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Emerging trends and new developments in information science: a document co-citation analysis (2009–2016)

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Abstract Characterizing the structure of knowledge, the evolution of research topics, and the emergence of topics has always been an important part of information science (IS). Our previous scientometric review of IS provided a snapshot of this fast-growing field up to the end of 2008. This new study aims to identify emerging trends and new developments appearing in the subsequent 7574 articles published in 10 IS journals between 2009 and 2016, including 20,960 references. The results of a document co-citation analysis show great changes in the research topics in the IS domain. The positions of certain core topics found in the previous study, namely, information retrieval, webometrics, and citation behavior, have been replaced by scientometric indicators (H-index), citation analysis (citation performance and bibliometrics), scientific collaboration, and information behavior in the most recent period of 2009–2016. Dual-map overlays of journals show that the knowledge base of IS research has shifted considerably since 2010, with emerging topics including scientific evaluation indicators, altmetrics, science mapping and visualization, bibliometrics, citation analysis, and scientific collaboration.

Keywords Information science · Information visualization · CiteSpace · Co-citation analysis

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Introduction

In recent years, the amount of research literature in the information science (IS) domain has rapidly increased. New trends and topics in research emerge constantly. The discipline of IS has been the subject of numerous studies in the past that aim primarily to uncover its structure and dynamics. Citation analysis is the most commonly used method in identifying the knowledge structure and dynamic evolution of a specialty. As early as 1981, White and Griffith (1981) characterized the intellectual structure of the IS domain in terms of author co-citation analysis (ACA). In a 1998 ACA analysis of 12 core journals (1972–1995), White and McCain (1998) showed that core research topics of the IS domain included experimental retrieval, practical retrieval, citation analysis/bibliometrics, citation theory, scientific/scholarly communication, and user theory. In 2007, using document co-citation analysis (DCA) and ACA, Astrom found that the core research topics of the IS domain were information retrieval (IR), bibliometrics, information seeking and use/information behavior, and World Wide Web/webometrics between 1990 and 2004. In 2008, Zhao and Strotmann (2008a, b, c), using ACA, author bibliographic-coupling analysis (ABCA) and all-author-based ACA, determined the core research topics of the IS domain to be user theory, evaluative citation analysis, experimental retrieval, webometrics, science communication, visualization of knowledge domains, user judgments of relevance, image retrieval, and web searching. These three research studies all detected certain IS research topics, including IR, citation analysis/bibliometrics, and user theory. In addition, the results of detection by both White and McCain (1998) and Zhao and Strotmann (2008a, b, c) included science communication, while the results of both Astrom (2007) and Zhao and Strotmann (2008a, b, c) included webometrics. The difference is that Astrom's (2007) results included information seeking and use/information behavior, while those of Zhao and Strotmann (2008a, b, c) included visualization of knowledge domains, image retrieval, and web searching. Although the results revealed that the research topics of the IS domain are increasingly detailed, all identified specialties are manually labeled. Manually labeling a cluster is a cognitively demanding task. Different researchers may offer different interpretations.

Through a multi-perspective co-citation analysis, Chen et al. (2010) employed the information visualization tool CiteSpace to detect the evolution and representative figures of the IS domain from 1996 to 2008 (Period I). As a result, five clusters, 10 highly cited papers, and representative academic groups (or researchers) in the IS domain were identified. The present study aims to identify important changes in the structure of IS through its literature. By comparing the results of this research and the results of the previous research by Chen et al. (2010), emerging trends and new developments in IS from 2009 to 2016 (Period II) can be revealed.

This research makes several contributions. It reveals:

1. The knowledge structure of the IS domain since 2009 (Period II) and the newest research fronts.
2. The evolution of the emerging research topics in the IS domain since 2009 (Period II).
3. The evolution of the knowledge base in the IS domain with the changing research fronts.

Related work

Although most recent studies have focused on the structural aspects of co-citation networks, including clusters, multivariate factors, and principal components, a large part of research has turned to identifying the research topics of the knowledge domain by manual labeling rather than computer-aided automatic labeling.

Manually labeling identified specialties

Manual cluster labeling can accurately identify the knowledge structure of the IS domain. Consensus is that the IS domain can be divided into two camps, namely, information retrieval/seeking and citation/bibliometrics (White and McCain 1998). In recent years, researchers have also explored certain new research topics, such as the h-index, information behavior, science mapping, webometrics, patent analysis, open access, and bibliometric evaluation (Yang et al. 2016). Employing DCA and ACA, Astrom (2007) detected the research fronts of the IS domain research between 1990 and 2004 in two main aspects: information measurement and IR. Klavans and Boyack (2011) drew local and global maps using DCA and identified the difference between the IS knowledge structures in these two kinds of maps. Zhao and Strotmann (2008a, b, c, 2014) employed ACA to trace the knowledge structure of the IS domain over more than 30 years. However, most research identifying the research topics through ACA have employed manual cluster labeling (Persson 1994, 2001, 2010; White and McCain 1998; Zhao and Strotmann 2008a, b, c, 2014; Klavans et al. 2009; Jeong et al. 2014; Yang and Wang 2015; Yang et al. 2016). Moreover, increasingly more research has employed content analysis or co-word analysis to manually label the cluster results (Milojević et al. 2011; Aharony 2012; Tuomaala et al. 2014; Chang et al. 2015).

However, a major weakness of manual labeling is its subjectivity. Take the example here, when you discuss possibly more appropriate labels, to a large extent you rely on your own knowledge of the domain rather than derive your claim from the actual data. Computer generated labels are not meant to replace the human inspection of these labels. Rather, computer generated labels provide the basis for finding even better labels. In fact, CiteSpace provides a ranked list of candidate terms that characterize each cluster rather than provides a single term. Furthermore, the labeling in CiteSpace is drawn from the citing articles rather than from the cited references because the labeling should reflect the role of a cited reference in terms of how it is cited.

Computer-aided automatic labeling of identified specialties

The development of large-scale literature databases provides more complete databases for identifying the knowledge structure of specialties. With the application and spread of information visualization technology, researchers require a method to identify research topics automatically. There has been little research integrating natural language processing (NLP) and text-mining techniques with network-analysis techniques (Chen 2006, 2010). At present, automatic cluster labeling has been widely used in different research fields, such as emerging trends and new developments in recommendation systems (Kim and Chen 2015), regenerative medicine (Chen et al. 2012, 2014), and Sloan Digital Sky Survey research (Zhang et al. 2011).

