Author Bibliographic Coupling: Another approach to citation-based author knowledge network analysis

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While bibliographic coupling (BC) as a measure of relatedness between documents was proposed a full decade before co-citation, interest in applying BC to mapping the intellectual structure of research areas has only recently resurged, perhaps because it allows researchers to circumvent problems of the so far dominant co-citation analysis. Especially for mapping the intellectual structure of a research field as represented by its authors, author co-citation analysis (ACA) has frequently been applied over the last two decades, but no author BC analysis has so far been attempted. In this paper, we define author BC and conduct an author BC analysis of the Information Science field using the same dataset as that used in our previous ACA study, which covers Information Science during 1996-2005. We find that these two citation-based author knowledge network analysis methods complement each other, with one providing a more realistic picture of the state of research within the IS field and the other revealing the structure of both internal and external influences on the IS research. In combination, the two methods provide a more comprehensive view of the intellectual structure of the IS field than either of them alone.

Introduction

Recent years have seen great interest in the study of knowledge networks manifested in recorded knowledge (e.g., published papers, books). Researchers analyze interrelationships between various facets (e.g., authors, publications, or institutions) of recorded knowledge, often aided by visual representations of these networks.

The analysis and visualization of knowledge networks can effectively assist in the discovery of new knowledge, and in the management and use of existing knowledge resources (Garfield, 1979; Swanson, 1986; Small, 1999; White, Buzydlowski, & Lin, 2000). This potential is now increasingly being studied and realized, as (a) recorded knowledge has become increasingly available in digital form, which provides large amounts and varieties of data for knowledge network studies; and as (b) sufficient computing power is now readily available to social scientists for analyzing and visualizing such vast networks of information (Shiffrin & Börner, 2004; Börner, et al., 2004; Boyack, et al., 2007; Henzinger & Lawrence, 2004).

A main method available today for studying knowledge networks is citation-based author network analysis. This approach looks at knowledge networks of authors inter-connected via their publications and the references they contain, using citation-based measures (e.g., cocitation counts) to estimate relatedness between authors. This approach is widely used in the social sciences (e.g., in sociology, management research, research policy) (e.g., Crane, 1972; Garvey, 1979; Mullins et al., 1977), but it is currently limited to author co-citation analysis (ACA) or co-authorship analysis. The latter is of a somewhat different nature as it emphasizes collaboration patterns rather than knowledge domains, and ACA has a number of limitations with respect to knowledge network analysis. It is therefore important to explore whether there are other ways to study author knowledge networks in order to provide new insight as well as address these limitations.

The present study is such an attempt. It aims to enhance our understanding of, and confidence in, citation-based author knowledge network analysis, and to improve our ability to obtain more thorough views of structures and networks of research fields, especially highly collaborative and highly dynamic research fields (e.g., biomedical research).

Problem statement and research questions

ACA has two main limitations: (a) Current trends analysis is not well supported as it is not the works of currently active authors that are mapped in ACA, but the older works of well-established authors that the current authors cite, and since author oeuvres need to mature before they appear in ACA studies that are based on citations to them. (b) It has so far largely been forced to only consider scholars' contributions as first authors because obtaining information on all authors of each of the cited references has been extremely difficult from current citation databases, which either disregard non-first authors in indexing cited references (e.g., ISI databases) or have other problems (e.g., Scopus, GoogleScholar). This is problematic in at least some fields even for quite robust methodologies (Lindsey, 1980; Long et al., 1980; Smith, 1981; Zhao, 2006a; 2006b; Schneider et al., 2007), and this problem is particularly serious in fields with high and rising levels of collaboration (e.g., bio-medical research).

Both these limitations may, theoretically, be addressed through extending the concept of bibliographic coupling (BC) from the document level to an author-aggregated (i.e., oeuvre) approach.

The BC concept was introduced a decade earlier (Kessler, 1963) than that of co-citation (Small, 1973) as a way to cluster research papers. The BC strength (or frequency) between two documents is indicated by the number of items they share in their reference lists. Knowledge network analysis based on BC frequencies therefore directly maps recent publications based on how they cite rather than the older publications that they cite as co-citation analysis does, thus supporting the study of more current knowledge networks (Weinberg, 1974; Egghe & Rousseau, 2002). A recent case study of BC patterns in nanotube-related patents found that BC is particularly suitable for anticipating technological breakthroughs (Kuusi & Meyer, 2007). It was also found that research fronts based on weak signals may be detected in BC analysis as papers analyzed using BC are not selected by the number of times they have been cited, unlike co-citation analysis that focuses more on detecting robust areas of research based on strong signals (Bassecoulard, et al., 2007; Glänzel & Czerwon, 1996).

