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Information sciences 1968–2016: A retrospective analysis with text mining and bibliometric

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ABSTRACT

This study provides a comprehensive overview of the publications in *Information Sciences* (INS) from 1968 to 2016 inclusive, which encompasses the history of this journal from its inception. 7721 articles containing 153,606 references, which are the primary data source were downloaded from the Web of Science. It studies the most prolific authors, most cited authors, most representative articles, top influential institutions and the nationalities of the authors whose papers were published in the journal. The key contributors and INS articles that have made profound impact are highlighted on a basis of bibliometric and customized text mining techniques. CiteSpace, a data visualization software, was used to make the comprehensive analysis of the 153,606 citations and construct the co-citation network maps, which can illustrate salient patterns and emerging trends. This paper not only provides the important reference to future studies by exploring the structures and trends of INS publications, which have evolved over time, but also offers a demonstration of an effective analytical method for evaluating journal citation and co-citation data in the future.

1. Introduction

Information Sciences (INS) is one of the most influential journals in the field of computer science. According to its official website, it has a high impact factor and enjoys wide readership. The 2015 Journal Citation Reports indicate that INS ranked 8th out of 144 'computer science, information sciences' - categorized journals and gained an impact factor of 3.364. Since INS started in 1968, it has made important contributions to the overall development of the discipline of information science. Nearing its 50th anniversary, it is of interest to complete a retrospective analysis of the INS publications.

Bibliometric techniques [82] are the widely used methods by scholars for analyzing a particular journal to provide an overview of the research trends encountered in that journal. When the publications of a single journal are analyzed based on bibliometric techniques, this generates a broad picture of the journal, offering an inner structure pattern [67,83]. It can reveal the quality, thematic and citation landscape of the journal in any field. This type of studies appeared about three decades ago. Heck and Bremser [24] analyzed the author and institutional contributors of the *Accounting Review* and discovered the development paths of this journal. Naqvi [47] completed a comprehensive review on *Journal of Documentation*

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based on bibliometric techniques and 251 publications appeared on this journal between 1994 and 2003. Some important conclusions were obtained such as the co-authorship and the annual distribution of its publications. Van Fleet et al. [66] completed a brief overview of the *Journal of Management,* which is one of the flagship journals in the field of management. The journal's possible future was also identified in this study. Chen et al. [14] studied the inner structure, topic clusters and citation landscapes of *Data & Knowledge Engineering* publications (1985–2007). A series of thematic trends were identified through co-citation analysis and citation burst detection. Chan et al. [10] presented a retrospective analysis of the publications of *European Financial Management* from 1995 to 2008. Borokhovich et al. [7] introduced a citation-based method for evaluating the journal's influence, a case study about the *Journal of Banking and Finance* was presented to illustrate the proposed method. In commemoration of the anniversary 25th of *Knowledge-Based System*, Cobo et al. [15] made a bibliometric analysis of the publications of the journal between 1991 and 2014. Two emerging research topics such as ontology and social networks were clearly identified. Calma and Davies [9] proposed a citation network-based approach for analyzing all publications of *Studies in Higher Education* from 1976 to 2013. In this study, the most cited keywords, productive authors and cited authors were revealed. Merigó et al. [44] presented a comprehensive overview of the publications of the *Journal of Business Research* by using bibliometric techniques. The main factors that affect the development of this journal have been explored. The publications of *Academy of Management Journal* from 1958 to 2014 were investigated and discussed in detail by Calma and Davies [8]. The most influential contributors, most cited articles, most productive institutions and countries responsible for the publications were also identified.

The above research results show that the bibliometric analysis of a single journal has received great attention from scholars all over the world and a series of remarkable achievements have also been made across various disciplines. The reason behind this phenomenon is that this type of analysis can form a general picture of the corresponding journal, offer an accurate description that provides an insight that is beyond the superficial [67]. INS is an important and significant journal in the field of computer science. Bibliometric analysis on the publications of INS is very important and indispensable since it could provide useful information for all the stakeholders of INS.

The aim of this study is to reveal the inner structure pattern and citation landscape of INS publications from a general perspective. Conventional bibliometric methods and customized text mining techniques were performed by analyzing annual publication outputs, publications distribution by country and institution, the authorship productivity and collaboration pattern to provide an alternate perspective on the evolvement and development of INS. Moreover, the innovative approach such as document co-citation network analysis, research clusters identification and analysis, and references citation bursts detection are performed to offer insights into the research topics and trends evaluation over time from different perspectives, which is helpful for future research.

2. Characteristics of article outputs

The data source for this study is 7721 INS articles found in the Web of Science dating between 1968 and 2016 (until September 20, 2016; to be more precise) and the contained 153,606 references.

2.1. Annual comparative analysis of INS publications

In the first year of publication (1968), INS published only 6 papers. In the following 24 years after its foundation, the annual number of publications was less than 90. Since 1992, the publication volumes increased significantly and the annual publication was greater than 100 with an exception of 1995 (84). Fig. 1 (Upper half) shows the INS publication-year distribution in Web of Sciences dating back to 1968. As it can be seen, over half of the articles have been published from 2007 onward.

Fig. 1 (Lower half) shows the distribution of citations by years (1968–2016). Interestingly, there are two peaks present in this figure. The INS publications, which appeared in 1975 and 2007 received 9769 and 12,566 citations, respectively. After further investigation, the 9769 citations of the articles published in 1975 mainly attributed to the three milestone articles about linguistic variable and its applications authored by Zadeh [88–90]. These three articles received 5160, 2269 and 2260 citations, respectively, which account for 99% of 9769 citations. The falloff of citations since 2008 does not imply that no excellent contributions appeared since then, but rather that it always needs about one decade for articles to be widely cited and recognized [55].

The characteristics of INS publications for the past three decades (1987–2016) are summarized in Table 1. Various indicators are used to demonstrate the characteristics of the INS publications such as author number (AN), publication number (PN), reference number (RN), international-collaborative number (ICN), non-international-collaborative number (NICN), inter-institution-collaborative publication number (IICPN), single-institution publication number (SIPN), single authored publication number (SAPN) and multi- authored publication number (MAPN). It should be noted that some INS publications downloaded from the Web of Sciences do not provide valid information about the authors including affiliated institutions, affiliated countries and address. Therefore, there is a slight inconsistency in some aspects, such as PN and the sum of ICN and NICN.

Table 1 shows that there are 7044 articles published between 1987 and 2016 (until September 20, 2016). As far as international cooperation is concerned, the total number of non-international-collaborative articles was greater than that of the international-collaborative articles, with the amount of 4847 and 1645, respectively. Fig. 2 shows the change trends of

