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Review

A Systematic Mapping with Bibliometric Analysis on Information Systems Using Ontology and Fuzzy Logic

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Abstract: The ontology-based information systems (IS) development is beneficial for analyzing, conceptual modeling, designing, and re-engineering complex IS to be semantically enriched and suitable for sophisticated reasoning on the IS content. On the other hand, fuzzy theory employment to handle uncertainty and fuzziness in IS becomes a hot topic in different practical domains, such as engineering, IS, computer sciences, etc. As such, ontology- and fuzzy-based IS are being developed. Consequently, there is a need to provide a comprehensive systematic mapping study (SMS) to build a structure on the ontology- and fuzzy-based IS field of interest and to grasp the main ideas. This paper presents findings of SMS, based on the papers extracted from Web of Science and Scopus and employing a bibliometric analysis tool to automate keyword mapping. We conclude this paper by summarizing the previous work and identifying possible research trends, which future investigations can extend. The main finding indicates that ontology and fuzzy logic contribute to ISs by expanding traditional IS to be intelligent IS, which is applicable for solving complex, fuzzy, and semantically rich (ontological) information collection, saving, processing, sharing, and reasoning in different application domains according to users' needs in various countries.

Keywords: ontology; fuzzy logic; information system; ontology-based information system; fuzzy information system; fuzzy ontology; systematic mapping; bibliometric analysis

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1. Introduction

Knowledge representation in Computer Science is a complex task, the appropriate solution of which allows us to create complex intelligent and cyber-physical systems. Therefore, automated reasoning with formal ontologies is employed to represent domain knowledge [1]. As [2] states, ontologies extend traditional applications to be intelligent by converting the raw data into smart data through semantic enrichment. In [3], the authors emphasize the advantage of ontology-driven conceptual modeling vs. traditional conceptual modeling, since ontologies can be applied to aid in the reasoning on the contents of a conceptual model [4,5], to articulate and formalize the conceptual modeling grammars by describing the structure and behavior of the modeled domain [6], or to improve conceptual modeling languages by constraints and structuring rules. Ontologies use an open-world assumption [7]. They can be characterized as descriptive, domain-relevant, and static [8]. In the context of modern information system (IS) development, an ontology describes the basic concepts, their definitions, and relationships comprising the vocabulary of a domain and the axioms for constraining interpretation of concepts and expressing the complex relationships between them [9,10]. If the information system is a traditional one, the application of domain knowledge is just embedded in its standard components. If it is an ontology-driven (or ontology-based) IS, then a separate component—an application domain ontology—will be developed and included in the IS [11,12]. However, in any case, to use an ontology for IS development or IS application automatically, it should be expressed formally and described in a particular formal language. Formal ontology, defined by a particular language, such as Ontology Web Language (OWL) or other, provides more formal semantics and reasoning support to IS [2]. The formal ontology definition for its automatic transformation to conceptual model and domain rules was proposed by [9,10]. The general formalization of ontology and its role in the IS life cycle is analyzed in [12]. Additionally, as the authors of [13] state, a principled methodology for building ontologies is still lacking. Their taxonomic structure is often poor and confusing. Therefore, the authors suggested a better understanding of the properties corresponding to taxonomic nodes by proposing some meta-properties.

In 1965, L.A. Zadeh [14] proposed expressing uncertain concepts using fuzzy set theory. Since then, it has been applied in various fields, such as approximate reasoning, fuzzy control systems, pattern recognition, decision making, operation research, etc. [15]. As described in [16], most applications of fuzzy sets, such as uncertainty modeling [17,18] and measuring [19], similarity measuring [20], reasoning with uncertainty [21], rule extraction [22–24], classification and feature selection [25–27] are related to IS. According to [16,28]: "*If each of its attributes in an information system is fuzzy, then this information system is called a full fuzzy information system*". The authors of [29] defined fuzzy IS as having objects with fuzzy relations among them. A fuzzy IS may be regarded as an IS under a fuzzy environment [30]. A fully fuzzy information system is an IS where each of its attributes determines a fuzzy set on the object set [31].

Consequently, in the literature, we can find different studies on either ontology-driven IS, such as [32–35], or fuzzy IS, such as [16], where either ontologies or fuzzy sets enrich IS with semantic power in different ways and for various purposes. Thus far, the study of both ontology- and fuzzy-based IS has been reported weakly.

Here, special attention should be paid to fuzzy ontology IS, as they are close to our topic of interest. It is necessary to explain how the existing studies on the fuzzy ontology IS topic, such as [2,36], differ from our study. The main difference between the mentioned studies on fuzzy ontology IS is that they deal with fuzzy extensions to ontology in IS. In the present study, we look more broadly; that is, this study includes both fuzzy ontology IS and IS, in which not only the ontology but also other attributes [16] are fuzzy.

Why do we study ontology- and fuzzy-based IS? This is because an ontology- and fuzzy-based IS can locate and extract both precise and imprecise descriptions of concepts and store them in a structured knowledge base [37], facilitate the finding of specific fuzzy knowledge relevant to a given domain [38], be used for solving the problems of uncertainty in sharing and reusing knowledge on the domain [39], reduce the manual workload of daily activities [40], improve the representation of information [41], etc. It is currently most important to understand the structure of ontology- and fuzzy-based IS field of interest and to grasp the main ideas and results.

This research increases the body of knowledge on the ontology- and fuzzy-based IS topic by providing a systematic keywords map of the subject and grasping the main topics in the research field. The paper is intended to support academic and industry researchers working on semantically enriched and knowledge-based IS. Additionally, the results of this research can help researchers and practitioners become familiar with the body of knowledge on the ontology- and fuzzy-based IS topic.

The remaining part of this paper is organized as follows. In Section 2, we described the materials and methods of this research. In Section 3, we present the systematic mapping study results on the ontology- and fuzzy-based IS topic. In Section 4, we discuss our findings. Finally, Section 5 summarizes this paper.

2. Materials and Methods

A systematic mapping study (SMS) on ontology- and fuzzy-based IS was employed as proposed in [42] with the application of bibliometric analysis. It allows us to identify research trends, detect topics that exist within the analyzed field [43], and visualize the findings [44]. SMS was systematically organized following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [45] as planning, conducting, and reporting. The main SMS steps are explained in the next sections. A summary of SMS is provided in the PRISMA checklist [45] as a supplementary material (File S1). *Note* that the present study is a systematic mapping study, but not a systematic literature review (SLR). They have some differences in their final goal, the research questions, search process, search strategy requirements, quality evaluation, and results [42,46,47]. Compared to SLR, in SMS the research questions are general as they aim to discover research trends, the research process is impacted and is based on a topic area, the search requirements are less stringent as we are only interested in research trends, the quality assessment is less essential and sometimes not performed, a category of solution proposals contain articles with no empirical evidence as it is important to spot trends of topics, and, finally, the outcome is an overview of the scope of the area, which allows us to discover research gaps and trends [42].

2.1. Research Questions

This SMS aims to build a structure on ontology- and fuzzy-based IS field of interest and to grasp the main ideas in this field. It leads to the following main research question (MRQ): *How do ontology and fuzzy logic contribute to information systems?* According to MRQ, the following RQs are defined:

- RQ-1: When is ontology- and fuzzy-based IS research published?
- RQ-2: Which ontology- and fuzzy-based IS development topics are covered?
- RQ-3: What are the main future directions found in the analyzed topic?
- RQ-4: What are the visible trends for the countries that participate in the study of ontology- and fuzzy-based IS?