Although the bibliographic coupling frequency between two documents is fixed once these two documents are published, and therefore does not support the study of changes in research fields over time (Small, 1973), author-aggregated BC analysis does not have this problem because the BC frequency between two authors (i.e., between their oeuvres) does change over time as long as at least one of them continues to publish.

In addition, as current citation databases (e.g., ISI databases) index all authors of source papers, author-aggregated BC analysis, which examines currently active authors themselves (i.e., authors of source papers) rather than authors they have cited (i.e., authors of cited references), does not need to be limited to first authors in the study of author knowledge networks, and can therefore provide more thorough views of the structure, characteristics and historical development of knowledge communities.

Extending BC to author-aggregated (i.e., oeuvre) analysis, therefore, promises to be a way to enable the study of current trends and their changes over time in author knowledge network analysis, taking into account authors' contributions as both first authors and non-first authors.

Despite its promises, BC as an indicator of relatedness between documents has rarely been applied to research evaluation or knowledge network analysis since its introduction in the 1960s, unlike co-citation analysis which has been dominating the mapping of knowledge networks and their changes over time. This is partly because it is difficult (and perhaps even impossible) to retrieve BC frequencies directly from the data source that citation analysis studies have heavily relied on, i.e., the databases by the Institute for Scientific Information (ISI). Although recent years have seen knowledge network analysis studies based on BC measures both at document level (e.g., Jarneving, 2005; 2007) and at journal level (e.g., Boyack, et al., 2007), we have not seen any author-aggregated BC analysis studies.

We have recently started to attempt to fill this gap by exploring how to extend the BC concept from the document level to an author-aggregated (i.e., oeuvre) approach and whether this extension lives up to its promises. The present study is part of this effort and uses one of several possible ways of defining author BC frequency and one of several possible ways of selecting authors for analysis, in order to address the following research questions:

a) Is the analysis of author knowledge networks based on author BC frequencies an effective approach to the study of intellectual structures of research fields?
b) What benefits does author BC analysis bring to knowledge network analysis?

Methodology

In order to address these questions, we collected citation data in the Information Science (IS) research field, a field that we and readers of this journal are familiar with, and one of the research fields we have studied using ACA (Zhao & Strotmann, 2008). We were careful to process the collected data in a way similar to our previous ACA study so that we could better evaluate author groups, and better compare author BC analysis with ACA in terms of the author knowledge networks they reveal. As ACA has long proved to provide valuable information about the intellectual structures of research fields, this comparison is essential for addressing our above research questions.

Data collection

We therefore use the same dataset that we used for our ACA study of the IS research field (Zhao & Strotmann, 2008), namely, Web of Science full records of all articles published during the years 1996 to 2005 in 12 core IS journals. These journals were used to define the IS research field in the landmark article on ACA and information science by White & McCain (1998). This dataset includes 4,422 records of source papers that altogether have 110,785 references, i.e., 25 references per source paper on average.

We developed Java programs to parse these downloaded records, and to store the resulting data fields such as authors, publishing sources and years of both source papers and cited references in a data structure that was convenient for later data analysis such as counting author BC frequencies, and to produce various matrices of author BC frequencies.

Data analysis

We study the intellectual structure of the IS field as manifested in the 4,422 IS publications by using author as the unit of analysis, author BC frequency as the measure of relatedness between authors, and factor analysis as a way to reveal the underlying structure of the interrelationships between these authors.

There are two factors here that affect the resulting networks: how to define author BC frequency, and how to select the set of authors to represent the IS field.

As the BC frequency between two documents is the number of references these two documents share, the BC frequency between two authors can be defined as the number of references these two authors' oeuvres share. This could be understood to mean the extent to which the individual publications in the two authors' oeuvres share references, and the BC frequency between these two authors could thus be calculated by adding up these document BC frequencies. Alternatively, we could treat an author's complete oeuvre as if it were a single publication, and calculate the BC frequency between two authors as the overlap between the reference sets of their oeuvres. We decided to limit our preliminary study to the latter as well as to first-author BC, defining an author's oeuvre as all publications with this author as the first author, even though information about all authors is readily available in our dataset.