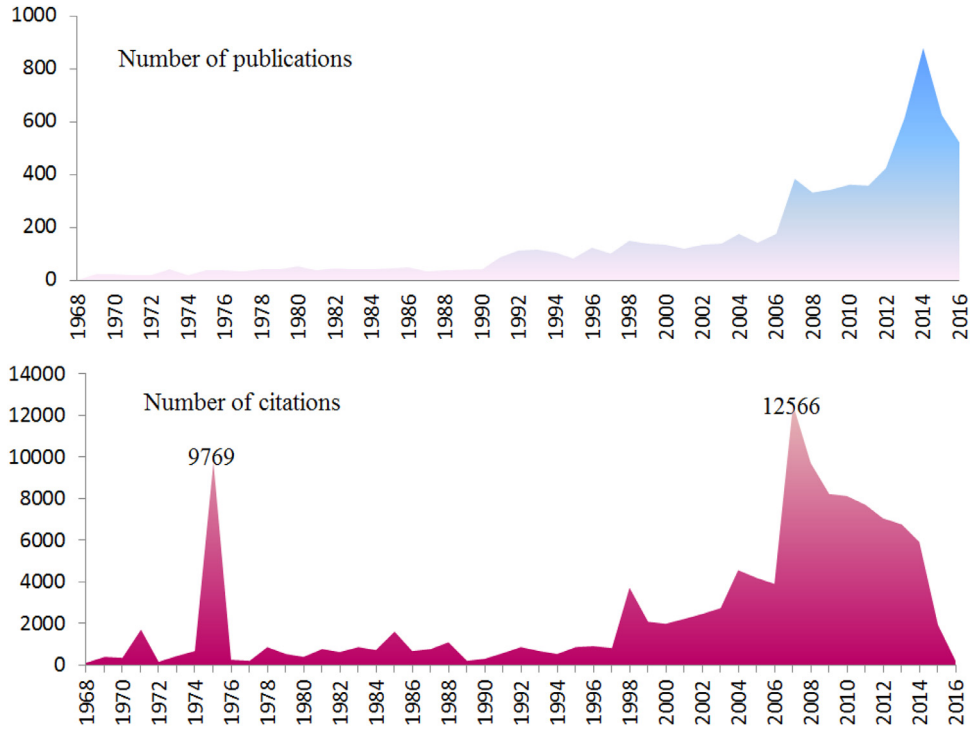


Fig. 1. INS publication (citations)-year distribution.

Table 1
INS publications characteristics from 1987 to 2016.

Year	PN	TC	AN/PN	RN/PN	TC/PN	NICN	ICN	SIPN	IICPN	SAPN	MAPN
1987	36	717	1.81	16.81	19.92	9	2	9	2	14	22
1988	39	1064	1.95	18.79	27.28	9	2	8	3	16	23
1989	41	188	1.98	19.07	4.59	13	0	12	1	18	23
1990	43	280	1.91	18.67	6.51	19	1	18	2	15	28
1991	87	542	1.77	18.63	6.23	37	2	32	7	37	50
1992	113	824	1.88	16.55	7.29	50	5	41	14	36	77
1993	116	664	2.00	16.45	5.72	47	4	40	11	38	78
1994	105	522	1.93	14.80	4.97	45	6	38	13	32	73
1995	84	848	1.89	18.08	10.10	24	0	18	6	28	56
1996	124	856	2.23	16.41	6.90	44	7	35	16	30	94
1997	104	802	2.32	20.73	7.71	40	6	34	12	22	82
1998	152	3689	2.24	18.57	24.27	125	17	98	44	42	110
1999	139	2073	2.19	19.25	14.91	112	26	82	56	37	102
2000	135	1982	2.17	19.27	14.68	115	17	85	47	41	94
2001	119	2215	2.42	20.19	18.61	91	26	61	56	30	89
2002	136	2424	2.43	17.51	17.82	102	33	70	65	33	103
2003	141	2723	2.50	18.71	19.31	111	29	72	68	27	114
2004	178	4578	2.56	19.40	25.72	137	41	82	96	27	152
2005	143	4184	2.23	23.17	29.26	115	28	83	60	26	109
2006	178	3909	2.46	25.53	21.96	138	39	94	83	42	136
2007	384	12,566	2.69	30.60	32.72	301	82	180	203	59	325
2008	330	9722	2.73	32.75	29.46	281	46	159	168	51	279
2009	342	8241	2.70	32.27	24.10	273	68	174	167	50	292
2010	360	8137	2.95	37.90	22.60	264	94	141	217	38	322
2011	359	7690	2.98	41.21	21.42	257	102	151	208	43	316
2012	423	7038	2.97	41.57	16.64	305	116	179	242	43	380
2013	612	6760	2.98	41.73	11.05	444	166	264	346	76	536
2014	876	5905	3.22	42.19	6.74	598	277	333	542	75	801
2015	624	1926	3.30	45.31	3.09	410	213	233	390	40	584
2016	521	183	3.42	45.00	0.35	331	190	171	350	34	487
Average	234.80	3441.73	2.43	25.57	15.40	161.57	54.83	99.90	116.50	36.67	197.90
Total	7044	103,252	72.81	767.12	461.93	4847	1645	2997	3495	1100	5937

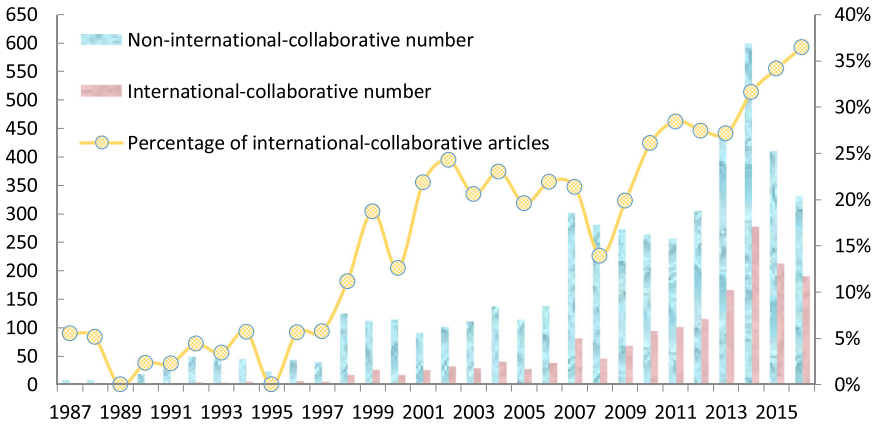


Fig. 2. International-collaborative and non-international-collaborative articles.

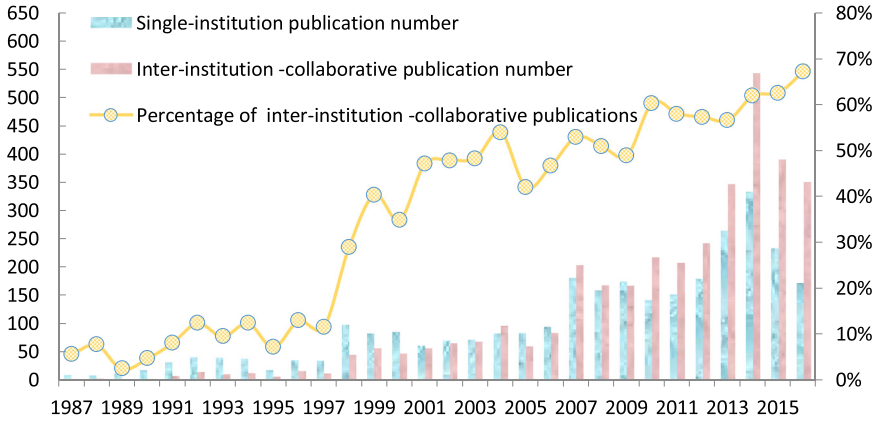


Fig. 3. Inter-institution collaborative and single-institution publications.

