output. Here, the nodes' size indicates the number of documents from that country, and the lines show co-authorship links.

A global research landscape is depicted on the map with three major collaborative hubs, as detailed in Table 3. (Cluster 2) describes the European Core as a dense and closely knit collaboration between Germany, Spain and the Netherlands. Cluster 1 reveals the hub between the Anglosphere (United States, United Kingdom) and its main East Asian trading partners, including China and Japan. The third European hub of significance (Cluster 3) centers on Italy and France. To illustrate, Germany and the USA are acting as important "bridge" nodes connecting these different groups of collaborators and, therefore, showing their leading role in the global research ecosystem. The configuration of this social structure is almost identical to that of the intellectual one, meaning that the major research fronts do not only telescope as different although connected collaborative communities but also as separate collective entities.

LIMITATIONS OF THE STUDY

This research has various limitations which should be taken into consideration. The first limitation is that the corpus was only based on the Scopus database. We admit that this may lead to less representation of works that can be found in other major databases like Web of Science or IEEE Xplore, which are very significant for the field of computer science that is heavily inclined towards conferences. Second, our search query was intentionally strict, requiring all three terms ('semantic web', 'linked data', 'linked open data'). While this was effective for isolating the core of the field, it may have excluded relevant studies that focus on only one or two of these concepts, or those that use related terminology (e.g., RDF, SPARQL, ontology learning). Lastly, our investigation is "snapshot, based" or static, only showing how the field is structured at a single time moment. It does not offer

Table 2: Top Keywords for the Main Conceptual Clusters.

Cluster	Cluster Theme	Dominant Keyword	Occurrences
1	Core Technology and Concepts	Semantics	581
1	Core Technology and Concepts	World Wide Web	236
1	Core Technology and Concepts	Semantic Web Technology	210
1	Core Technology and Concepts	Data Integration	182
1	Core Technology and Concepts	Information Management	138
2	Applied Data Science and Web	Linked Open Data (LOD)	315
2	Applied Data Science and Web	Social Networking (Online)	208
2	Applied Data Science and Web	Knowledge-Based Systems	161
2	Applied Data Science and Web	Data Mining	160
2	Applied Data Science and Web	Natural Language Processing Systems	147
3	Core Open Data and Ontology	Linked Open Datum	875
3	Core Open Data and Ontology	Linked Open Data	705
3	Core Open Data and Ontology	Open Data	599
3	Core Open Data and Ontology	Ontology	526
3	Core Open Data and Ontology	Semantic-Web	177
4	Core Terminology and Metadata	Semantic Web	2099
4	Core Terminology and Metadata	Linked Data	1126
4	Core Terminology and Metadata	Linked Datum	627
4	Core Terminology and Metadata	Metadata	279
4	Core Terminology and Metadata	Open Data	134
5	Data Handling and Querying	Data Handling	639
5	Data Handling and Querying	RDF	235
5	Data Handling and Querying	Search Engines	145
5	Data Handling and Querying	Sparql	135
5	Data Handling and Querying	Query Processing	120
6	Diverse Web Applications	Websites	132
6	Diverse Web Applications	Web Services	131
6	Diverse Web Applications	Web Of Datum	97
6	Diverse Web Applications	Semantic Annotations	80
6	Diverse Web Applications	Birds	46
7	Semantic Recommender Systems	Recommender Systems	71
7	Semantic Recommender Systems	Semantic Similarity	26
7	Semantic Recommender Systems	RDF Triples	18