Specifically, we created a reference set for each of the first authors in our dataset in which the references from their publications are weighted. For example, if author A's oeuvre contains *X* papers, author A's reference set will include all distinct / unique items in the reference lists of these *X* papers; if an item appears in *N* of the *X* reference lists in author A's oeuvre, this item will appear in author A's reference set with a weight of *N*. If the same item appears in author B's reference set with a weight of *M*, then this item adds min(*N*, *M*) (i.e., the smaller of *N* and *M*) to the BC frequency between authors A and B. We weighted references in calculating BC frequencies between authors to recognize that re-citation, i.e., the fact that an author often cites the same papers or authors multiple times, largely defines an author's citation identity (White, 2001).

For this exploratory study, we decided to select the set of authors to examine by average BC frequency, and to leave the testing of other author selection methods (e.g., by number of publications or by number of citations) to a future study. An author's average BC frequency is of course the sum of this author's BC frequency with each of the other authors in the dataset divided by (*K*-1), with *K* being the total number of authors in the dataset. A high average BC frequency indicates to some extent that this author either is bibliographically coupled to some degree to many other authors, or that he or she has strong BC links, i.e., high BC frequencies, with several authors. Using top-ranked authors by average BC frequency as "core authors" to represent a research field is thus consistent with findings from Glänzel & Czerwon (1996) that strongly *and* frequently coupled documents comprise "core documents" of a research field.

Using specially developed software, authors with a high average BC frequency in the dataset collected for this study were selected to represent the IS field, and a matrix of BC frequencies between these authors was created. This way, we selected 121 authors, a number that is very close to that in the ACA study (120) with which we compare its results.

As in our earlier ACA study of the IS field, this matrix was analyzed using SPSS' Factor Analysis routine to explore the underlying structures of the interrelationships between the selected authors. The diagonal values were treated as missing data and replaced by the mean in that routine. Factors were extracted by Principal Component Analysis (PCA), and the number of factors extracted was determined based on an examination of the Scree plot, total variance explained, communalities, and correlation residuals (Hair, et al., 1998). This resulted in an 11-factor model which explains 73% of the total variance, and the differences between observed and implied correlations were smaller than 0.05 for the most part (92%). About 90% of the communalities are above 0.6, with the highest being 0.92. The model fit is quite good.

We applied an oblique rotation (SPSS Promax) to this factor model. The resulting pattern and structure matrices are visualized as two-dimensional maps using the technique introduced in Zhao & Strotmann (2007; 2008) to aid interpretation. On the maps, authors are represented by square nodes and factors by circular

nodes. The size of a factor node corresponds to the sum of the loadings on this factor by all authors who load sufficiently on it (i.e., 0.3 or higher in this case). The thickness of a line that connects an author with a factor is proportional to the value of the loading of this author on this factor, as is its grey-scale value, with darker lines corresponding to higher loadings. The color of an author node indicates the number of factors that this author loads on with a value of at least 0.3 each: yellow for authors who only load sufficiently on a single factor, green for those who co-load on two factors, red for three factors, and blue, for four factors.

These results were compared with those from the ACA study reported in Zhao & Strotmann (2008) in order to evaluate whether author BC analysis is an effective approach to the study of intellectual structures of research fields, and to identify its pros and cons as compared to ACA in the study of knowledge networks. To this end, several relevant network features that they reveal were examined, such as which specialties (i.e., groups of authors) are identified, which specialties are most active, how these specialties are related to each other, and what the individual scholars' memberships are in these specialties (White, 1990; White & McCain, 1998).

Results and discussion

Figures 1 and 2 represent the pattern matrix and structure matrix, respectively, of the results of a factor analysis with oblique rotation. Factors are labelled upon examining the articles written by authors in the corresponding factors, and are listed in Table 1. As authors – especially well-established ones – often write on a range of topics, we felt it more difficult to label factors from an author BC analysis than those from ACA in which one can focus on the highly cited articles by each author. Given the meaning of BC, i.e., documents sharing references, we found that looking for common themes in articles by different authors in a factor appears to be a good way to go about it. The picture we see from an author BC analysis therefore focuses on an author's research areas that are in common with those of a good number of other authors, whereas ACA finds areas of an author' research that have had high impact on the field.