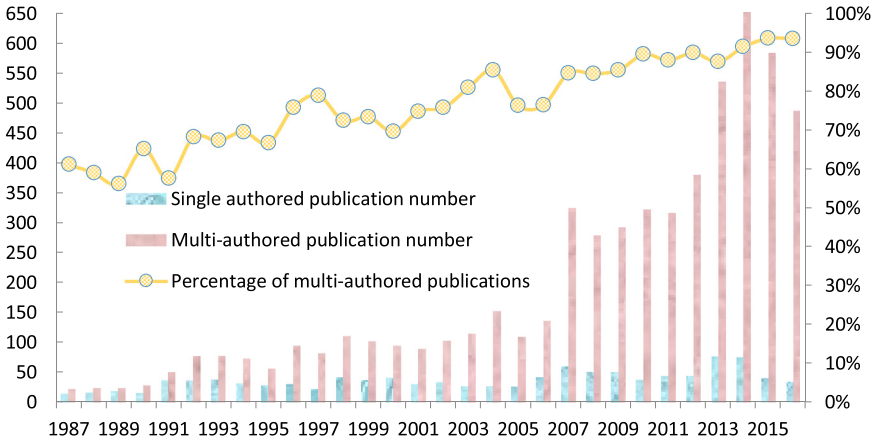


Fig. 4. Multi-authored and single-authored publications.

the international-collaborative and non-international collaborative publications, as well as the percentage of international-collaborative articles. We found that both international-collaborative and non-international collaborative publications increased in the past few decades. Regarding the international-collaborative articles, its percentage increased from 5% in 1987 to 36% in 2016 with fluctuations, indicating that the international communication and collaboration in information sciences has become increasingly important.

Figs. 3 and 4 present the institutional level of cooperation and the author level of cooperation, respectively. Based on which, the change trends of the inter-institution-collaborative as well as the collaboration between multiple authors are

Table 2
Numbers of Sources/Countries/Territories/ Institutions' papers citing INS publications.

Rank	Source	Total articles	Country/Territory	Total articles	Institution	Total articles
1	Information Sciences	4821	China	20,509	Chinese Academy of Sciences	891
2	Lecture Notes in Computer Science	2296	USA	7451	Islamic Azad University	857
3	Fuzzy Sets and Systems	2117	Taiwan	4614	University of Granada	780
4	Lecture Notes in Artificial Intelligence	1479	Spain	3932	Harbin Institute of Technology	582
5	Expert Systems with Applications	1420	India	3742	Northeastern University	567
6	Applied Soft Computing	1009	Iran	3208	Huazhong University of Science and Technology	549
7	Journal of Intelligent Fuzzy Systems	832	Canada	2447	Polish Academy of Sciences	502
8	Neurocomputing	804	England	2358	City University of Hong Kong	489
9	IEEE Transactions on Fuzzy Systems	743	South Korea	2114	Dalian University of Technology	469
10	Knowledge Based Systems	709	Japan	2085	Indian Institutes of Technology	449
11	Mathematical Problems in Engineering	639	France	2083	Tsinghua University	444
12	IEEE International Conference on Fuzzy Systems	633	Turkey	2006	Zhejiang University	421
13	Soft Computing	577	Australia	1892	Shanghai Jiao Tong University	420
14	Communications in Computer and Information Science	445	Italy	1865	Nanyang Technological University	416
15	International Journal of Intelligent Systems	431	Poland	1762	Xidian University	412

clearly demonstrated. For example, we can witness that more than 90% of the INS publications are multi-authored. The cooperation between different institutions is becoming more and more obvious and more than half of INS publications are completed by the authors who come from different institutions since 2007. This percentage increased to 67% in 2016.

2.2. Who is paying attention to INS

INS is a highly internationalized journal in the field of computer science. The readers and authors are distributed throughout the world. In the following, we investigate who is paying attention to INS. This summary mainly includes three parts, i.e., source, country/territory and institution. Table 2 shows the top 15 sources (journals and conference proceedings), countries/territories and institutions that have more publications citing INS articles. Detailed information is presented in Table 2.

In terms of the citing sources, INS itself is ranked in the first place with 2821 articles. *Lecture Notes in Computer Science* and *Fuzzy Sets and Systems* have followed with 2296 and 2117 articles citing INS publications. They were closely followed by *Lecture Notes in Artificial Intelligence* (1479), *Expert Systems with Applications* (1420), *Applied Soft Computing* (1009), *Journal of Intelligent Fuzzy Systems* (832), *Neurocomputing* (804), *IEEE Transactions on Fuzzy Systems* (743), and *Knowledge Based Systems* (709), respectively.

As far as the country/territory is concerned, the most publications citing INS articles are authored by Chinese scholars. USA, Taiwan, and Spain have 7451, 4614 and 3932 publications citing INS articles and are ranked in the second to the forth positions. India, Iran, Canada, England, South Korea and Japan complete the top 10 of this ranking list.

On the institution side, the Chinese Academy of Sciences from China has 891 publications cited INS articles and it is ranked first. Islamic Azad University from Iran and University of Granada from Spain exhibit a solid positions with 857 and 780 publications, respectively. Ten institutions from China (including one institution from Hong Kong) appear in the ranking list, which suggests that INS has aroused special attentions from scholars worked in the Chinese institutions. In other words, INS is highly recognized for its established scientific reputation.

2.3. The most cited articles published in INS

Since INS started being published, it has published a series of influential research results, which have a remarkable impact on information science and other fields. A list of 50 most cited INS articles are presented in Table 3. The top 4 most cited articles are all authored by Zadeh, the father of fuzzy set theory, and have received more than 1000 citations. The first three are all about the linguistic variable and its application to the field of approximate reasoning. They have laid an important foundation for the development of fuzzy theory and applications. Not surprisingly, Zadeh dominates this list with a total of seven and six among the top 10 ranks. Most articles in the ranking list are published before 2000 although some articles were published in the last ten years. A large percentage of the highly cited INS articles involve fuzzy set and rough set although some other themes also appear in the ranking list, including decision-making and information fusion. Besides the total number of citations (TC), some other indexes such as citations per year, author number (AN), reference number (RN), institution number (IN) and Country/territory number (CN) are also used to describe the highly cited articles.

Table 3 shows that half of the highly cited INS articles are single authored. A total of 17 and 7 articles were published by two and three authors, respectively. Moreover, only a single article was completed by four authors and no articles were

Table 3
The 50 most cited papers in INS according to WOS.

Rank	Most-cited documents	TC	Citations/ Year	AN	RN	IN	CN
1	Zadeh [88]	5160	122.86	1	61	2	1
2	Zadeh [89]	2269	54.02	1	60	2	1
3	Zadeh [90]	2260	53.81	1	60	2	1
4	Zadeh [85]	1100	23.91	1	25	1	1
5	Pawlak and Skowron [51]	782	78.2	2	342	1	1
6	Rashedi et al. [57]	744	93	3	36	1	1
7	Kwakernaak [35]	616	15.79	1	9	1	1
8	Zadeh [92]	575	47.92	1	58	2	1
9	Kryszkiewicz [37]	558	29.37	1	12	1	1
10	Yager [76]	519	14.42	1	12	1	1
11	Pawlak and Skowron [52]	506	50.6	2	98	1	1
12	Montanari [46]	502	11.67	1	14	2	1
13	Dubois and Prade [19]	486	15.19	2	84	1	1
14	Dubois and Prade [18]	460	13.53	2	38	2	1
15	Sugeno [63]	443	13.84	1	80	1	1
16	Pawlak and Skowron [53]	436	43.6	2	135	1	1
17	Karnik and Mendel [30]	430	26.88	2	22	1	1
18	Yager [77]	425	14.17	1	15	1	1
19	Zadeh [93]	420	46.67	1	110	1	1
20	García et al. [20]	402	57.43	4	54	2	1
21	Yao [79]	396	20.84	1	50	1	1
22	Yao [80]	384	20.21	1	27	1	1
23	Van den Bergh and Engelbrecht [65]	340	30.91	2	31	1	1
24	Lin and Wonham [40]	335	11.55	2	13	1	1
25	Kryszkiewicz [38]	332	18.44	1	15	1	1
26	Xu [71]	329	25.31	1	31	1	1
27	Zhu and Wang [98]	329	23.5	2	24	2	2
28	Wu et al. [69]	311	22.21	3	31	2	1
29	Aktaş and Çağman [2]	307	30.7	2	29	1	1
30	Diamond [16]	300	10.34	1	18	1	1
31	Herrera et al. [25]	286	13	3	25	1	1
32	Prade and Testemale [56]	280	8.48	2	37	1	1
33	Xu [73]	277	27.7	1	63	1	1
34	Xu [72]	268	20.62	1	36	1	1
35	Pawlak [50]	265	17.67	1	9	1	1
36	Mendel [42]	259	25.9	1	101	1	1
37	Kwakernaak [36]	259	6.82	1	4	1	1
38	Xu and Xia [75]	243	40.5	2	55	1	1
39	Wu and Zhang [70]	241	18.54	2	44	2	1
40	Akay and Karaboga [1]	240	48	2	55	1	1
41	Kahraman et al. [29]	238	17	3	53	2	2
42	Yang et al. [78]	234	26	3	29	2	2
43	Zadeh [86]	232	5.04	1	46	1	1
44	Merigó and Gil-Lafuente [43]	230	28.75	2	45	1	1
45	Bonikowski et al. [6]	228	12	3	13	1	1
46	Kosko [34]	228	7.35	1	24	1	1
47	Zhu [97]	220	22	1	38	3	2
48	Mi et al. [45]	217	16.69	3	21	3	1
49	Yao and Zhao [81]	212	23.56	2	52	1	1
50	Bellman and Giertz [3]	210	4.77	2	1	4	1