Certain research in the IS domain has already employed the method of computer-aided automatic labeling, particularly the wide application of text-mining techniques and cluster algorithms in analyzing the structure of knowledge domains. Full-text analysis can effectively improve the accuracy and efficiency of analyzing knowledge structures. General steps include extraction of the subject terms in the full text, multidimensional scaling, clustering, and visualization. The process of clustering subject themes can greatly reduce the complexity of manually labeling cluster results and can allow for the evaluation and identification of cluster topics directly according to the subject terms of clusters (Janssens et al. 2006, 2008). Glenisson et al. (2005a, b) proposed combining text-mining and bibliometric techniques and effectively identified the structure of the scientific discipline based on automatic clustering of subject terms in the full text (Glenisson et al. 2005a, b; Jassens et al. 2005; Ibekwe-SanJuan 2009), employing automatic summarization and language models. They also conducted comparative analysis on the difference between the knowledge structures of the IS domain in 1996–2005 and 2006–2008 with the help of text-mining systems Term Watch and Pajek and identified emerging research topics such as the h-index, Google Scholar, and the Open Access model. All these results were generated automatically without using manual labeling of specialties or reading the publication titles (Ibekwe-SanJuan 2009). In 2010, Chen et al. combined co-citation analysis and the language model (NLP and automatic abstract) with CiteSpace and presented an analysis function of automatic label clustering. Chen et al. (2010) revealed the research fronts in the IS domain by 12 core journals from 1996 to 2008.

Definition and mapping of IS

Researchers have defined the IS domain specialty by selecting different journals from different perspectives, according to distinctive selection criteria, and have drawn the scientific knowledge map of this specialty (Table 1). Four methods are used in selecting journals. The first and most common approach is for researchers to select core IS journals as the analysis objects (Zhao and Strotmann 2014). This selection method was first used by White and McCain (1998). Using the 53 titles listed by the Journal Citation Report for the Social Sciences Citation Index (SSCI) in the category "Information Science and Library Science" in 1993, they selected 12 core IS journals to define this specialty. In 2003, White employed Pathfinder Networks to analyze the IS domain research topics again. Then, Zhao and Strotmann (2008a, b, c, 2014) used these 12 journals to trace the research topics of the IS domain in different periods during its 34-year development. Yang et al. (2016) further presented the method of author keyword coupling analysis (AKCA) and used these 12 journals to identify the IS domain research topics. These 12 journals were important IS journals based on the ranking of JCR impact factors in 1993. As time has passed, however, JCR impact factors have changed, and the JCR ranking of journals has changed accordingly. Second, researchers may take the impact factors in the category "Information Science and Library Science" in JCR for that year as the criterion. Yang and Wang (2015) selected 16 journals to define the IS domain according to the ranking of the 5-year mean impact factors in"JCR SSCI-2011". Astrom (2007) selected 21 journals for analysis according to the JCR ranking of impact factors in 2003. Third, researchers may select a certain number of journals according to expert judgments. For instance, some research selected 16 journals (Milojević et al. 2011; Nisonger and Davis 2005), 5 journals (Janssens et al. 2006, 2008), a single issue of *JASISIT* (Persson 1994; Jeong et al. 2014), or 580 highly cited papers (Chang et al. 2015). These selection methods are all highly subjective.

Table 1 Related research of the IS domain

Study	Period	Data	Analysis	Topics or sub-field
White and McCain (1998)	1972–1995	12core journals	ACA	Experimental retrieval, practical retrieval, citation analysis/ bibliometrics, citation theory, scientific/scholarly communication, user theory
White (2003)	1972–1995	12core journals	Pathfinder Networks	
VanDenBesselaar and Heimeriks (2006)	1986–2002	8core journals	Word-reference co-occurrences	IR, Scientometrics, web studies, other
Janssens et al. (2006, 2008)	2002–2004	5core journals	Full-text analysis and hybrid clustering methods	Bibliometrics, IR, webometrics and patent studies
Astrom (2007)	1990–2004	21core journals	DCA and ACA	IR, bibliometrics, information-seeking and use/information behavior, World Wide Web/ webometrics
Zhao and Strotmann (2008a)	1996–2005	12core journals	ACA, FA	User theory, evaluative citation analysis, experimental retrieval, webometrics, science communication, visualization of knowledge domains, userjudgments of relevance, image retrieval, web searching
Zhao and Strotmann (2008b)	1996–2005	12core journals	ABCA	
Zhao and Strotmann (2008c)	1996–2005	12core journals	All-author-based ACA	
Ibekwe-SanJuan (2009)	1996–2008	12core journals	Text mining	Automated IR, web-based studies, citation studies, vector space, open access, Google Scholar and h-index
Klavans et al. (2009)	2001–2005	12core journals	Coco analysis	Citation analysis, IR, information behavior
Chen et al. (2010)	1996–2008	12core journals	Multiple co-citation	H-index, interactive IR, academic web, IR, citation behavior
Klavans and Boyack (2011)	2000–2008	12core journals	DCA, Local and global map	Information-seeking behavior, scientometrics, co-citation analysis, citation behavior, computer-enhanced retrieval
Milojević et al. (2011)	1988–2007	16core journals	Word analysis	Library science, IS, information-seeking behavior, bibliometric and scientometrics, bibliographic instruction
Aharony (2012)	2007–2008	16core journals	Content analysis	Information technology, methodology and social IS
Jeong et al. (2014)	2003–2012	JASIST	Content-based ACA	Bibliometrics, including journal citation analysis, evaluation indicators, and visualization; webometrics; network analysis
Tuomaala et al. (2014)	1965–2005	42core LIS journals	Content analysis	Information storage and retrieval, scientific communication, library and information-service activities, information seeking

Table 1 continued

Study	Period	Data	Analysis	Topics or sub-field
Chang et al. (2015)	1995–2014	580 highly cited LIS articles	keyword, bibliographic coupling, and co-citation analyses	Information seeking, IR, bibliometrics
Yang et al. (2016)	2006–2015	12core journals	AKCA	IR, patent analysis, open access, mapping of science, bibliometric evaluation

Fourth, researchers may select a certain number of journals through JCA. Van Den Besselaar and Heimeriks (2006) selected 8 core IS journals through JCA based on JASIST.

On the whole, most existing research has taken different journals in the IS domain as the objects of analysis and analyzed the research topics and research fronts over different periods. However, these research results indicate that the research topics and specialties of the IS domain research have always been evolving and that the IS domain research topics have changed greatly over time (Zhao and Strotmann 2014). Comparing the research topics in the IS domain in Period I and Period II, this research aims to reveal the dynamic evolution of the knowledge structure of the IS domain from 1996 to 2016 ($\text{Period}_{\text{total}}$) and the trends of emerging research fronts in Period II. We employ an unusual method in selecting data, namely, the 2-step refinement procedure, which represents the methodological contribution to data collection by this research. This procedure has two steps: (1) Select the ten most representative journals in the IS domain in the past 8 years based on the journal co-citation analysis of three journals, including *JASIST*, *Scientometrics*, and *Journal of Informetrics*; (2) Collect the original research articles and review articles published by these ten journals.