Below the searching protocol is presented, developed by the first author, and later reviewed by the second author.

2.2. Conducting the Search

The PICOC (Population, Intervention, Comparison, Outcomes, Context) framework used by Kitchenham and Charters [48] was developed to identify keywords and formulate search strings from MRQ.

Population: In our context, the population consists of research papers on ontology- and fuzzy-based IS.

Intervention: In the context of this study, we investigate how ontology and fuzzy logic are related to the IS field.

Comparison: In this study, a comparison is not made.

Outcomes: No measurable outcome is considered, as we do not focus mainly on the outcomes of the papers.

Context: This study is made in the academic context by analyzing existing papers on ontology- and fuzzy-based IS.

Consequently, we identified three main terms: "ontology," "fuzzy," and "information system".

The keyword "information system" was not included in the main string since the primary analysis of papers shows that a significant part of authors does not use this concept. They usually talk about some aspects of IS, such as information sharing, uncertainty modeling, similarity measuring, reasoning, etc. [16].

Finally, the remaining two terms were combined to one search string. The obtained string was processed on the Web of Science (WoS) and Scopus. The limitations (as search string, document type, language, categories) used in the search can be found in Table 1. We have limited categories during the search (i.e., Computer Science or Engineering) to exclude studies not related to the present SMS.

Table 1. Search strings in Web of Science (WoS) and Scopus.

Database	Search String	Document Type	Language	Categories	Search Results
WoS	("ontolog*" AND "fuzzy")	article OR review	English	Computer Science OR Engineering	508
Scopus	("ontolog*" AND "fuzzy")	article OR review	English	Computer Science OR Engineering	647
		Total [1]:			1155

[1] In this step, duplicates are not excluded.

This study was conducted in January 2021 without year restrictions on the search. The document type has been limited to articles and reviews, since conference papers rarely provide enough detail of the methods used due to space limitations in conference proceedings [49]. Moreover, conference papers are often expanded in journal papers.

The WoS and Scopus databases have been chosen for this SMS based on the experience reported in [50].

2.3. Study Selection and Quality Assessment

After downloading search results from WoS and Scopus into Mendeley (https://www.mendeley.com/ (accessed on 13 January 2021)), they were checked for duplicates. An initial set of total references consisted of 1155 entities, in which Mendeley found 807 unique references. After excluding duplicates, the review of abstracts of the included papers was performed by both authors. During the analysis of abstracts, the following inclusion criteria (IC) and exclusion criteria (EC) were applied:

- IC1: Include papers that are works on ontology- and fuzzy-based IS.
- EC1: Exclude papers that contain relevant research keywords, but the ontology- and fuzzy-based IS topic is not discussed in the abstract.
- EC2: Exclude duplicate papers that repeat ideas described in earlier works, and their abstracts are similar, i.e., if one paper is an extension of another, the less extended (i.e., containing fewer pages) paper is excluded [51].
- EC3: Exclude papers that analyze generic topics, such as fuzzy mathematical operations, ontological approximation, etc., without concrete application in IS.

Finally, a set of relevant 652 papers was obtained and translated to VOSviewer to map and develop the keywords map. An initial set of papers, a set of excluded papers, and a set of included papers are presented in GitHub (https://github.com/Jolantux13/Onto_Fuzzy_IS (accessed on 25 February 2021)).

The overall results of the paper's selection procedure are illustrated in Figure 1 as a PRISMA flow diagram. Note that in the flow diagram, not all steps correspond to the original PRISMA flow diagram, because we conduct SMS, not SLR.

2.4. Used Tools

In this study, we have used the following tools: (1) Mendeley for managing bibliographic references and (2) VOSviewer for bibliographic analysis and developing keywords map.

In [52–54], scientists have used different mapping tools, including VOSviewer, BibExcel, CiteSpace, CoPalRed, Sci2, VantagePoint, and Gephi, for analyzing, mapping, and visualization of bibliographic data. A detailed review of visualization tools is not the main aim of this paper. Therefore, we have used VOSviewer (https://www.vosviewer.com/ (accessed on 5 February 2021)) as an analysis and mapping tool, which is easy to use and intuitive. VOSviewer generates a network from the given bibliographic data. For more details about VOSviewer, see [55].

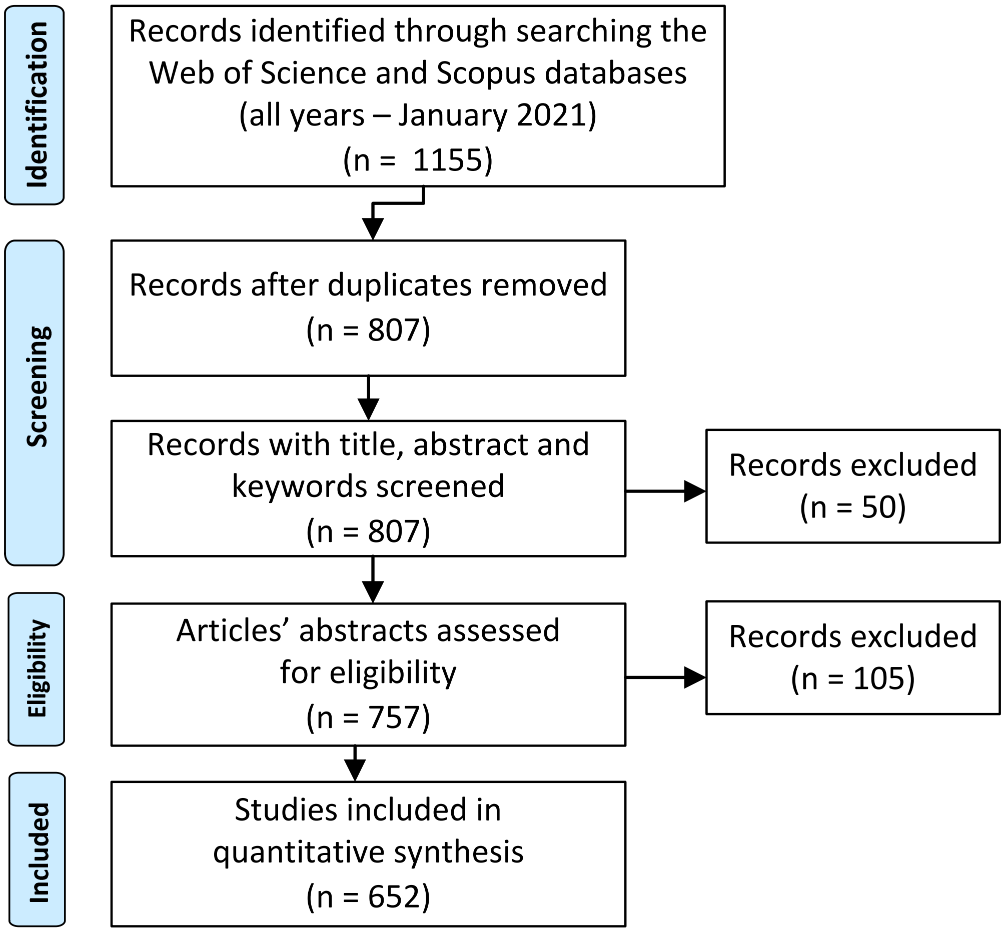

Figure 1. The PRISMA flow diagram (according to [45]) of the current SMS.