published by five or more authors. The RN of the associated highly cited articles vary widely. The maximum of RN of the highly cited INS articles is 342 and the minimum is one, with an average of 46.9.

There are 35 highly cited articles, which were completed by single institutions and the rest 15 articles were published by authors coming from the two or more institutions. International co-operation is a trend in academe, but it is not very common among the top 50 most cited INS articles. Only 4 articles were coming as a result of international-collaborative activities and the other 46 articles were completed without the cooperation between authors coming from different countries.

2.4. The most productive countries/territories

The authors of INS publications are distributed throughout the world. The geographical distribution of the 7721 INS publications covers more than 100 countries/territories. Table 4 presents the 15 most productive countries/territories of INS publications. Moreover, this analysis also focuses on the international co-operation of the publications. The numbers of non-international-collaborative publications (NIP) and international-collaborative publications (IP) with their corresponding total citations (TC) are also presented in Table 4.

Table 4
The 15 most productive countries/territories of INS publications.

Rank	Country/Territory	TP	NICN (Non-international-collaborative Number)				ICN (International-collaborative Number)			
			NIP	TC	TC/NIP	NIP (%)	IP	TC	TC/IP	IP (%)
1	China	1919	1237	20,811	16.82	64.46%	668	10,119	15.15	34.81%
2	USA	1568	773	19,486	25.21	49.30%	504	6959	13.81	32.14%
3	Taiwan	708	591	7771	13.15	83.47%	88	1433	16.28	12.43%
4	Spain	571	349	5347	15.32	61.12%	207	2492	12.04	36.25%
5	South Korea	411	274	2863	10.45	66.67%	127	1834	14.44	30.90%
6	India	344	205	2680	13.07	59.59%	69	1000	14.49	20.06%
7	Japan	340	184	2722	14.79	54.12%	83	941	11.34	24.41%
8	Canada	328	112	2790	24.91	34.15%	186	2720	14.62	56.71%
9	Australia	295	76	828	10.08	25.76%	196	1975	10.08	66.44%
10	England	293	92	1403	15.25	31.40%	197	3032	15.39	67.24%
11	Italy	268	163	1512	9.28	60.82%	92	1433	15.58	34.33%
12	Iran	194	121	2519	20.82	62.37%	70	1076	15.37	36.08%
13	Turkey	192	130	2948	22.68	67.71%	61	1644	26.95	31.77%
14	France	191	80	2376	29.70	41.88%	98	1023	10.44	51.31%
15	Poland	172	103	4538	44.06	59.88%	59	955	16.19	34.30%

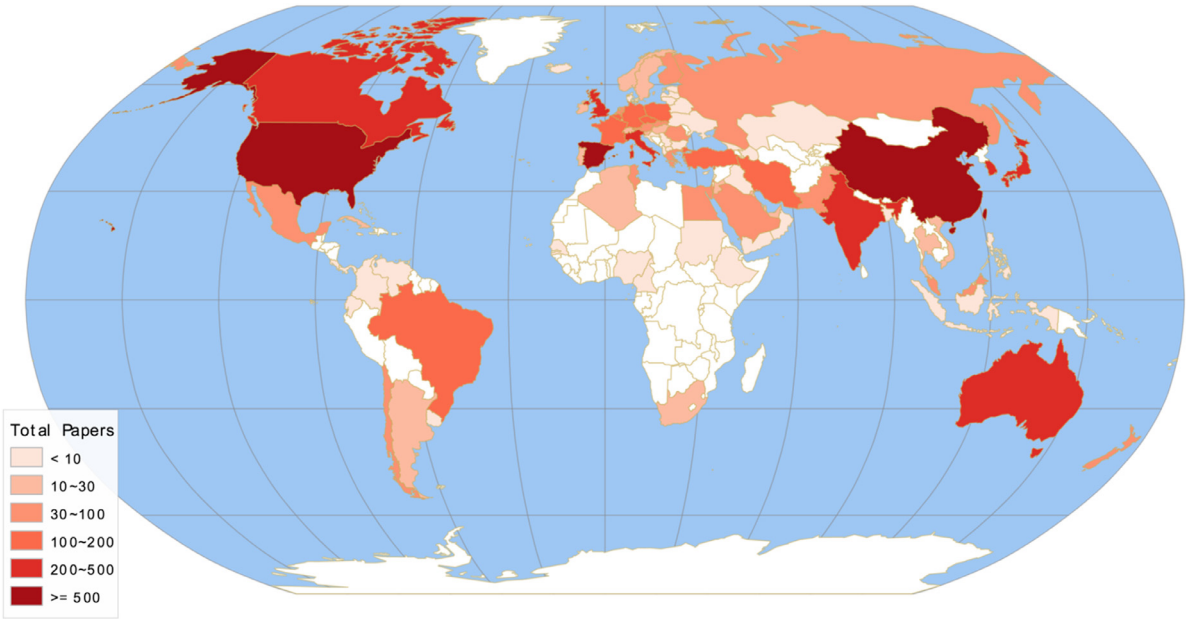


Fig. 5. Global geographic distribution of INS publications.

According to the total number of publications (TP), China leads with this regard with 1919 publications in total published in INS. USA and Taiwan appear in the second and third positions, respectively. Fig. 5 presents the geographic distribution of the INS publications. The map indicates that productive countries/territories are from North America, West Europe, East Asia, and Oceania.

Fig. 6 presents the cumulative percentage distribution of INS publications in the top 30 countries/territories. It suggests that the top 10 countries/territories have contributed the 69.17% of all the INS publications, the top 20 have contributed 86.11% and the top 30 92.56%.

Fig. 7 presents the changes in INS publication number of the top five countries/territories (China, USA, Taiwan, Spain and South Korea) between 1997 and 2016. It suggests the increasing dominance of China, particularly since 2007.