Data and methods

Data collection

Most research takes 12 journals as the body of literature to define IS domain. However, we should bear in mind the following factors. First, the selection of these 12 journals primarily followed the paper by White and McCain (1998). IS has developed rapidly. After more than 20 years, current journals in this field and impact factors of different journals have changed greatly. For example, the *Journal of Informetrics*, launched in 2007, has rapidly become an established journal in recent years and has become an important part of the IS domain. Therefore, it becomes necessary to review the original 12 journals and also take new journals into account. Second, the subject category of *Information Science and Library Science* covers many disciplines, including information systems, IS, and library science. Even if we select journals based on their impact factors in the category *"Information Science and Library Science"* in JCR or the 5-year mean impact factors as the criterion (Yang and Wang 2015), the selected journals may not necessarily and sufficiently represent the IS field. For example, high-impact-factor journals mainly include information systems journals that we may wish to exclude. Third, our goal is to analyze co-citation patterns at the level of cited references. Simply selecting journals based on their impact factor may include journals that contain articles that are not relevant to the core of the IS field and exclude journals that contain individual articles relevant to the IS field. In other words, selecting journals based on their impact factor alone has limitations and these limitations can be resolved to an extent by the two-step selection method such that the relevance of a journal is derived not only from the impact factor alone but also from the relevance reveal from a journal co-citation analysis.

Therefore, this study attempts to select journals from another perspective: using an additional scientometric analysis as a preliminary study. In addition to the data chosen from the 12 core journals from 1996 to 2008, namely, Period I. we include core journals with a high influence on the IS domain from 2009 to 2016. In particular, we selected the largest cluster of IS journals through a JCA analysis of papers published in *JASIST*, *Scientometrics*, and *Journal of Informetrics.* General disciplinary journals and non-IS journals (such as *Science* and *Nature*) were removed from the selection. Finally, we obtained a set of 10 journals for the period from 2009 to 2016 (Period II) as the dataset. Out of the total number of articles and citations in Period II, *Scientometrics* is the highest, accounting for 30.18% of articles published, and 26.06% of total citations in the 10 journals. The subject of *Scientometrics* periodicals has a major impact on the research topics in the field of IS (Table 2). The year-by-year distribution of data collected in Period I and Period II is shown in Fig. 1. Currently, there are many sample selection methods based on the journal or paper or author or keyword level (Yang et al. 2016). However, this paper used a two-step method of JCA to choose and analyze 10 core journals: (1) articles from three of those, *JASIST, Scientometrics, and Journal of Informetrics,* can represent the most important and emerging research topics in current field of IS although they do not represent the total IS field (Milojević and Leydesdorff 2013 define the iMetrics using *Scientometrics, Journal of Informetrics and partly JASIST*). (2) According to JCA analysis, these three journals also have the high citation frequency, and thus can be treated as the knowledge basis for main research and emerging trends in IS, which also represent its knowledge structure. (3) To make the data more accurate and efficient, General disciplinary journals and non-IS journals (such as Science and Nature) in the JCA analysis had been removed.

This study establishes several literature databases in data processing. First, data derived from issues of these 12 journals in the IS domain published from 1996 to 2008 form dataset A, i.e., A = 1996–2008. Second, articles published in these 10 journals between 2009 and 2016 form dataset B, i.e., B = 2009–2016. The other four databases also contain literature data from different periods, i.e., A1 = 1996–2000, A2 = 2001–2005, A3 = 2006–2010, and A4 = 2011–2016. These datasets aim to better identify the recent changes to the literature in each period. Finally, this study integrates the data in all these periods, removes duplicates, and defines D_{total} as the total dataset of data in the period 1996–2016, i.e., D_{total} = 1996–2016. This database forms the primary source of this research. A summary of these datasets is shown in Table 3.

CiteSpace tools

As for the analysis tools, this research chooses the information visualization software CiteSpace. Although increasingly more science mapping systems and generic tools exist, few systems are particularly designed to generate a systematic review of a fast-moving and complex field, “especially with features to facilitate the detection and interpretation of emerging trends and transition patterns for analysts who are not domain experts.”CiteSpace is designed to support the visualization and analysis of scientific literature and has

Table 2 Source journals of the IS dataset (period II)

Journal	2009 (aticle/ reference)	2010 (aticle/ reference)	2011 (aticle/ reference)	2012 (aticle/ reference)	2013 (aticle/ reference)	2014 (aticle/ reference)	2015 (aticle/ reference)	2016 (aticle/ reference)	Total (aticle/ reference)
Scientometrics	192/3946	233/4191	226/5153	267/6166	262/7510	362/8912	365/11,544	379/11,600	2286/59,022
JASIS/JASIST	244/6825	243/7397	212/7523	215/8169	220/5489	215/7832	216/9694	230/4927	1795/49,856
Information Research an International Electronic Journal	76/1278	93/2179	82/1654	87/1873	130/3925	103/2020	94/3182	47/1182	712/17,293
Journal of Informetrics	36/1264	69/1593	67/1033	78/1682	103/2328	90/2360	84/2591	104/2944	631/15,793
Information Processing and Management	61/1433	60/1996	68/2278	82/3014	92/3487	52/2432	68/3023	75/3346	558/21,009
Journal of Documentation	74/2039	59/2074	68/2566	55/1981	55/1876	62/2593	70/3587	60/3139	503/19,855
Journal of Information Science	47/1837	50/2172	52/1847	43/1434	62/2369	66/2283	59/2436	59/2480	438/16,858
Library and Information Science Research	40/1268	45/1276	46/1596	41/1814	45/1851	31/1329	47/2191	33/1452	328/12,777
Research Evaluation	42/830	35/994	42/1108	37/1079	32/1132	30/1363	37/1532	32/1294	287/9332
ARIST	11/1819	13/2156	12/738	0/0	0/0	0/0	0/0	0/0	36/4713

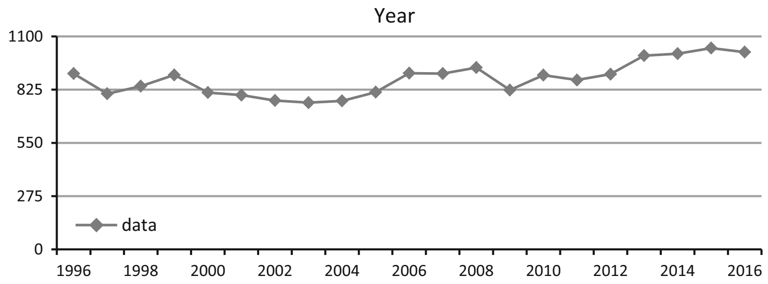

Fig. 1 Year-by-year distribution of literature data in period I and period II

Table 3 A summary of the datasets collected

Dataset	Duration	Results	Articles	Reviews	References	Authors	Institutions
A	1996–2008	10,926	6301	2584	58,218	8413	2872
B	2009–2016	7574	6499	128	20,960	9499	2955
A1	1996–2000	4226	2122	1158	20,232	3281	1328
A2	2001–2005	3903	2241	895	24,550	3520	1297
A3	2006–2010	4567	3322	812	28,322	5310	1918
A4	2011–2016	5851	5120	84	12,737	8033	2533
D_{total}	1996–2016	18,500	12,800	2712	79,178	17,912	5010

been widely used in scientometric studies (Chen and Leydesdorff 2014). The reasons for using DCA are as follows: (1) DCA focuses the connections between specific references, thus it provides more specific information than relations represented in ACA. In contrast, if two authors are co-cited in ACA, the nature of the connection is subject to a much wider range of plausible interpretations than DCA. This is the primary reason we chose to use DCA. (2) By comparing the results of this study and the results of the previous study by Chen et al. (2010). This study aims to identify important changes in the structure of IS through its literature. Chen et al. (2010) mainly used DCA to detect the research and emerging topics of IS. Therefore, this paper also adapted DCA to complete comparative analysis. (3) Zhao and Strotmann had used ACA to analyze ACA. And, based on ACA analysis, Yang and Wang (2015), Yang et al. (2016) further put forward ADCA and AKCA to make visual analysis about the knowledge structure of IS. Thus, through DCA analysis this paper can get corresponding results, and then compare and cross reference the results.