2.5. Data Extraction

To extract data from the identified studies and create a keywords map on ontology- and fuzzy-based IS, we have downloaded titles and abstracts of the selected papers to VOSviewer. It selects keywords using an automatic keywords identification technique [55] and creates the keywords map by considering the closeness and strength of existing links. The closeness and strength are calculated from the number of papers, in which both keywords have occurred together (i.e., using binary counting). VOSviewer also clusters keywords and portrays topics by colors. The size of the bubbles presents the density of occurrence of keywords. VOSviewer uses a unified approach to keywords' mapping and clustering [56].

When a map is created based on bibliographic data or text data, there often is a need to perform data cleaning [57]. For this purpose, we have created a VOSviewer thesaurus file (https://github.com/Jolantux13/Onto_Fuzzy_IS (accessed on 25 February 2021)). Both authors have developed it according to the following limitation rules:

1. Merge different spellings of the same word, such as "fuzzy cognitive maps" and "fuzzy cognitive map," "modelling," "modeling," etc.;
2. Merge abbreviated keywords with full keywords, such as "ontology web language" and "OWL";
3. Merge synonyms, such as "fuzzy theory" and "fuzzy set theory";
4. Exclude general keywords, such as paper, study, goal, etc., since they provide very little information, and the usefulness of a map tends to increase when they are excluded.

The thesaurus consists of 155 merged and excluded keywords. Finally, VOSviewer has identified 7227 keywords, among which 238 keywords occur at least five times in the titles and abstracts of the selected 652 papers. The analysis of the created keywords map is presented in Section 3.

2.6. Method Used for the Results Analysis

The content analysis was used to perform the analysis of the obtained keywords map. It consists of the following parts:

- Keywords chronological occurrence analysis, based on analyzing the keywords occurrences per year (RQ-1, RQ-3).
- Keywords occurrence analysis, based on the Pareto distribution (80-20) [58] (RQ-2).
- Keywords co-occurrence analysis, based on the analysis of the relationships among keywords (RQ-2).
- Keywords clustering analysis, based on the analysis of the keywords clustering in VOSviewer [59] (RQ-2).
- Countries occurrence and co-occurrence analysis (RQ-4).

2.7. Validity Evaluation

According to [42], the following types of validity are identified in this study: internal validity, construct validity, and external validity. Although we carefully followed the SMS process to minimize the validity threats, we faced some threats that deserve further discussion.

Construct validity refers to the concepts being studied. When defining the SMS scope and keywords, we faced uncertainty about whether researchers referred to IS, ontology, and fuzzy theory in a relationship or not. Consequently, the primary analysis of papers was done to familiarize with ontology- and fuzzy-based IS and define the related keywords more precisely. It shows that the keyword "information system" in a search string significantly reduces the set of candidate papers for the SMS, and important research is omitted. Moreover, as the authors of [16] identified, a number of researchers talk about IS without mentioning its name. Therefore, only general terms, as ontology and fuzzy, were included in the search string, which gives us a sufficient number of papers for SMS. We have used WoS and Scopus for the search, since they enable us to find the most suitable and high-quality peer-reviewed papers. Finally, considering the significant number of the primary set of papers (1155), we have decided that our results and findings are valuable for providing researchers and practitioners with an overview of the state of the art of ontology- and fuzzy-based IS.

An **internal threat to validity** in this research refers, first, to the individual researcher's bias in (1) deciding whether to include or exclude a paper for SMS analysis, and (2) analyzing the results. The second threat is that most of the papers do not provide an accurate and direct statement of ontology, fuzzy theory, and IS relationship. We have used a clearly defined searching strategy, carefully reviewed titles and abstracts of primarily found papers and assessed the obtained results together to minimize the researcher's bias.

External validity refers to this review's results and conclusions. They are only valid for IS. We have made great efforts to systematically set up the review protocol and apply it to ensure that general conclusions are valid irrespective of the lack of consensus.

To ensure the repeatability of our SMS, we have explicitly described all of the steps performed in SMS, created thesaurus, and provided evidence about our findings (https://github.com/Jolantux13/Onto_Fuzzy_IS (accessed on 25 February 2021)).

3. Results

3.1. Chronological Distribution Analysis (RQ-1)

Figure 2 chronologically shows the paper numbers between 1988 and 2020, which sum up to 652. Consequently, this chronological distribution allows us to answer RQ-1 ("When is ontology- and fuzzy-based IS research published?"). Preliminary conclusions are that research on ontology- and fuzzy-based IS started in 1996 and has risen sharply since 2003. This indicates the increasing interest of scholars in this field of research over the last period.

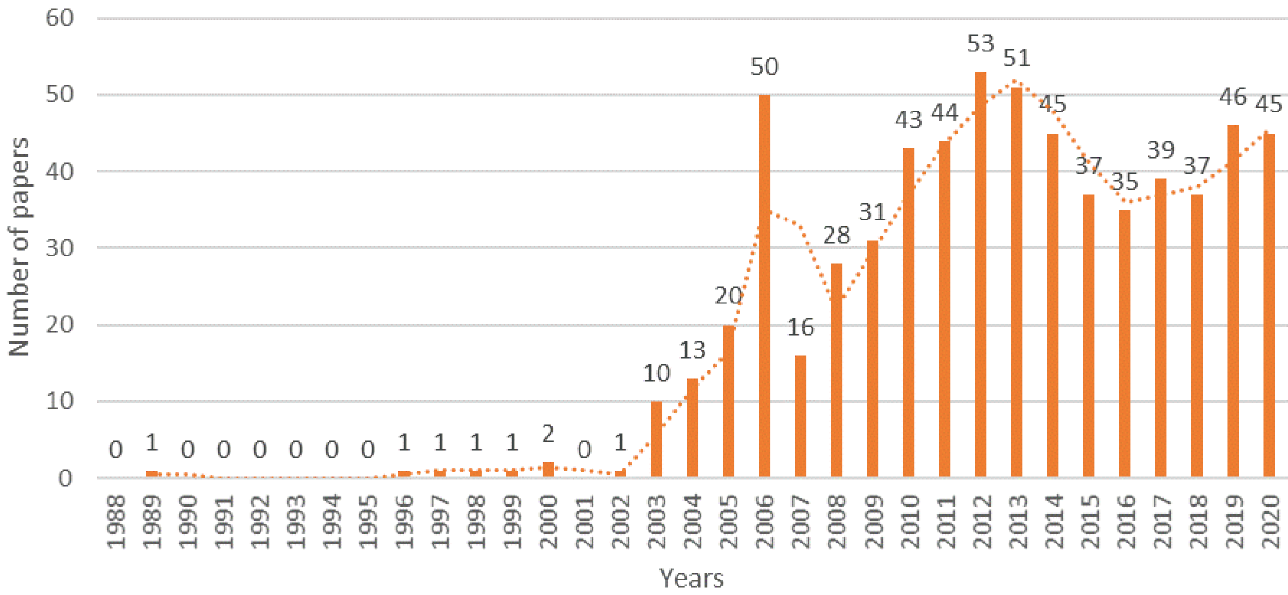

Figure 2. Chronological distribution of ontology- and fuzzy-based IS research.

3.2. Keywords Occurrence Analysis (RQ-2 and RQ-3)

Based on the analysis methods (see Section 2.6), two keyword maps of the ontology- and fuzzy-based IS field were created as the following: (1) the most occurring keywords map (Pareto distribution—20) to view the mostly analyzed topics (RQ-2); and (2) the moderately occurring keywords map (Pareto distribution—80) to view the analyzed topics (RQ-2) and the future directions (RQ-3).