2.5. The most productive institutions and authors

In the following, the most productive institutions are investigated. Table 5 presents the top 15 most productive institutions in INS. Similar to the country//territory analysis, a series of indexes such as single institution publication number (SIP), the average citations of the single institution publications (TC/SIP), inter-institution-collaborative publication number (IICPN), and the average citations of the inter-institution- collaborative publications (TC/IICP) are used in this analysis. The Chinese Academy of Sciences and University of Granada are the leading institutions. Most of the top 15 institutions are

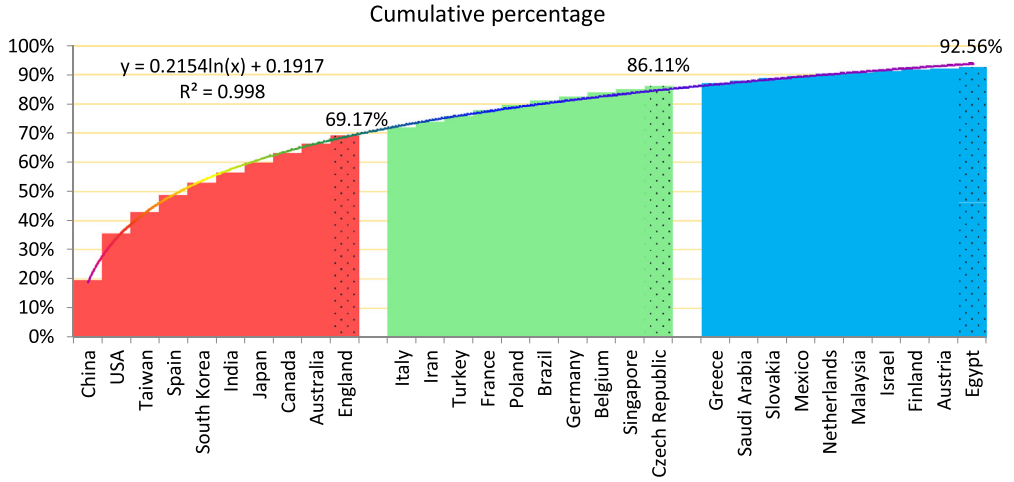


Fig. 6. INS publication cumulative percentage of top 30 countries/territories.

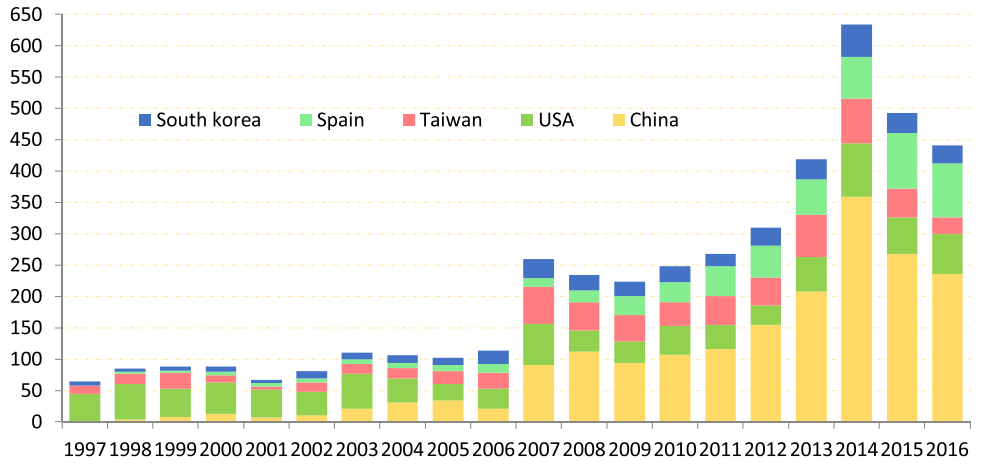
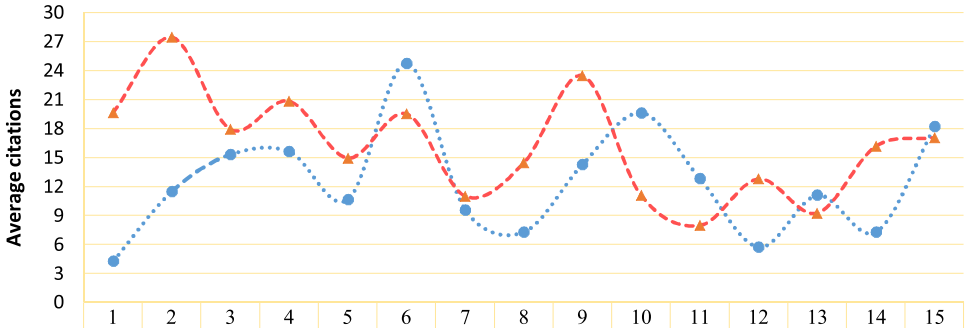


Fig. 7. INS publication distribution per year of top 5 countries/territories.

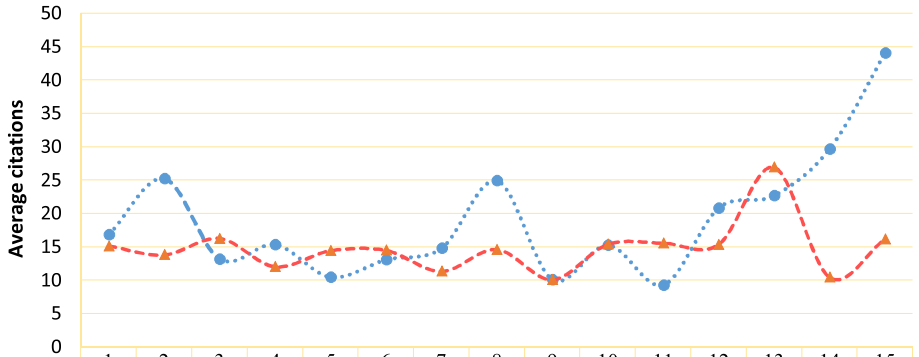
Table 5
The 30 most productive and influential institutions of INS publications.

Rank	*Institutions*	Country/Territory	TP	SIPN				IICPN			
				SIP	TC	TC/SIP	SIP (%)	IICP	TC	TC/IICP	IICP (%)
1	Chinese Academy of Sciences	China	120	9	39	4.33	7.50%	111	2180	19.64	92.50%
2	University of Granada	Spain	111	19	219	11.53	17.12%	89	2444	27.46	80.18%
3	City University of Hong Kong	China	96	9	138	15.33	9.38%	87	1559	17.92	90.63%
4	Indian Statistical Institute	India	77	28	438	15.64	36.36%	34	709	20.85	44.16%
5	National Chiao Tung University	Taiwan	76	29	310	10.69	38.16%	42	628	14.95	55.26%
6	Harbin Institute of Technology	China	74	19	471	24.79	25.68%	55	1074	19.53	74.32%
7	Xidian University	China	71	29	278	9.59	40.58%	42	462	11.00	59.15%
8	Shanghai Jiao Tong University	China	65	3	22	7.33	4.62%	62	895	14.44	95.38%
9	Hong Kong Polytechnic University	China	65	21	301	14.33	32.31%	44	1033	23.48	67.69%
10	Zhejiang University	China	63	14	275	19.64	22.22%	49	543	11.08	77.78%
11	Huazhong University of Science and Technology	China	63	18	231	12.83	28.57%	45	358	7.96	71.43%
12	University of Maryland	USA	62	32	184	5.75	51.61%	19	243	12.79	30.65%
13	Indian Institutes of Technology	India	61	24	267	11.13	39.34%	21	194	9.24	34.43%
14	Ghent University	Belgium	60	18	132	7.33	30.00%	41	663	16.17	68.33%
15	Northeastern University	USA	60	18	328	18.22	30.00%	42	716	17.05	70.00%



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
TC/SIP	4.33	11.53	15.33	15.64	10.69	24.79	9.59	7.33	14.33	19.64	12.83	5.75	11.13	7.33	18.22
TC/IICP	19.64	27.46	17.92	20.85	14.95	19.53	11	14.44	23.48	11.08	7.96	12.79	9.24	16.17	17.05

Fig. 8. Average citations of top 15 productive institutions.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
TC/NIP	16.82	25.21	13.15	15.32	10.45	13.07	14.79	24.91	10.08	15.25	9.28	20.82	22.68	29.7	44.06
TC/IP	15.15	13.81	16.28	12.04	14.44	14.49	11.34	14.62	10.08	15.39	15.58	15.37	26.95	10.44	16.19

Fig. 9. Average citations of top 15 productive countries/territories.

from China although there are some other universities from USA, Spain and Taiwan. Fig. 8 shows the average citations of the inter-institution-collaborative publications and single institution publications. Essentially, the average citation of the inter-institution-collaborative publications is higher than single institution publications. This suggests that co-operation between different institutions is essential to highly cited papers. However, this finding is not applicable to the international co-operation, which is illustrated in Fig. 9.