CiteSpace 5.0 R3, employed by this study, has two new functions: analyzing the labels of topic clustering year by year and analyzing journals via dual-map overlays. The first function can show the topic clustering year by year based on DCA and reveal the logic of the change in topics in topic clustering according to the time period. Journal dual-map overlay analysis provides a global visualizing map of literature growth on the academic level (Chen and Leydesdorff 2014). Through journal co-citation analysis, dual-map overlays can show the relationship between the distributions of the cited journals and citing journals in the literature and reveal the evolution of the distribution with time. In addition, employing burst detection to analyze the DCA results of burst documents can reveal the emerging research trends of the research knowledge field.

Results

Research topics: period I versus period II

To compare the changes in the IS domain research topics in Period I and Period II, we conducted cluster analyses on data in Period II based on DCA through a landscape view (Fig. 2). DCA in Period II formed 64 clusters in total, including 485 nodes and 2464 lines. Among these clusters, the sizes of 7 clusters are larger than 20, and the number of nodes of these 7 clusters accounts for 83.3% of the total. Therefore, this research takes the former 7 clusters for analysis (Table 4).

According to the cluster duration from the timeline view in Period II, #1 triple helix/scientific collaboration and #6 information behavior had already become notable research topics prior to 2000. #1 triple helix/scientific collaboration remained a notable research topic through 2016 and is still currently a hotspot and active research front. #6 information behavior remained a notable research topic until 2012. #2 citation performance emerged in 2002 and maintained a presence until 2015, with its mean year of the cluster being 2009. #3 citation count emerged in 2003 and maintained a presence until 2016, with a mean year of 2010. With the closest mean years, clusters #2 and #3 are the emerging fronts and hotspots in the current IS domain.

This study matches the cluster labels of Period I and Period II according to their semantic similarity in the following ways: (1) Perfect matching, i.e., the labels (or meanings) are exactly or almost the same; (2) Partial matching, i.e., the labels (or meanings) are very similar or closely connected; and (3) Mismatching, i.e., the labels (or

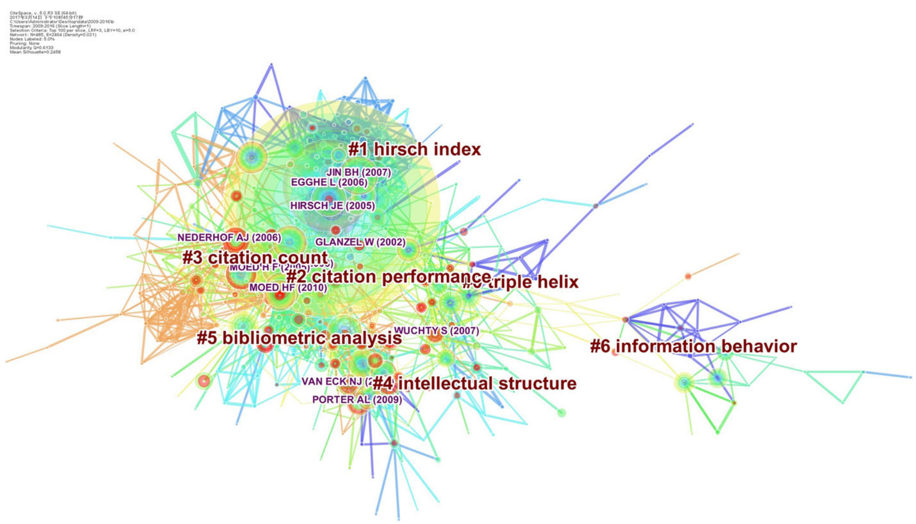

Fig. 2 A landscape view of the co-citation network, generated by top 100 per slice between 2009 and 2016 (Dataset B) (LRF = 3, LBY = 10, and e = 5.0)

Table 4 The seven largest clusters of co-cited references of the network (period II)

Cluster ID	Size	Silhouette	Label (LSI)	Label (LLR)
0	80	0.795	Scientific collaboration; cooperation	**Triple helix** (37444.13, 1.0E − 4); bibliometric analysis (37014.52, 1.0E − 4)
1	80	0.902	Hirsch index; universality	**Hirsch index** (208869.77, 1.0E − 4); new bibliometric indicator (142944.31, 1.0E − 4)
2	76	0.727	Citation analysis; biomedical research	**Citation performance** (43700.89, 1.0E − 4); citation distribution (40168.24, 1.0E − 4)
3	61	0.821	Social science; publication pattern	**Citation count** (39590.59, 1.0E − 4); social science (36357.98, 1.0E − 4)
4	47	0.767	Citation analysis; author co-citation analysis	**Intellectual structure** (21081.61, 1.0E − 4); information science (20633.05, 1.0E − 4)
5	33	0.803	Bibliometrics; international collaboration	**Bibliometric analysis** (24695.05, 1.0E − 4); science citation index (14880.67, 1.0E − 4)
6	27	0.987	Information; seeking behavior	**Information behavior** (21253.21, 1.0E − 4); information use (12666.64, 1.0E − 4)

meanings) are irrelevant or only slightly relevant. The results of these matchings are shown in Table 5.

H-index is a perfect matching of research topics in Period I and Period II. The h-index research topic ranked fifth in cluster size in Period I but became the top research topic in Period II. Since Jorge Hirsch (2005) proposed the h-index, is has drawn increasingly higher attention by researchers, among which Egghe (2006), Jin et al. (2007), Bornmann and Daniel (2008), Bornmann et al. (2011), and Waltman and Van Eck (2012a) have a relatively large influence. These research studies also promoted the rapid development of scientific evaluation indicators and their application. The core research topics in Period I, including citation behavior, academic web, interactive information retrieval, and information retrieval, all changed from 2009 to 2016 and no longer hold predominant positions.