3.2.1. The Most Occurring Keywords

We have created the most occurring keywords map, which is presented in Figure 3. For its development, we have restricted the minimum number of keywords' occurrences to 17 (it corresponds to 20% of all found keywords by Pareto distribution). VOSviewer has identified 48 keywords that meet the threshold. The 10 most occurring keywords are fuzzy ontology (139), knowledge (139), information (136), data (96), framework (86), concept (85), domain (75), semantic web (72), reasoning (71), and user (66).

As can be seen from Figure 3, those keywords were divided into three clusters. According to [59], clustering in VOSviewer is based on minimizing distances between keywords, i.e., the most related keywords fall into one cluster. Consequently, the five closest keywords in those three clusters are the following: (1) information, domain, user, query, and term; (2) fuzzy ontology, knowledge, concept, semantic web, and reasoning; and (3) data, framework, development, context, and rule. Preliminary conclusions can be drawn that the first cluster represents the user's needs, the second cluster represents knowledge representation through fuzzy ontology for reasoning about concepts, and the third cluster represents data framework development according to context and rules, i.e., IS development.

In Table 2, a part of the keywords co-occurrence matrix is presented (for the whole matrix, please see GitHub (https://github.com/Jolantux13/Onto_Fuzzy_IS (accessed on 25 February 2021)). The columns and the rows of the matrix present keywords, and the cells are the co-occurrence strength of two keywords. Moreover, the intensity of the green color indicates that keywords tend to appear together. The more intense the green, the stronger the co-occurrence.

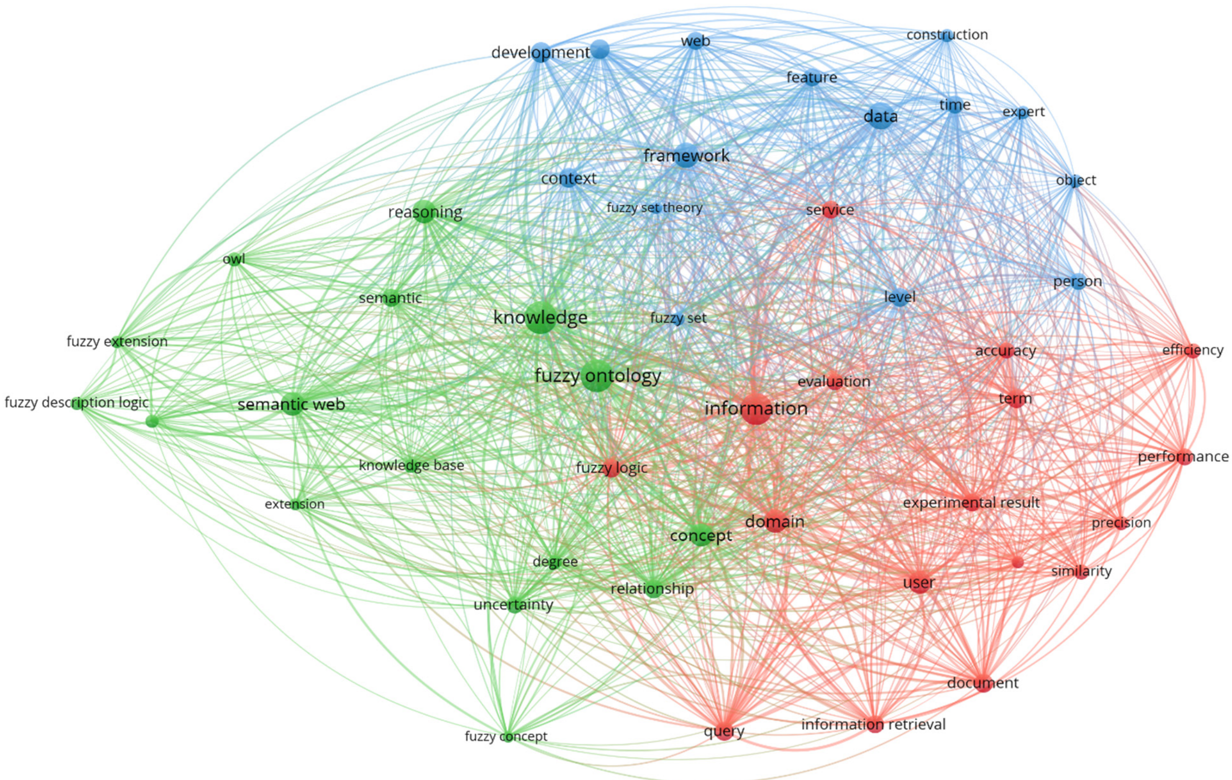

Figure 3. The most occurring keywords map.

The most co-occurring keywords are the following: fuzzy ontology and knowledge (46), knowledge and information (42), fuzzy ontology and information (38), information and user (38), concept and information (37), and domain and knowledge (37).

3.2.2. The Moderately Occurring Keywords

The moderately occurring keywords map is presented in Figure 4. For its development, we have restricted the number of keywords' occurrences from 5 to 17 (it corresponds to 80% of all found keywords by Pareto distribution). VOSviewer has identified 147 keywords that meet the threshold. The 10 most occurring keywords are the following: retrieval (55), collection (16), comparison (16), experience (16), imprecision (16), preference (16), quality (16), support (16), attribute (15), and case study (15).

As can be seen from Figure 4, those keywords were divided into seven clusters. The closest and the most occurring keywords in each cluster are the following: (1) preference, attribute, image, recommendation system, and fuzzy markup language; (2) collection, experience, support, characteristic, fuzzy rule, identification, and scenario; (3) patient, decision making, activity, decision support system, location, monitoring, and practice; (4) imprecision, knowledge representation, knowledge management, interval, and fuzzy information; (5) retrieval, quality, search engine, information retrieval system, user query, and cost; (6) comparison, case study, dataset, keyword, and semantic similarity; and (7) data mining, formal concept analysis, entity, treatment, and www. Preliminary conclusions are that the 1st, 2nd, 3rd, 5th, 6th, and 7th clusters represent different application domains of ontology- and fuzzy-based IS. The 4th cluster represents fuzzy information representation and management topic. Moreover, in each cluster, we can see data in different forms, such as documents, images, scenarios, sensors data, user profiles data, etc. Information retrieval is also observed through collection, access, interpretation, decision-making, monitoring, inference, etc. Knowledge is found through knowledge representation, knowledge management, rules, axioms, fuzzy knowledge, uncertain knowledge, etc.

Table 2. The co-occurrence matrix of the most occurring keywords in the ontology- and fuzzy-based IS field.