Several thousand of scholars published their research contributions on INS. Table 6 shows the most productive and influential authors of INS publications. A series of indexes is also applied to provide more exhaustive description about the authors. Besides the TP, TC and TP/TC, the SAPN, MAPN, IICPN, SIPN, NICN and ICN also appear in the ranking list. The institutions and countries/territories where the authors are currently working at are also included.

3. Bibliographic landscape

In this section, we mainly focus on the visualization of INS publications with the help of CiteSpace which is a freely available Java application designed for knowledge domain visualization [11,39,62]. This section mainly studies the networks of document co-citation and the keywords co-occurring for exploring the knowledge structure and development trends of INS.

3.1. Document co-citation network

Through the analysis of document co-citation network, the most influential researches and the intellectual base of INS publications can be explored. Fig. 10 shows the document co-citation network of INS publications. There are 1918 nodes and 13,737 edges in the mentioned network. The nodes shown in Fig. 10 represent the cited document of the INS publications and the top most cited ones are labeled with the first author and the year of publication. Moreover, the large-sized nodes denote the highly cited references.

Table 7 lists the top 8 most cited articles by INS publications. In other words, these articles are the most favorite ones of INS publications.

Table 6
The most productive and influential authors of INS publications.

Rank	Name	Institution	Country/ Territory	TP	TC	TP/TC	SAPN	MAPN	IICPN	SIPN	NICN	ICN
1	Yager, RR	Iona College	USA	48	2207	45.98	14	34	11	21	24	8
2	Herrera, F	University of Granada	Spain	42	2072	49.33	42	0	39	2	18	23
3	Mesiar, R	Slovak University of Technology	Slovakia	36	538	144.94	36	0	36	0	1	35
4	Chang, CC	Feng Chia University	Taiwan	34	614	18.06	30	4	24	10	28	6
5	Shi, P	University of Adelaide	Australia	33	648	19.64	33	0	33	0	0	33
6	Castillo, O	Tijuana Institute of Technology	Mexico	30	990	33.00	30	0	10	20	28	2
7	Pal, SK	Indian Statistical Institute	India	30	621	20.70	27	3	3	15	17	1
8	Inoue, K	Yamaguchi University	Japan	29	274	9.45	27	2	7	9	15	1
9	Kandel, A	University of South Florida	USA	27	236	8.74	25	2	10	15	20	5
10	Li, YM	Liaoning University of Technology	China	27	448	16.59	26	1	14	13	26	1
11	Pedrycz, W	University of Alberta	Canada	27	416	15.41	25	2	20	5	5	20
12	Melin, P	Tijuana Institute of Technology	Mexico	26	863	33.19	26	0	8	18	23	3
13	Bustince, H	Universidad Publica de Navarra	Spain	25	519	20.76	25	0	22	3	8	17
14	Davvaz, B	University of Yazd	Iran	25	753	30.12	21	4	17	8	9	16
15	Ruan, D	Ghent University	Belgium	23	1056	45.91	22	1	22	1	2	21
16	Chen, SM	National Taiwan University of Science & Technology	Taiwan	22	204	9.27	22	0	11	11	22	0
17	Jun, YB	Gyeongsang National University;	South Korea	22	720	32.73	19	3	18	4	8	14
18	Mendel, JM	University of Southern California	USA	22	1545	70.23	16	6	4	16	17	3
19	Xu, ZS	Sichuan University	China	21	2156	102.67	15	6	13	8	18	3
20	Xu, Y	Southwest Jiaotong University	China	20	514	25.70	20	0	17	3	9	11
21	De Baets, B	Ghent University	Belgium	20	248	12.40	20	0	11	9	10	10
22	Rosenfeld, A	University of Maryland College Park	USA	20	187	9.35	16	4	8	8	13	3
23	Herrera-Viedma, E	University of Granada	Spain	19	1019	53.63	19	0	18	0	9	9
24	Takanami, I	Yamaguchi University	Japan	19	167	8.79	19	0	2	6	7	1
25	Turksen, IB	University of Toronto	Canada	19	332	17.47	18	1	18	1	3	16
26	Wang, PP	Duke University	USA	19	106	5.58	12	7	8	7	12	3
27	Yao, YY	University of Regina	Canada	19	2176	114.53	13	6	6	13	13	6
28	Wang, W	Dalian University of Technology	China	18	334	18.56	18	0	14	4	7	11
29	Hu, QH	Tianjin University	China	17	660	38.82	17	0	11	6	16	1
30	Suganthan, PN	Nanyang Technological University	Singapore	17	588	34.59	17	0	13	4	4	13

Table 7
Top 8 most cited articles by INS publications.

Cited Frequency	Title	Authors	Year	Source
539	Fuzzy sets	Zadeh, LA	1965	Information and Control
263	Rough sets	Pawlak, Z	1982	International Journal of Computer & Information Sciences
245	The concept of a linguistic variable and its application to approximate reasoning—I	Zadeh, LA	1975a	Information Sciences
202	Toward a generalized theory of uncertainty (GTU)–an outline	Zadeh, LA	2005	Information Sciences
184	Rough sets – theoretical aspects of reasoning about data	Pawlak, Z	1991	Book
163	Genetic algorithms in search, optimization and machine learning	Goldgerg, DE	1989	Book
149	Particle Swarm Optimization	Kennedy, J and Eberhart, R	1995	Proceedings paper
131	Is there a need for fuzzy logic	Zadeh, LA	2008	Information Sciences

The first is a paper authored by Zadeh appeared on *Information and Control* in 1965 [84]. It discussed the meaning and content of fuzzy set, the fuzzy set theory frame was also proposed. According to the web of science, it has received more than twenty-two thousand times of citations. It made a large contribution to the development of information science and engineering technology. The second is the work of Pawlak [48], which proposed the theory of rough sets. Ranked in the third place is also the paper of Zadeh [88] introducing the concept of linguistic variable. The fourth paper [92], is devoted to the generalized theory of uncertainty. It presented a new direction to deal with uncertainty and information. The book titled "Rough sets-theoretical aspects of reasoning about data" [49] ranks the fifth. Another book titled "Genetic algorithms in search, optimization and machine learning" [23] ranks sixth. The second from the bottom is the conference proceedings paper [31], on particle swarm optimization. The last paper is the one by Zadeh [93].

All the above eight mentioned articles made great contributions to the development of INS. Moreover, there are four articles authored by Zadeh. It is interesting to note that only one article is co-authored and the rest seven articles are all single authored.