Table 5 Matching of research topics: period I and period II

Items	Period I	Period II
Clusters	50	64
Selection	51.60%	83.3%
Total match	h-index (4.43%)	h-index (16.5%)
Partial match	Citation behavior (6.72%)	Citation performance (15.67%)
	Information retrieval (7.02%)	Information behavior (5.57%)
No match	Interactive information retrieval (22.9%)	Citation count (12.58%)
	Academic web (10.53%)	Triple helix/scientific collaboration (16.5%)
		Intellectual structure/citation analysis (9.69%)
		Bibliometric analysis (6.8%)

There are two pairs of partially matching research topics. The first pair is citation behavior in Period I and citation performance in Period II. Citation behavior focuses on the motivation and behavior in the process of citation and highlights the analysis of subjective citation. Citation performance evaluates the efficiency and influence of cited papers and belongs to objective scientific evaluation. These two topics are closely interrelated. Papers by Bornmann et al. (2011), Finardi (2013), Liu and Yang (2014), and Cimenler et al. (2014), published in the *Journal of Informetrics*, exerted great influence on the research into citation performance in Period II. The second pair is information retrieval in Period I and information behavior in Period II. Early research on information behavior focused on information retrieval (i.e., searching a context-specific system) by both researchers and users. Later research tended to focus on user behavior (Fidel 2012). The remaining research topics are mismatched. Among these research studies, citation count is the core research topic in Period II. Bornmann and Daniel (2008), Bornmann (2012), Fiala et al. (2015), Thelwall and Maflahi (2015), Thelwall (2016), and Zhao and Zhao (2016) focused extensively on this research topic. In addition, other research topics, including triple helix, intellectual structure, and bibliometric analysis, are also important in Period II.

The sizes of the clusters to which these research topics belong in these two periods differ greatly in their proportions in the complete cluster. #1 interactive information retrieval in Period I accounts for 22.9% of the total cluster, and #2 academic web accounts for 10.53%. The proportions of the remaining topics are all less than 8% each. The research topics in Period I are relatively centralized. The top four clusters in Period II account for 16.5, 16.5, 15.67, and 12.58% in terms of the total number of nodes. Their proportions are all above 10% and differ slightly from each other, showing the diversity of research topics in Period II. Moreover, two emerging research topics, citation performance (15.67%) and citation count (12.58%), both occupy relatively large proportions.

Overlay maps by DCA: period I and period II with period$_{total}$

To detect the evolutionary relationship of the research topics in Period I and Period II, we drew overlay maps using CiteSpace and a document co-citation network knowledge map using DCA in Period$_{total}$, Period I, and Period II. We overlapped the maps in Period I and Period II with the map in Period$_{total}$ (Figs. 3, 4 and 5). Period$_{total}$ (Fig. 3) has 1286 nodes and 4147 lines in total, with 288 clusters formed. Among these clusters, the sizes of 11 clusters (#0 to #10 contain 843 nodes) are accounting for 65.6% of the total nodes.

We evaluate the importance of related research topics according to the complexity and density of the overlays of the clustering networks. More complex networks of the node overlays imply greater influence on the research topics that these nodes represent in the overlay map, i.e., more complexity indicates that the research topic is a core topic. According to the network cluster map of Period$_{total}$, clusters #0 to #10 highlight the research topics for the entire period. These topics are identical to the research topics in Period I and Period II. However, it is notable that the networks of Period I and Period II in this network structure are clearly different and that the complete network is divided into two parts.

According to the overlap of the networks of Period I and Period$_{total}$ (Fig. 4), the densely overlapped clusters #0 information retrieval system and #2 academic website in Period I were the core research topics in Period I. Clusters #4 information behavior, #9 query log, and #10 digital libraries also overlapped, but they were not core research topics in Period I. According to the time period of node connection, clusters #5 Hirsch index and #6 author self-citation were the emerging research topics in Period I.

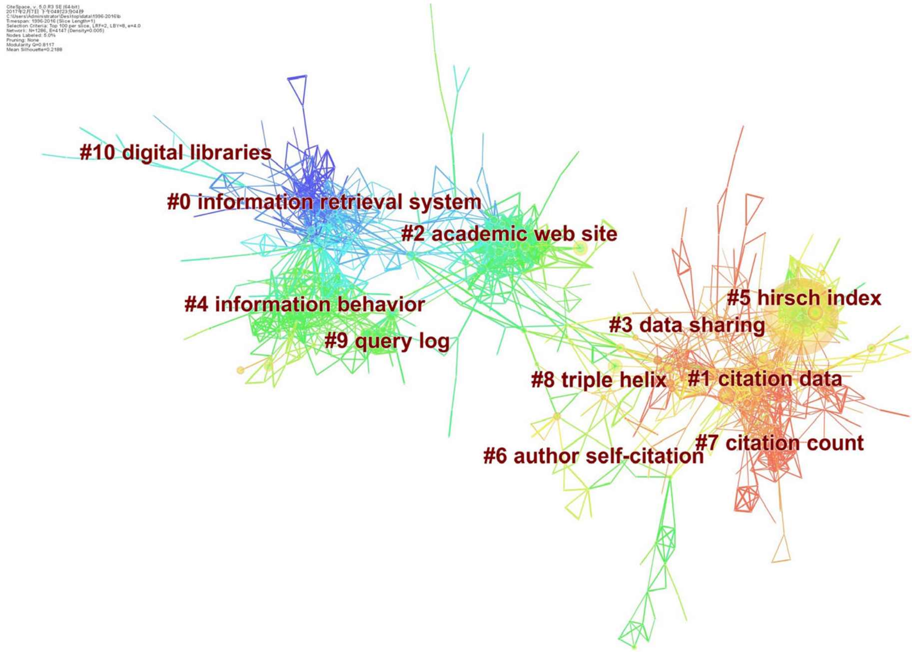

Fig. 3 Cluster map of the IS domain in period$_{total}$ (1996–2016)