Keywords	Feature	Framework	Fuzzy Extension	Fuzzy Logic	Fuzzy Ontology	Fuzzy Set	Fuzzy Set Theory	Information	Information Retrieval	Knowledge	Knowledge Base	User
accuracy	6	4	1	4	12	2	1	12	3	12	2	4
concept	7	17	4	7	23	5	6	32	10	29	6	16
context	5	8	5	6	13	5	3	20	4	14	4	12
data	12	25	0	8	26	8	3	32	6	30	5	15
degree	3	3	2	4	8	7	2	10	4	13	2	5
development	4	14	4	6	12	2	5	13	3	16	2	4
document	2	5	1	5	15	1	5	17	16	14	4	12
domain	8	14	3	9	26	3	6	28	6	**37**	5	13
experimental result	5	5	0	7	15	2	3	20	3	20	5	11
expert	1	5	0	0	10	5	1	7	0	12	1	1
feature	0	7	1	2	13	3	3	15	3	19	1	6
framework	0	0	2	9	21	5	4	26	9	22	2	14
fuzzy logic	0	0	0	0	12	1	2	20	6	20	1	10
fuzzy ontology	0	0	0	0	0	6	8	38	11	**46**	10	14
information	0	0	0	0	0	0	0	0	18	**42**	8	**38**
information retrieval	0	0	0	0	0	0	0	0	0	11	6	9
knowledge	0	0	0	0	0	0	0	0	0	0	15	16

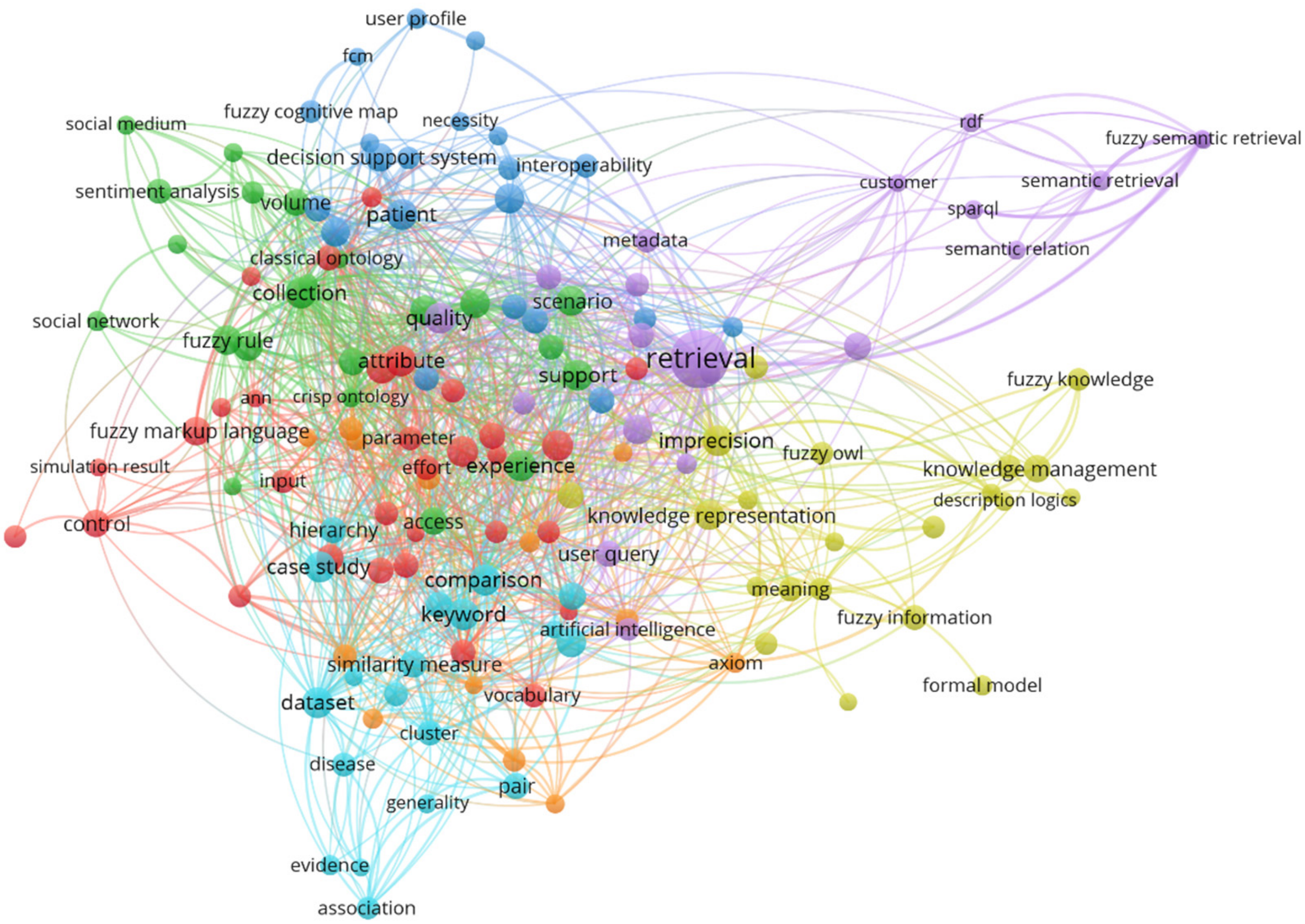

Figure 4. The moderately occurring keywords map.

Table 3 presents the part of the co-occurrence matrix of the moderately occurring keywords in the ontology- and fuzzy-based IS field. As can be seen, the most co-occurred keywords are the following: keyword and retrieval (8), collection and retrieval (6), image and retrieval (6), fuzzy semantic retrieval and semantic query expansion (5), semantic retrieval and fuzzy semantic retrieval (5), and semantic query expansion and semantic retrieval (5). Consequently, it can be said that semantically rich information retrieval requires semantic query expansion.

Figure 5 presents the moderately occurring keywords distribution according to Average Publication Year (APY), which indicates the average publication year of the documents in which a keyword occurs [57]. The yellow-colored keywords present currently the most analyzed topics in the ontology- and fuzzy-based IS field as the following: social network (APY 2019), social medium (APY 2018), IoT (Internet of Things) (APY 2018), sentiment analysis (APY 2017), web ontology language (APY 2017), cloud service (APY 2016), sensor (APY 2016), recommendation system (APY 2016), dataset (APY 2016), wordnet (APY 2016), SWRL (Semantic Web Rule Language) (APY 2015), etc.

Table 3. The co-occurrence matrix of the moderately occurring keywords in the ontology- and fuzzy-based IS field (the whole co-occurrence matrix is presented in GitHub (https://github.com/Jolantux13/Onto_Fuzzy_IS (accessed on 25 February 2021)).

Keywords	Retrieval	Search Engine	Semantic Query Expansion	Semantic Relation	Semantic Retrieval	Semantic Similarity	Similarity Measurement	Social Medium
collection	6	3	0	0	1	0	0	3
dataset	4	0	0	0	0	2	3	0
fuzzy semantic retrieval	3	0	5	2	5	0	0	0
image	6	0	0	0	0	0	0	0
information retrieval system	5	3	1	0	1	0	0	0
keyword	8	4	0	0	1	0	0	0
relevance	4	1	0	0	0	0	0	0
retrieval	0	4	3	1	3	2	3	0
semantic query expansion	0	0	0	2	5	0	0	0