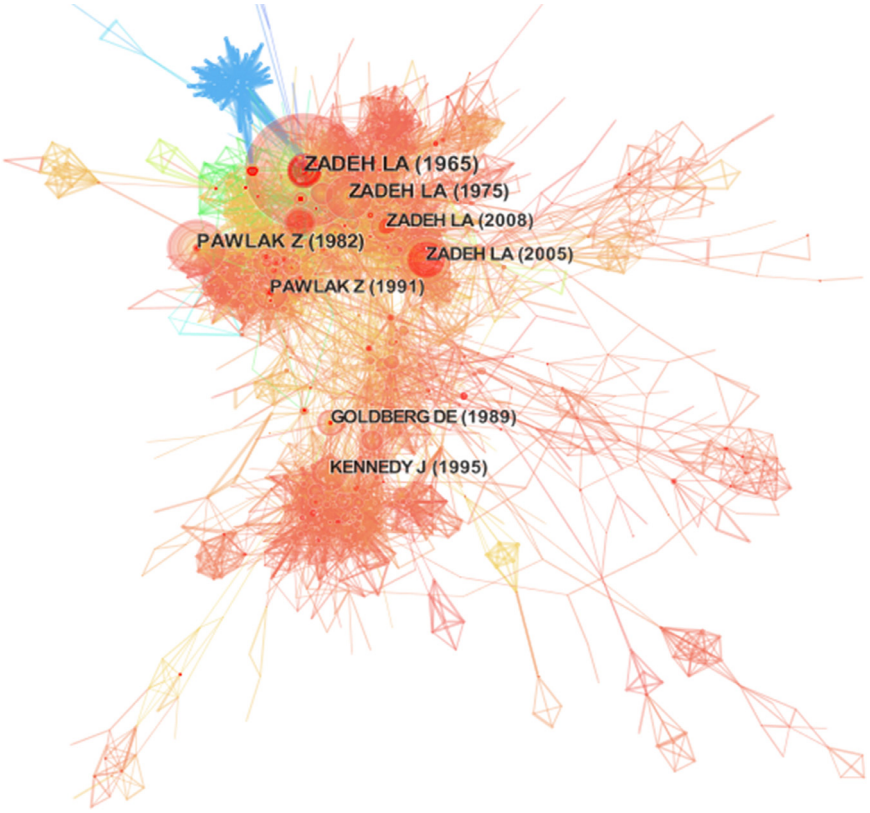


Fig. 10. The document co-citation network of INS publications.

Table 8
Top 11 clusters in INS publications.

Cluster ID	Size	Silhouette	Label (TFIDF)	Label (LLR)	Label (MI)	Mean (Citee Year)
0	257	0.716	Aggregation function	Intuitionistic fuzzy set	Backpropagation	2000
1	246	0.883	Differential evolution	Differential evolution	Ensemble strategies	2005
2	211	0.832	Rough set	Rough set	Combination	2004
3	183	0.841	Rule	Genetic tuning performance	Classe	2001
4	136	0.865	Preference relation	Group decision	Axiomatic approaches	2004
5	116	0.956	3d object recognition	3d object recognition	Evolution	2007
6	99	0.949	Infinity	Fuzzy system	Access structure	2006
7	49	0.991	Concept	Concept	Access structure	1966
8	48	0.993	Using spline	Using spline	Comparison	1968
9	44	0.972	Tv program	Tv program	Using complex network	2005
10	41	1	Petri	Petri net	Cellular automata	2007

3.2. Clusters detecting and analyzing

Based on CiteSpace, the research patterns and emerging trends of INS publications are explored. Fig. 11 displays document co-citation clusters and are labeled with title terms. Furthermore, these title terms are noun phrases extracted from the titles of articles which are cited by INS publications based on three specialized metrics—term frequency–inverse document frequency (TF*IDF), log-likelihood tests (LLR) and mutual information tests (MI) [28,32]. The font size is proportional to the size of the corresponding cluster [95]. In this instance, the whole document co-citation network is divided into 29 co-citation clusters. Table 8 visualizes the top 11 clusters.

Fig. 11 and Table 8 suggest that, *intuitionistic fuzzy set, differential evolution* and *rough set* form the three largest clusters. *3d object recognition* and *petri net* are the two youngest clusters, and *concept* and *spline* are the two oldest clusters. The minimum value of silhouettes is 0.716, indicating robust and meaningful cluster results.

The largest cluster (#0) has 257 members and a silhouette value of 0.716. It is labeled by *intuitionistic fuzzy set* by LLR, *aggregation function* by TFIDF, and *backpropagation* by MI. The most active citer to the cluster is the paper titled “some information measures for interval-valued intuitionistic fuzzy sets” [94]. By statistical analysis on the titles of these citers in

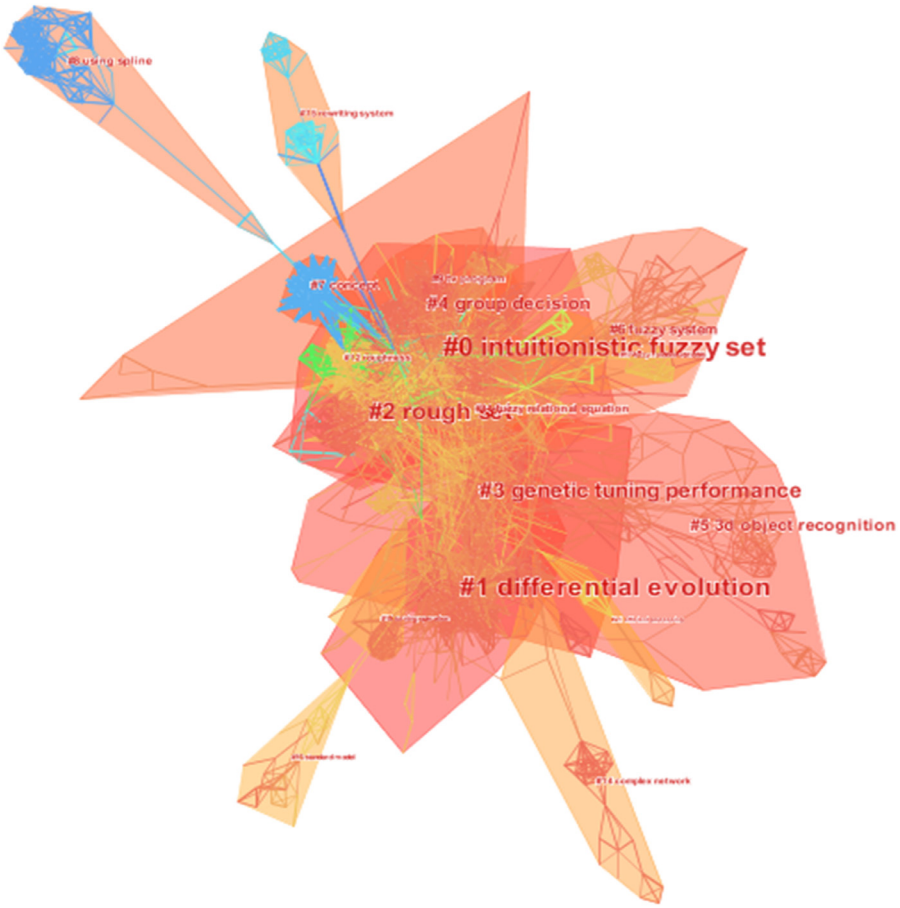


Fig. 11. Document co-citation clusters visualization.

the cluster #0, research results related to intuitionistic fuzzy sets and aggregation operators shaped the knowledge base of the field [74,96]. This cluster contains a series of interests, indicting interdisciplinary nature of intuitionistic fuzzy set and its use.