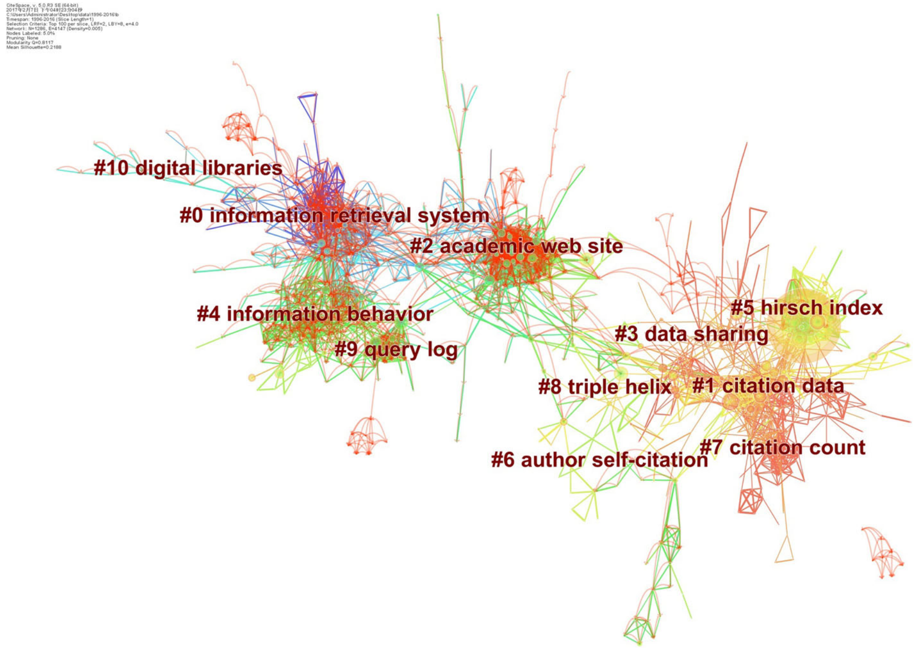

Fig. 4 Overlay cluster map in period I

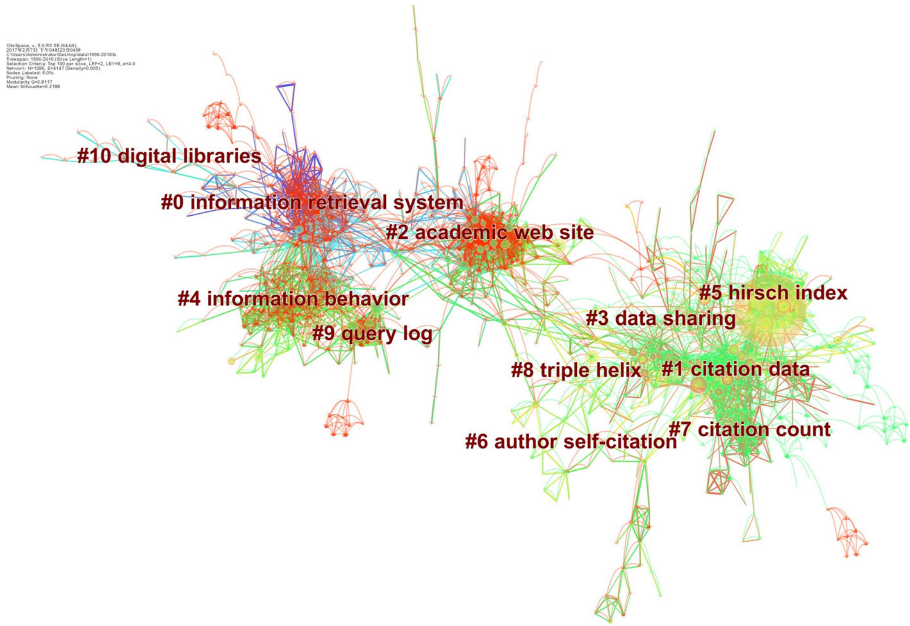

Fig. 5 Overlay cluster map in period II

According to the network overlap of the networks of Period II and Period$_{total}$ (Fig. 5), many nodes of Period II and Period$_{total}$ overlapped in almost every region of the network. Overlap of nodes in cluster #5 Hirsch index notably increased, and this topic became the core topic in Period II. New clusters in Period II, including #7 citation count, #1 citation data, #3 data sharing, and #8 triple helix, also became research topics, with #7 citation count being the emerging research topic in Period II. Note that after overlapping Period I and Period II with Period$_{total}$, the overlaps of the network nodes of #4 information behavior are similar. However, #4 was the core topic of Period I but not Period II, showing that #4 information behavior was a potential trend in Period I.

Evolution of research topics year by year: period II

To reveal the origins of the evolution of research topics in Period II, we employed the year-by-year cluster function of CiteSpace5.0R3 to draw the timeline map of the cluster of research topics year by year (Fig. 6). Based on terms identified by latent semantic indexing, the new version of CiteSpace provides a new function of generating labels of a cluster year by year (Chen 2017). This research focuses primarily on the seven largest clusters.

The timeline view of the cluster of research topics year by year reveals the evolution of the IS research topics in Period II. The duration of a cluster is also interesting. Cluster #0, as the largest cluster, is still active after a 16-year period, and clusters #2 and #3 span a period of 14 years (Table 6).

The two biggest clusters, #0 triple helix and #1h-index, were the core research topics in Period II. The year-by-year cluster label and topics of these two clusters are similar. The cluster label of #0 triple helix remained scientific collaboration (except for 2015) and the

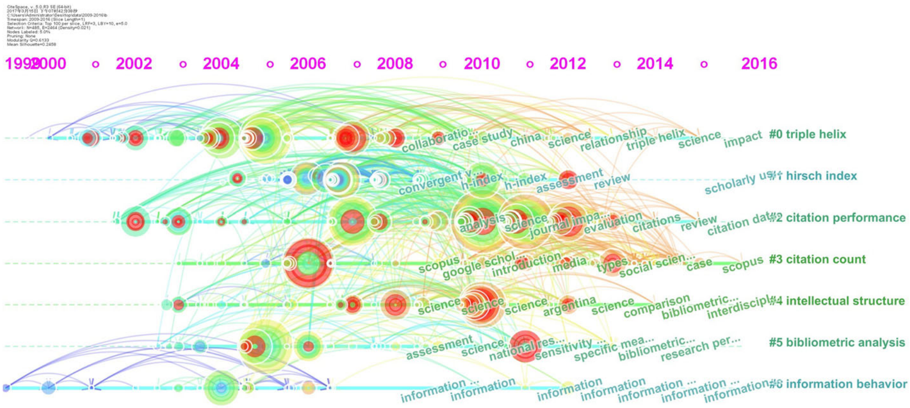

Fig. 6 Timeline view of research topics year by year (period II)

Table 6 Temporal properties of major clusters

Cluster ID	Size	From	To	Duration	Median	Sustainability	Activeness	Theme
0	80	2000	2015	16	2007	+++++	Active	Scientific collaboration
1	80	2005	2012	8	2008			H index
2	76	2002	2015	14	2008	++++	Active	Citation performance
3	61	2003	2016	14	2009	++++	Active	Citation count
4	47	2003	2014	12	2008		Inactive	Intellectual structure
5	33	2003	2013	11	2007		Inactive	Bibliometric analysis
6	27	1999	2012	14	2005	++++	Inactive	Information behavior

cluster label of #1 H-index remained the h-index (except for 2016). The year-by-year cluster labels of two emerging research topics, #2 citation performance and #3 citation count, changed greatly. For example, the cluster label of #3 citation count changed from Google Scholar to science, research performance, webometrics, citation analysis, publication and then to bibliometrics, showing great uncertainty of emerging research topics, no long-lasted focus of research, and substantial changes in research direction (Fig. 7).

According to cluster labels of the research topics year by year (Fig. 8), the h-index ranks the first in the frequency of occurrence, followed by scientific collaboration, citation analysis, and bibliometric analysis. These results show that these research topics performed well in their own periods and became the focus of researchers. Moreover, scientific evaluation, dominated by h-index research, became the largest research topic. Repetition of the cluster labels of different research topics year by year demonstrates that substantial overlaps exist among different research topics and that these research topics are interrelated with high mobility of knowledge.