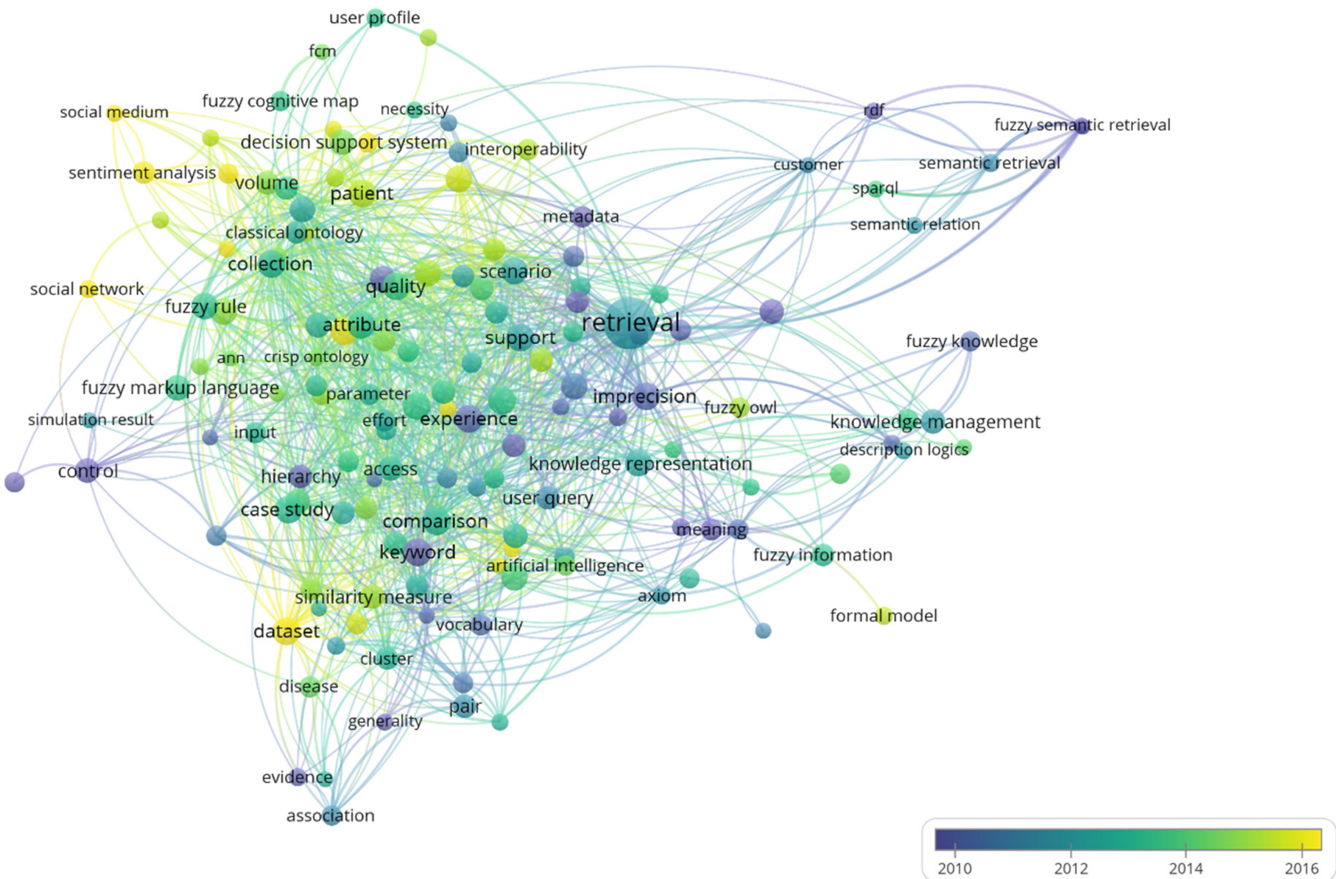

Figure 5. The moderate keywords occurrence according to years.

3.3. Countries Participating in the Study (RQ-4)

We have created two country participation maps for WoS and Scopus to investigate visible trends for the countries participating in the study of ontology- and fuzzy-based IS field (RQ-4). *Note* that we have developed two separate country maps for investigating differences in WoS and Scopus. Additionally, separate country maps were created because of inconsistent search models and query options of digital libraries, limited possibility to crawl libraries to retrieve results, limited access to bibliographic information of papers, inconsistencies when exporting search results from digital libraries, and differences in the formatting (i.e., author names, country names, etc.) [60].

Figure 6 presents the country map generated from the WoS dataset on ontology- and fuzzy-based IS. The five most occurring countries in the map are the following: Peoples R China (80), Spain (58), Italy (47), Taiwan (36), and India (31), where the number near the country indicates the number of papers published by a country.

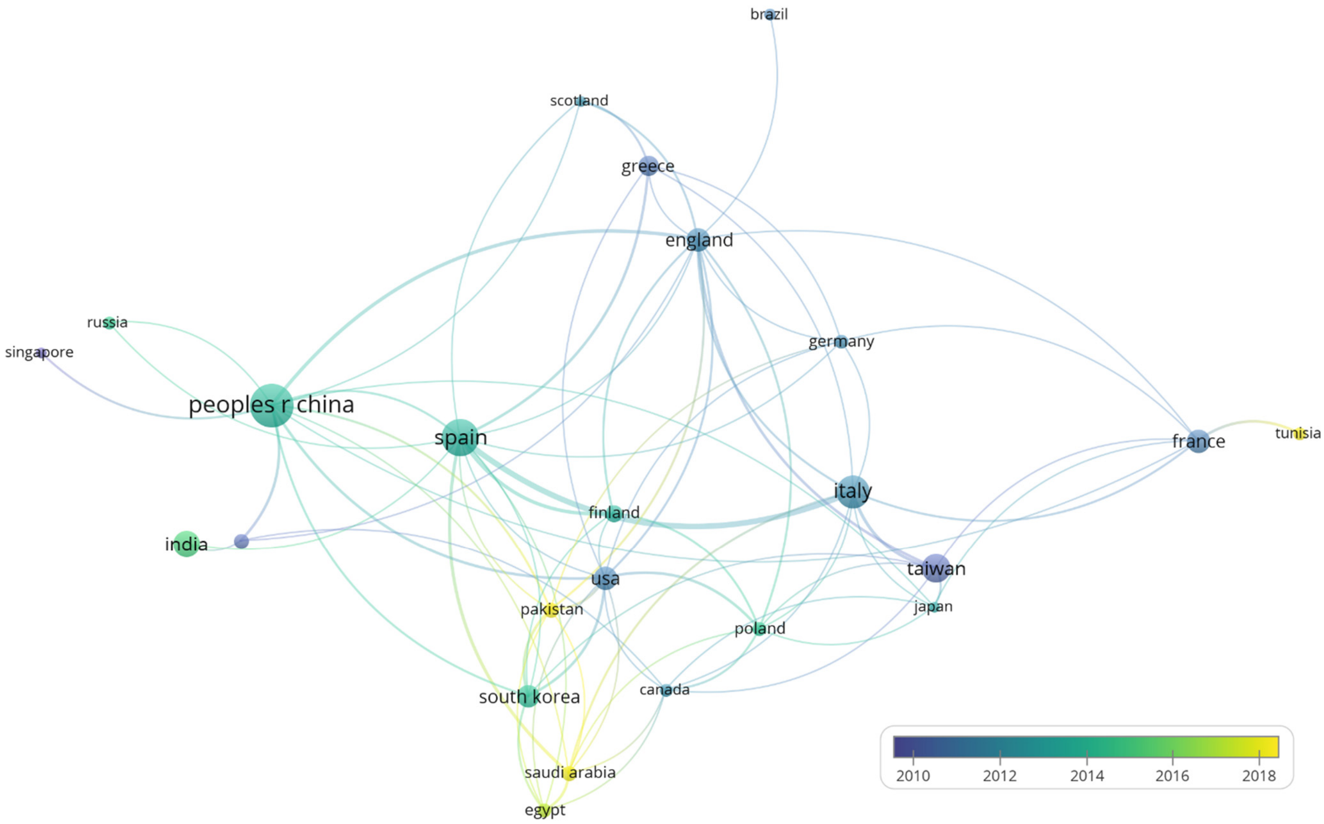

Figure 6. The country map on the ontology- and fuzzy-based IS topic generated from WoS.