Fig. 12 presents a timeline visualization of the 22 clusters, based on which, their relationships can also be discovered. All the clusters are plotted horizontally. Fig. 12 shows a series of characteristics of each cluster, such as the length of its history, citation patterns, and the relationships between other clusters.

3.3. References with strong citation bursts

The research publications received the surging frequency of citations can be used to reflect the emerging trends in scientific research field. The citation burst suggests that the scholars have paid special attention on the corresponding publications [12,13]. Table 9 lists the top 30 references with the strongest citation bursts cited by INS publications.

Among the top 30 references with strongest citation bursts, Zadeh [84], titled “Fuzzy sets”, was on the top of the list with the burst strength of 78.8636. As discussed in the above section, this article published in *Information and Control* proposed the concept of fuzzy set. The second article [92] with strongest citation bursts outlined the approaches to uncertainty. It has the strongest citation burst, which started in 2006, the second year after publication, and ended in 2011. The next article is by Rosenfeld [58], the author who used concepts of fuzzy sets to algebra and introduced fuzzy subgroup of group.

4. Conclusions

In this study, we have provided a comprehensive perspective at the evolution and development of INS. Based on the use of the bibliometric methods and customized text mining techniques, we have analyzed the patterns of INS publications, geographic distribution, source journals, source institutes, international collaboration, inter-institutional collaboration, document co-citation network and the references citation bursts detection.

Table 9
Top 30 references with strongest citation bursts [4,5,17,21,22,26,27,33,41,54,59–61,64,68,87,91].

References	Strength	Begin	End	1968 - 2016
Zadeh [85]	78.8636	1984	2006	
Zadeh [93]	64.6994	2006	2011	
Rosenfeld [59]	40.2088	1984	2006	
Zadeh [94]	39.7484	2009	2011	
Pedrycz [55]	38.6873	2014	2016	
Zadeh [92]	35.772	1979	2006	
Shafer [61]	27.8959	1981	2006	
Zadeh [91]	26.4706	1978	2006	
Goldgerg [24]	21.1586	1994	2005	
Klir and Yuan [34]	21.1558	1997	2007	
Zadeh [90]	20.7614	1978	2007	
Zadeh [88]	19.4343	1975	2007	
Pawlak and Skowron [53]	19.0494	2007	2010	
Shannon [62]	19.005	1977	2006	
Hopcroft and Ullman [28]	18.8424	1969	2002	
Takagi and Sugeno [65]	18.7225	1993	2007	
Zadeh [89]	18.6961	1978	2007	
Liu [42]	17.9965	1984	2006	
Pawlak [50]	17.4327	1996	2009	
Dubois and Prade [18]	17.3673	1989	2005	
Pawlak and Skowron [54]	17.0184	2008	2010	
Pawlak and Skowron [52]	16.6318	2007	2010	
Zadeh [86]	16.4159	1975	2006	
Garey and Johnson [22]	16.0352	1984	2007	
Bernstein and Hadzilacos [5]	14.4951	1991	2003	
Goguen [23]	14.4497	1969	2001	
Blum and Hewitt [6]	14.3375	1977	2006	
Rosenfeld [60]	13.9016	1981	2004	
Wang and Yang [69]	13.8995	2010	2012	
Holland [27]	13.7631	1993	2009	

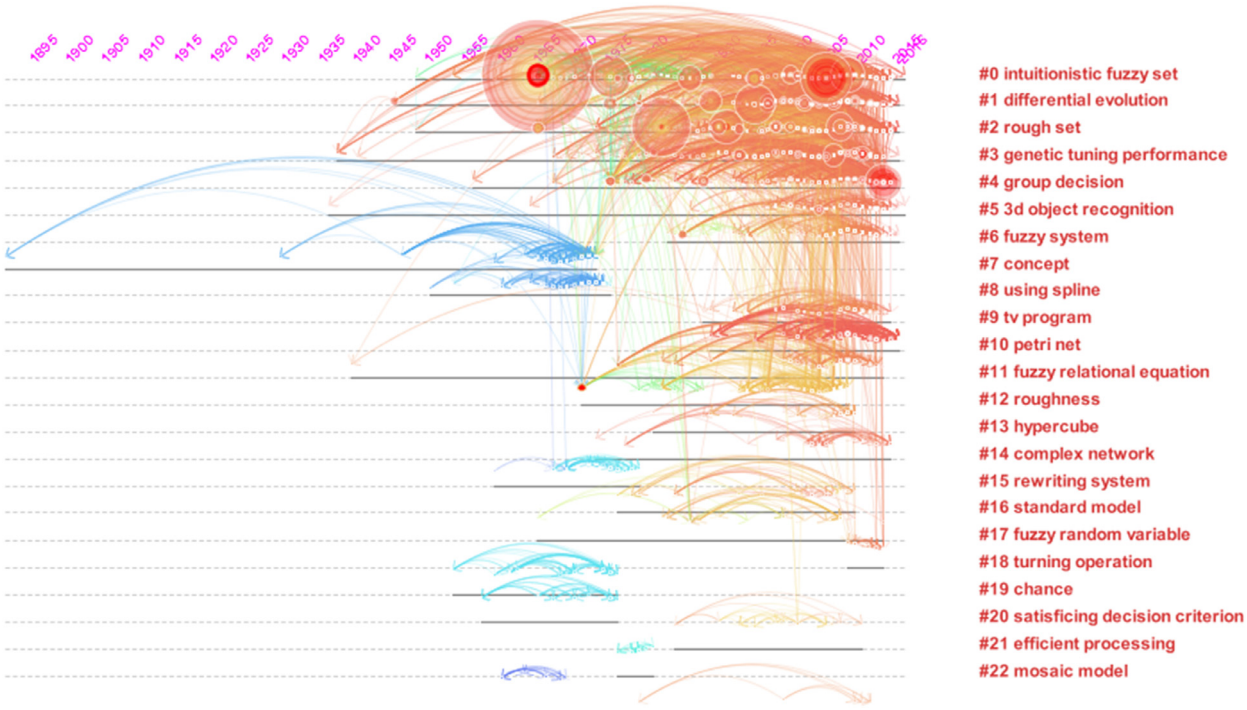


Fig. 12. Timeline view for document co-citation clusters.

INS itself, *Lecture Notes in Computer Science, Fuzzy Sets and Systems, Lecture Notes in Artificial Intelligence* and *Expert Systems with Applications* have the most articles cited the INS publications. China, USA, Taiwan, Spain, India are the most productive countries/territories. The productive countries/territories are those located in North America, West Europe, East Asia, and Oceania. Chinese Academy of Sciences from (China), Islamic Azad University (Iran), and University of Granada (Spain) are listed on the first three places according to the INS publication numbers reported at the institutions level.

A handful of authors coming from the productive countries/territories have published a large number of INS publications: the top 10 countries/territories contributed 69.17% and the top 20 contributed 86.11% of the total number of publications. Chinese authors dominate in the number of the INS publications, coming also with the largest number of citations. The research results have suggested that the co-operations among different institutions are essential to highly cited papers. However, this finding is not applicable to the international co-operation.

Zadeh dominates the most highly cited INS publications list with a total of seven and six among the top 10 ranks. A large percentage of the highly cited INS articles involves fuzzy sets and rough sets although some other themes also appear on the ranking list, including decision making and information fusion.

The terms *intuitionistic fuzzy set, differential evolution, rough set, Genetic tuning performance* and *Group decision making* form the five largest research clusters. *3d object recognition* and *petri net* are the two youngest clusters, and *concept* and *using spline* are the two oldest clusters.

In general, this study has explored the scientific publications pattern and citation landscape in INS journal. It provides an important reference for scholars to capture the current situations and influential trends in this field.

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