Fig. 7 Burst nodes of the clusters of citation performance and citation count

Cluster	#0 triple helix	#1 h index	#2 citation performance	#3 citation count
2009	research collaboration	hirsch index	classification	google scholar
2010	scientific collaboration	hirsch index	impact factor	science
2011	research performance	hirsch index	bibliometric indicator	research performance
2012	scientific collaboration	hirsch index	citation analysis	webometrics
2013	scientific collaboration	hirsch index	publication	questionnaire
2014	scientific collaboration	———	publication	citation analysis
2015	nanotechnology	———	collaboration	publication
2016	collaboration	social science	citation analysis	bibliometrics

Fig. 8 Distribution of the research topics in period II year by year (#0–#3)

Emerging trends of the IS domain

The burst rate of a document can reflect the burst of citation of this document within a certain specialty in a certain period. A stronger burst shows higher attention to this research topic and can better exemplify the research front in this period. The research fronts of the IS domain in each period can be detected through analyzing literature with high burst rates. Based on DCA in Period II, this research extracts burst references from its time of burst until 2016 using CiteSpace (Table 7). This time interval is depicted as a blue line. The time period in which a reference was found to have a burst is shown as a red line segment, indicating the beginning year and the ending year of the duration of the burst. Nine of the 34 burst references (26.5%) were published in Period I. Furthermore, when we selected the top 5 references with the strongest burst, four of these burst references were published in Period II. All references have a burst time from 2014 to 2016. In terms of time period, these high-burst papers were published predominantly in 2010 (7 papers), 2011 (6 papers), and 2012 (6 papers). In terms of the literature source, these papers were published primarily by *JASIST* (9 papers), the *Journal of Informetrics* (6 papers), and *Scientometrics* (6 papers). The main authors of these papers include Bornmann (3 papers), Waltman (3 papers), and Bornmann and Waltman as co-authors.

Current research fronts in the IS domain include scientific evaluation, bibliometrics, citation analysis, scientific collaboration, knowledge mapping and visualizations, andaltmetrics. Emerging scientific evaluation research promoted by the h-index in 2005 is

Table 7 References with the most recent bursts until 2016

References	Year	Strength	Begin	End	2009–2016
Bar-Ilan (2008)	2008	4.7132	2013	2016	
Rafols and Meyer (2010)	2010	3.2787	2013	2016	
Albarran and Ruiz-Castillo (2011)	2011	3.6647	2013	2016	
D'Angelo et al. (2011)	2011	3.8012	2013	2016	
van Eck and Waltman (2009)	2009	6.2108	2013	2016	
Wagner et al. (2011)	2011	7.6285	2013	2016	
De Bellis (2009)	2009	3.9472	2013	2016	
Waltman and Van Eck (2012a)	2012	7.0612	2013	2016	
Bornmann (2013)	2013	7.8753	2014	2016	
Liu et al. (2005)	2005	7.2257	2014	2016	
Wang et al. (2013)	2013	5.1293	2014	2016	
Franceschet (2010)	2010	4.7865	2014	2016	
Wuchty et al. (2007)	2007	9.8841	2014	2016	
Priem and Hemminger (2010)	2010	4.7865	2014	2016	
Glanzel and Schubert (2005)	2005	6.0364	2014	2016	
González-Pereira et al. (2010)	2010	2.7611	2014	2016	
Thelwall et al. (2013)	2013	12.3531	2014	2016	
Waltman and Van Eck (2012b)	2012	9.9396	2014	2016	
Bornmann (2012)	2012	8.1991	2014	2016	
Waltman et al. (2012)	2012	16.8502	2014	2016	
Rafols et al. (2010)	2010	2.5042	2014	2016	
Bornmann et al. (2011)	2011	7.3185	2014	2016	
Engels et al. (2012)	2012	8.1991	2014	2016	
Weingart (2005)	2005	6.0364	2014	2016	
van Eck and Waltman (2010)	2010	12.6201	2014	2016	
Gorraiz et al. (2013)	2013	4.4439	2014	2016	
Stirling et al. (2007)	2007	2.9632	2014	2016	
Li et al. (2010)	2011	8.6321	2014	2016	
Eysenbach (2011)	2011	7.8753	2014	2016	
Blondel et al. (2008)	2008	13.0437	2014	2016	
Nederhof (2006)	2006	3.6384	2014	2016	
Chen et al. (2010)	2010	5.4163	2014	2016	
Wouters and Costas (2012)	2012	7.3336	2014	2016	
Sonnenwald (2007)	2007	6.4384	2014	2016	

currently the main research front. Research originally focusing on methods and theories (such as the h-index and g-index) has turned to the current application of evaluation indicators for the ranking of institutions (universities and institutions), scientific research measures, and academic prestige of journals. Traditional research topics in the IS domain, including bibliometrics, citation analysis, and scientific collaboration, remain as the current research fronts. Under the influence of scientific evaluation research, bibliometric research has turned from traditional bibliometric analysis to the current research of bibliometric indicators (citation counts, citation performance, research performance evaluation, author influence indicators, and journal cluster indicators); research fronts of citation analysis, such as author name disambiguation; and research fronts of scientific collaboration, such as triple helix theory, international scientific collaboration, and the influence of author collaboration on the quality of papers. Science mapping and information visualization, which have become hotspots in the IS domain since the start of the 21st century, remain as current research fronts, focusing in particular on information visualization tools and automatic word extraction algorithms such as CiteSpace, VOSviewer, and automatic topic identification algorithms. Altmetrics, put forward by Jason Priem in 2010, has already become the most promising research front, centering on the research into the academic influence of social networks, including Twitter and blogs. According to the trend of the citation of burst documents, these topics will continue to be the research fronts in the IS domain for the next several years.

New changes in the knowledge base by dual-map overlays

We drew the journal dual-map overlays for the periods 1996–2000, 2001–2005, 2006–2010, and 2011–2016 using the “JCR Journal Maps” function of CiteSpace (Figs. 9, 10, 11 and 12). These overlays reveal the evolution of the knowledge base of the IS domain by comparing the changes of citation structure of IS journals in each period.