In Figure 6, countries are colored according to APY, which indicates the average publication year of the documents published by a country [57]. The yellow-colored countries present the new countries-contributors to the study topic. They are the following: Tunisia (2018), Pakistan (2018), Saudi Arabia (2018), and Egypt (2017). Since those countries have recently contributed to the ontology- and fuzzy-based IS topic, their APY is recent. Countries, such as the Peoples R China, Spain, Italy, England, the USA, and France, have a high volume of papers; therefore, their APY is in the middle according to the year distribution.

Table 4 presents the co-occurrence of countries according to WoS. The columns and the rows of the matrix present countries, and the cells—the co-occurrence strength of two countries. The blank cell means the absence of a relationship between countries. The intensity of the green color indicates that countries tend to appear together. The more intense the green, the stronger the co-occurrence. As can be seen, the most co-occurred countries (RQ-4) are the following: Italy and Spain (13), England and the People R China (5), and Finland and Spain (5).

Table 4. WoS co-occurrence of the countries in the ontology- and fuzzy-based IS field.

Countries [1]	Australia	Brazil	Canada	Egypt	England	Finland	France	Germany	Greece	India	Italy	Japan	Pakistan	Peoples R China	Poland	Russia	Saudi Arabia	Scotland	South Korea	Spain
Egypt			1																	
England	1	1																		
Finland					2															
France					1															
Germany					1		1													
Greece					1			1												
India	1																			
Italy			1		2		2	1	1											
Japan			1				1				1									
Pakistan				1	2			1												
Peoples R China	3				5		1					1	2							
Poland			2		2	2					1	1								
Russia														1						
Saudi Arabia			1	3							2		1	1	1					
Scotland					2				2					1						
Singapore														2						
South Korea				2		1							3	2						
Spain				1	1	5		1	3	1	13		1	2		1	4	1	1	
Taiwan			1		3		1				4	2			1				1	
Tunisia							3													
USA			1	1	2	1		1	1				3	3	3		1		3	1

[1] Note that countries are named as they appear in WoS.

Figure 7 presents the country map on the ontology- and fuzzy-based IS topic generated from the Scopus dataset. The five most occurring countries in the map are the following: China (136), India (79), Italy (72), Spain (68), and Taiwan (54). Note that the five most occurring countries in Scopus are the same as in WoS, except their order of occurrences.

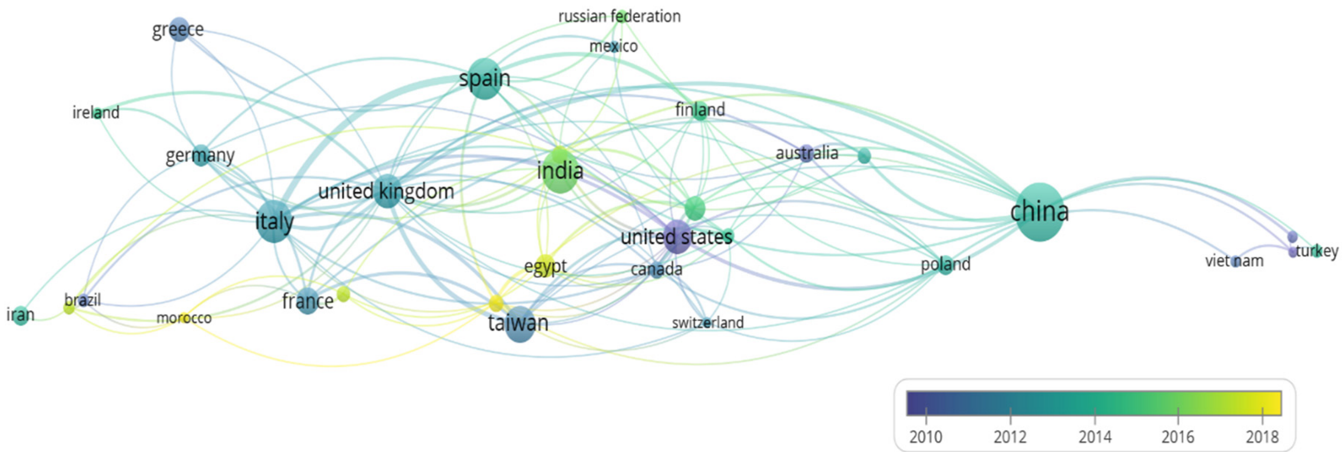

Figure 7. The country map on the ontology- and fuzzy-based IS topic generated from Scopus.

In Figure 7, countries are colored according to APY. The yellow-colored countries presenting the new countries-contributors to the study topic are the following: Morocco (2018), Saudi Arabia (2018), Egypt (2017), Tunisia (2017), and Malaysia (2017). Comparing to WoS, in Scopus, three newly contributed countries are the same (i.e., Tunisia, Saudi Arabia, and Egypt), and two countries differ (i.e., Morocco and Malaysia). Countries, such as China, Spain, Italy, and the United Kingdom, have a high volume of papers; therefore, their APY is in the middle according to the year distribution.

Table 5 presents the co-occurrence of the countries according to Scopus. The columns and the rows of the matrix present countries, and the cells present the co-occurrence strength of two countries. The blank cell refers to the absence of a relationship between countries. The intensity of the green color indicates that countries tend to appear together. The more intense the green, the stronger co-occurrence. As can be seen, the most co-occurred countries (RQ-4) are the following: Italy and Spain (19), Taiwan and United Kingdom (9), United Kingdom and China (6), and Finland and Spain (6).

Table 5. Scopus co-occurrence of the countries in the ontology- and fuzzy-based IS field.

Countries [1]	Australia	Brazil	Canada	China	Egypt	Finland	France	Germany	Greece	Hong Kong	India	Iran	Ireland	Italy	Japan	Malaysia	Mexico	Morocco	New Zeeland	Pakistan	Poland	Russian Federation	Saudi Arabia	Singapore	South Korea	Spain	Switzerland	Taiwan	United Kingdom
China	2																												
Egypt			1																										
Finland			1																										
France				2																									
Germany		1	2				3																						
Greece								1																					
Hong Kong	3			4																									
India	1				1																								
Ireland								2																					
Italy		1	2				2	2	1			1	1																
Japan			2	1	1					1				2															
Malaysia		2										1		1															
Mexico											1				1														
Morocco		1					1									1													
New Zeeland				3																									
Pakistan				2	1			1		1						1													
Poland			2			1								1	2														
Russian Federation				1													2			1									
Saudi Arabia			1	1	5									1				1			1								
Singapore				2															1										
South Korea				2	3	1														3	1								
Spain	1		1	2	1	6		2	2					19			2			2		2	3		1				
Switzerland			2											1	1						1		1						
Taiwan			2	1			4							5	3						1				1				
Tunisia					1		3				1							1					1						
Turkey				1																				1					
United Kingdom	2	2	1	6		1	3	4	1	2	2		4	5	1	2		1		3	1	1				2	1	9	
United States			2	5	1	1		1			2			4	1					3	2		1		4		2	1	3
Vietnam																					2			2					

[1] Note that countries are named as they appear in Scopus.

4. Discussion

Ontology and fuzzy logic are beneficial in IS, since they extend traditional IS to be intelligent IS by its semantic enrichment, sharing and reusing knowledge on the domain. Therefore, it is important to understand the structure of ontology- and fuzzy-based IS field of interest and to grasp the main ideas and results of those systems. Finally, in this section, we can answer the RQs and discuss the obtained results of SMS.