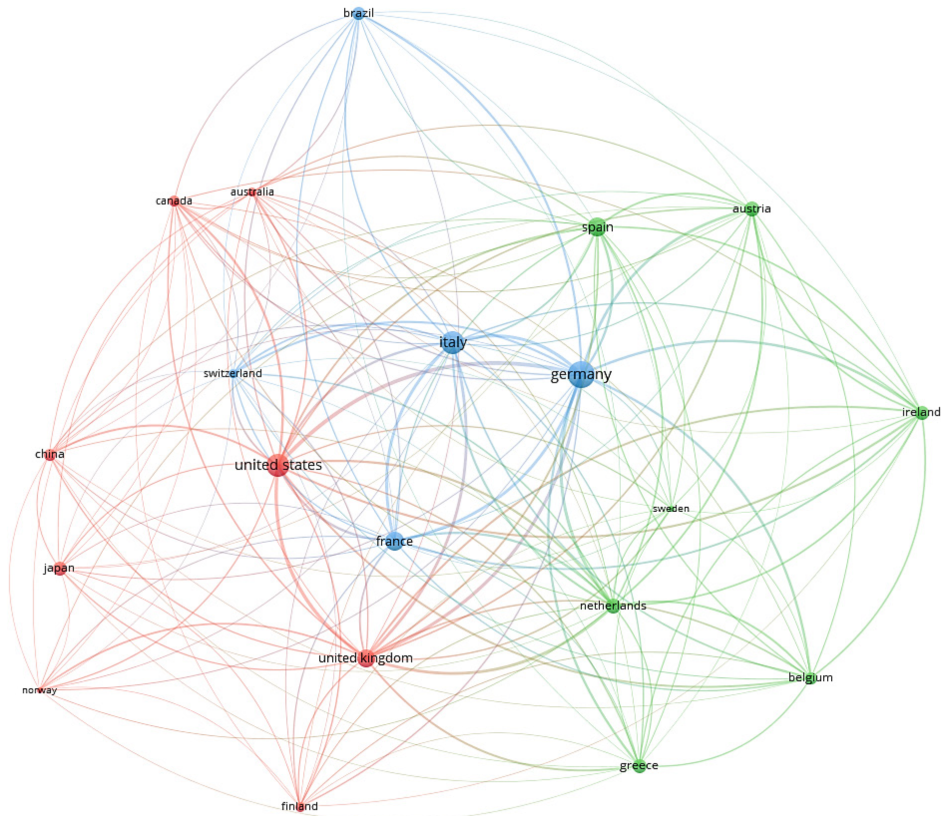

Figure 5: Co-authorship Network of Countries.

Table 3: Top Countries by Document Count and Collaborative Cluster.

Cluster	Country	Documents
1	United Kingdom	209
1	United States	340
1	China	95
1	Japan	121
2	Germany	467
2	Spain	219
2	Netherlands	148
2	Austria	147
3	Italy	325
3	France	241
3	Brazil	106
3	Switzerland	68

detailed and dynamic changes of a longitudinal study; however, our temporal overlay analysis (Figure 4) serves as a bridge by showing the field's developmental direction.

CONCLUSION

This study has successfully outlined the Semantic Web community of scholars as the conceptual and intellectual core for the research community. Our major achievement is thus the first comprehensive, multi, layered "science map" of a community of researchers at a very specific intersection of the Semantic Web and Linked Open Data. The inquiry reveals a vibrant scholarly area with a logical structure where a strong technological core is playing a key role in distinct but interrelated application domains. Although the field is mature, our study has identified some intellectual gaps and potential points of crossover for future research, particularly in bridging the gap between formal ontology engineering and social data analysis.

Though the research area is mature, our study has found some clear intellectual gaps and potential points for future research, especially in connecting the gulf between formal ontology engineering and social data analysis. We suggest next research to concentrate on creating more reliable semantic models for social network analysis and investigating how core LOD principles can be used in different interdisciplinary areas based on these results. This map serves as an essential tool and invaluable device for researchers to aid in understanding the significant big themes, important works and the architecture of this important field. This indicates clear directions for future methodological research and delineates clear paths for applied research.

ACKNOWLEDGEMENT

None.

ABBREVIATIONS

LOD: Linked Open Data; **RDF:** Resource Description Framework; **SPARQL:** SPARQL Protocol and RDF Query Language; **OWL:** Web Ontology Language; **URI:** Unique Identifiers; **NLP:** Natural Language Processing; **CSV:** Comma-Separated Values; **BOLD:** Big and Open Linked Data; **VOSviewer:** Visualization of Similarities viewer; **MetS:** Metabolic Syndrome.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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