The knowledge base of the IS domain research from 1996 to 2000 contains 15 specialties. The mainstream basic specialties are #1 SYSTEM, COMPUTING, COMPUTER and #7 PSYCHOLOGY, EDUCATION, SOCIAL. The mainstream basic specialties did

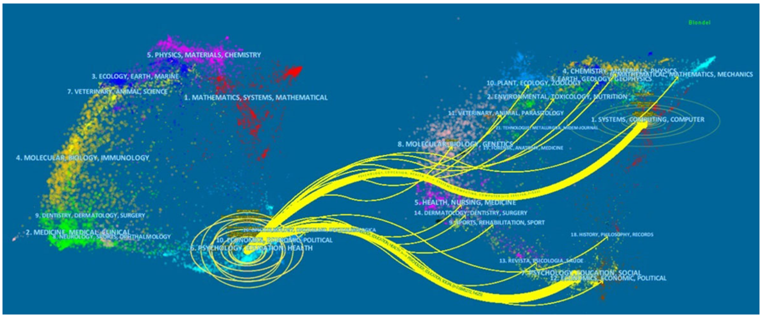

Fig. 9 1996–2000

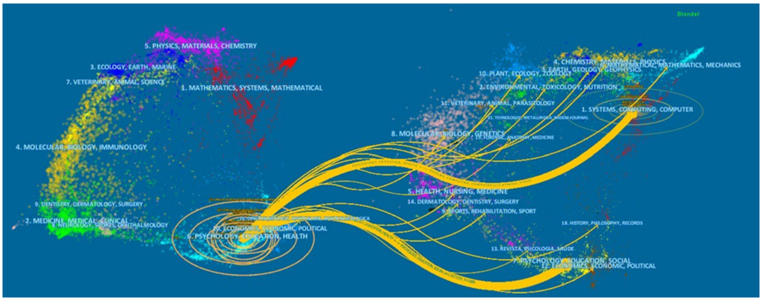

Fig. 10 2001–2005

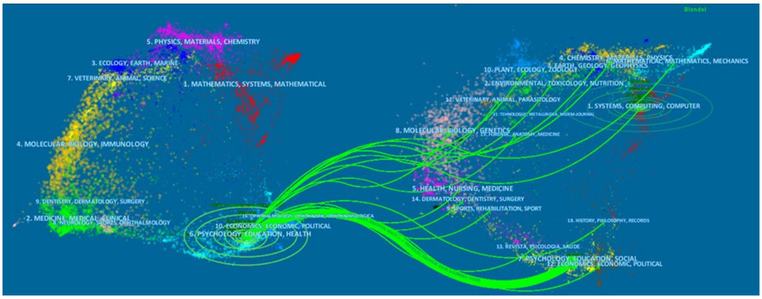

Fig. 11 2006–2010

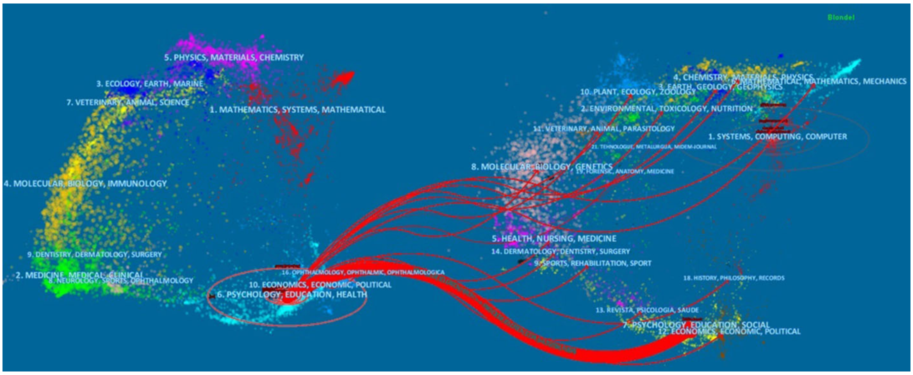

Fig. 12 A dual-map overlay of the information science literature (2011–2016)

not change from 2001 to 2005, while the total number of specialties changed to 16, including the new specialty #19 FORENSIC, ANATOMY, MEDICINE. Compared to the last period, the basic specialties from 2006 to 2010 remained the same. However, the mainstream specialties and basic specialties all changed from 2011 to 2016. The mainstream specialties changed from #1 SYSTEM, COMPUTING, COMPUTER and #7 PSYCHOLOGY, EDUCATION, SOCIAL 2006–2010 to #1 SYSTEM, COMPUTING, COMPUTER; #7 PSYCHOLOGY, EDUCATION, SOCIAL was no longer a mainstream specialty. The number of basic specialties turned to 17 with the new specialty #21 TEHNOLOGUE, METALURGUA, MIDEM-JOURNAL.

Conclusions and discussion

In conclusion, we selected 10 core journals through JCA to define the IS domain, detected the emerging trends and newest developments of the IS domain from 2009 to 2016 by employing two new functions of the newest version of CiteSpace5.0 R3, the timeline knowledge map of DCA cluster year by year and dual-map overlays. The conclusions of this research are as follows:

1. By comparing the research topics from 2009 to 2016 and from 1996 to 2008, we find substantial changes in the research topics in the IS domain. The core topics from 1996 to 2008, including information retrieval, webometrics, and citation behavior, clearly turned to scientometric indicators, citation analysis (citation performance and bibliometrics), scientific collaboration, and information behavior, and particularly the scientific evaluation indicators represented by the h-index. The ranking of the h-index among core topics rose from fifth from 1996 to 2008 to the top.
2. This research reveals the evolution of research topics between 2009 and 2016 using the timeline knowledge map through DCA clustering year by year. First, scientific evaluation indicators, represented by the h-index, have become the core topic in the IS domain and have driven the shift of research topics for the entire IS domain. Second, research topics may overlap. For instance, research performance appeared in current topics, including bibliometrics and scientific collaboration. Third, the emerging research topic information behavior (information; seeking behavior, information use, interactive information retrieval) has remained an independent and fast development path. Fourth, emerging research topics have appeared in cluster #2 citation performance and #3 citation count, although this cannot be easily detected from the label tag of the entire cluster.
3. This study finds that the emerging scientific evaluation promoted by the h-index in 2005 is currently the most important research front. This research front primarily involves research on evaluation indicators for the ranking of institutions (universities and institutions), interdisciplinary scientific research measures, and academic prestige of journals. Traditional IS research topics, including bibliometrics, citation analysis, and scientific collaboration, currently remain research fronts. Science mapping and visualization pay special attention to research on visualization tools and automatic word extraction algorithms. Altmetrics, represented by researchon social networks including Twitter and blogs, has already become the most promising research front at present.
4. According to the journal dual-map overlays, the knowledge base of the IS domain research has changed greatly, particularly after 2010, showing that the changes in research topics and knowledge base are interactive and that the change of research topics must lead to changes in the knowledge base. The knowledge base of the IS domain also changed greatly at each time node of the shift of the IS domain research topics.

However, there are some deficiencies in choosing these 3 journals as original Journals for JCA in 2009–2016. First, although articles from three of these, JASIST, Scientometrics, and Journal of Informetrics, can represent the most important and emerging research topics in current field of IS, they cannot represent the IS field as a whole perfectly. Second, the *Scientometrics* journal published the largest volume of literature in 2009–2016 and the total cited in 10 journals. Therefore, in period II, the related subject of scientometrics is the main topic of research in IS, which plays a major role in the research frontier in the field of IS. Lastly, CiteSpace can be used to label clusters automatically and avoid subjectivity in research fronts analysis to a great extent. However, subjectivity cannot be completely avoided in choosing and defining research topics.

Future research is expected to improve the methods used in selecting literature data to define IS. In addition, for accurate and objective results, future research should try to minimize subjectivity when choosing core research topics. To achieve this, expert opinions should be taken into consideration.

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