In this research, we have applied a systematic mapping with bibliometric analysis techniques to answer the main research question (MRQ): *How do ontology and fuzzy logic contribute to information systems?* Consequently, MRQ was decomposed to the following sub-questions: (RQ-1) *When is ontology- and fuzzy-based IS research published?*, (RQ-2) *Which ontology- and fuzzy-based IS development topics are covered?*, (RQ-3) *What are the main future directions found in the analyzed topic?*, and (RQ-4) *What are the visible trends for the countries participating in the study of ontology- and fuzzy-based IS?*

The conducted systematic mapping study (SMS) on the ontology- and fuzzy-based IS topic shows a significant increase of papers since 2003 (RQ-1). It can be attributed to technological development and raise the applicability of fuzzy theory to present uncertainties in various application domains. Moreover, our observed growth of publications on the ontology- and fuzzy-based IS topic corresponds to the growth of publications on the ontology topic found by [53].

To answer RQ-2, we have performed a keywords occurrence, co-occurrence, and clustering analysis using VOSviewer. Moreover, the developed keywords occurrence maps were analyzed applying the Pareto distribution. The most occurring keywords map (Pareto distribution—20) allows us to determine the most analyzed ontology- and fuzzy-based IS topics. They are the following: fuzzy ontology information systems, semantic web, and reasoning. The cluster analysis of the most occurring keywords map allows us to identify three main areas in ontology- and fuzzy-based IS as the following: (1) users' needs, (2) knowledge representation through fuzzy ontology for reasoning about concepts, and (3) data framework development according to context and rules, i.e., IS development. The co-occurrence matrix confirms these findings.

The moderately occurring keywords map (Pareto distribution—80) allows us to determine the sub-topics (RQ-2) of the main identified topics (Pareto distribution—20) and to view the possible future directions (RQ-3). Based on keywords occurrence and clustering analysis, we have found different application domains of ontology- and fuzzy-based IS (i.e., image recognition, scenario analysis, user's experience collection, decision making, information retrieval, semantic similarity, and data mining) and fuzzy information representation and management topic. Moreover, depending on the application domain, in modern IS, we observe a need for collecting, saving, sharing, and analyzing data in different forms, such as documents, images, scenarios, sensors data, user profiles data, etc. Information retrieval is also observed through the collection, access, interpretation, decision making, monitoring, inference, etc. Knowledge is found through knowledge representation, knowledge management, rules, axioms, fuzzy knowledge, uncertain knowledge, etc. The co-occurrence matrix confirms that semantically rich information retrieval, storage, and analysis requires traditional IS to be extended to semantically rich and intelligent IS.

The moderately occurring keywords according to APY allow us to predict possible future directions (RQ-3) in the ontology- and fuzzy-based IS topic as the following: social network, social medium, IoT (Internet of Things), sentiment analysis, web ontology language, cloud service, sensor, and recommendation system.

We have analyzed two separate country maps for WoS and Scopus to investigate visible trends for the countries participating in the study of ontology- and fuzzy-based IS field (RQ-4). The results obtained from the WoS country map and the Scopus country map are highly similar. Summing up, the most frequently occurring countries are the following: China, Italy, Spain, India, and Taiwan. The recently contributing countries are as follows: Tunisia, Saudi Arabia, Egypt, Morocco, Malaysia, and Pakistan. The most co-occurring countries are the following: Italy and Spain, Taiwan and United Kingdom, United Kingdom and China, and Finland and Spain. From these findings, we can conclude that though the leading positions in the ontology- and fuzzy-based IS field belong to China, Spain, Italy, India, and Taiwan, the research is expanding to new countries. We also observed that the leading countries in the ontology- and fuzzy-based IS topic have strong international collaboration (through co-occurrence matrix). Thus, we can conclude that such international collaboration among countries allows to develop the topic of interest and increase international visibility.

Summing up, ontology and fuzzy logic contribute to IS topic by expanding traditional IS (MRQ) to be *intelligent IS*, which are applicable for solving complex, vague (fuzzy), and semantically rich (ontological) information collection, saving, processing, and sharing tasks in different application domains of various countries.

Another significant advantage and result of this SMS is the usage of two scientific databases WoS and Scopus. It allows us to observe larger effects with sufficient precision and make more general conclusions. Moreover, two separate country maps for WoS and Scopus allow us to determine that found visible trends for the countries participating in the study of the ontology- and fuzzy-based IS field is similar. Based on this, we can summarize that if we want to get a rough view of the field of interest (i.e., the ontology- and fuzzy-based IS field) in a short time, it may be sufficient to use one database, i.e., either WoS or Scopus. However, if we want to explore the field of interest in depth, it is better to use more data sources, e.g., both WoS and Scopus.

Based on the found answers to the defined research questions, we have proposed a better understanding of the ontology- and fuzzy-based IS field. It encourages further research directions for more effective and efficient IS development. However, some in-depth research methods, such as root cause analysis, co-citation, co-authorship, etc., will be necessary to apply in future research. Moreover, it would be useful to extend the current study to other scientific databases.

5. Conclusions

In this study, we have conducted systematic mapping study (SMS) with bibliometric analysis on the ontology- and fuzzy-based IS topic and achieved the keywords map, which provides a systematic view on the topic of interest and grasps the main ideas.

The analysis of the chronological distribution of the papers on the ontology- and fuzzy-based IS topic shows a significant rise of papers since 2003. This means that the topic of interest is relevant and widely explored.

According to the most occurring keywords analysis, we have identified the research focus in fuzzy ontology information systems, semantic web, and reasoning. The cluster analysis of the most occurring keywords map allows us to identify three main areas in ontology- and fuzzy-based IS as the following: user's needs, knowledge representation through fuzzy ontology for reasoning about concepts, and data framework development according to context and rules.

The moderately occurring keywords analysis allows us to identify different application domains of ontology- and fuzzy-based IS as the following: image recognition, scenario analysis, user's experience collection, decision making, information retrieval, semantic similarity, and data mining. Moreover, it allows us to view a variety of modern IS through collecting, saving, retrieving, sharing, and analyzing data in different forms, such as documents, images, scenarios, sensor data, user profiles data, etc. This shows the complexity and variety of the analyzed topic and the need to extend traditional IS to intelligent IS, capable of storing, retrieving, sharing, and analyzing semantically rich information.

According to APY, the moderately occurring keywords analysis shows possible evolution trends and future lines of in the ontology- and fuzzy-based IS topic as the following: social network, social medium, IoT (Internet of Things), sentiment analysis, web ontology language, cloud service, sensor, and recommendation system.

Notably, in this SMS, we have obtained quantitative results based on keyword mapping. To gain a new perspective and open up new research avenues in studying ontology-and fuzzy-based IS, researchers should also consider a systematic literature review with quantitative and qualitative research in the future.

The ontology- and fuzzy-based IS research is an emerging and multidisciplinary field. Therefore, its interdisciplinary research would be an interesting and meaningful future analysis from the aspects of knowledge integration and diffusion. Effective indicators should also be established to aid in interdisciplinary research assessment.

Another significant advantage and result of this SMS is the usage of two scientific databases, i.e., WoS and Scopus, which allows us to observe larger effects with sufficient precision and make more general conclusions. Moreover, the analysis of two separate country participation maps for WoS and Scopus shows similar trends for the countries participating in the study of the ontology- and fuzzy-based IS field.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/app11073003/s1, All data relevant to the research supplementary material is provided in: GitHub and as Supplementary material File S1 (the RISMA document).

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