Table 1: Factors and their labels

Label	Size	Highest loading	Label	Size	Highest loading
IR interaction	36	1.04	Children's web searching behaviour	8	0.96
Mapping of Science	15	0.93	Evaluative citation analysis	8	0.65
Collaboration	12	1.04	Information seeking in context	6	0.71
Mathematical bibliometrics	12	0.97	Scholarly communication(?)	4	0.86
IR systems	11	0.98	Search engine log analysis	1	0.77
Webometrics	8	0.96			

We interpret large factors as research areas, and an author's loadings in a factor as indication of this author's interest in that area. Figure 1 thus shows the research areas identified and authors' interests in these areas, as an author's loading in the pattern matrix represents this author's unique contribution to the corresponding factor, i.e., how well the research area represents the author's work. The interrelationships between research areas and the overall structure of the IS field are shown in Figure 2, as loadings in the structure matrix represent a combination of authors' unique contributions to corresponding research areas and the correlations between research areas (Hair, et al., 1998; Zhao & Strotmann, 2008).

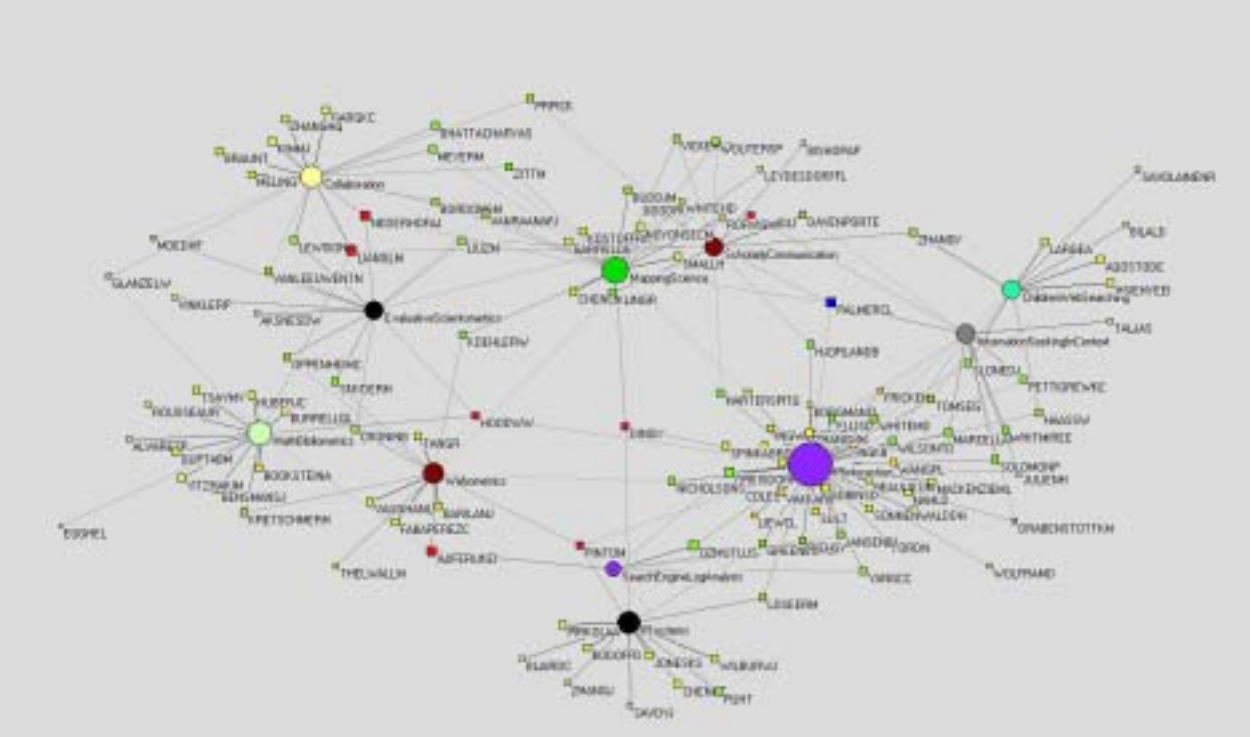

Figure 1: Pattern matrix of factor analysis with oblique rotation

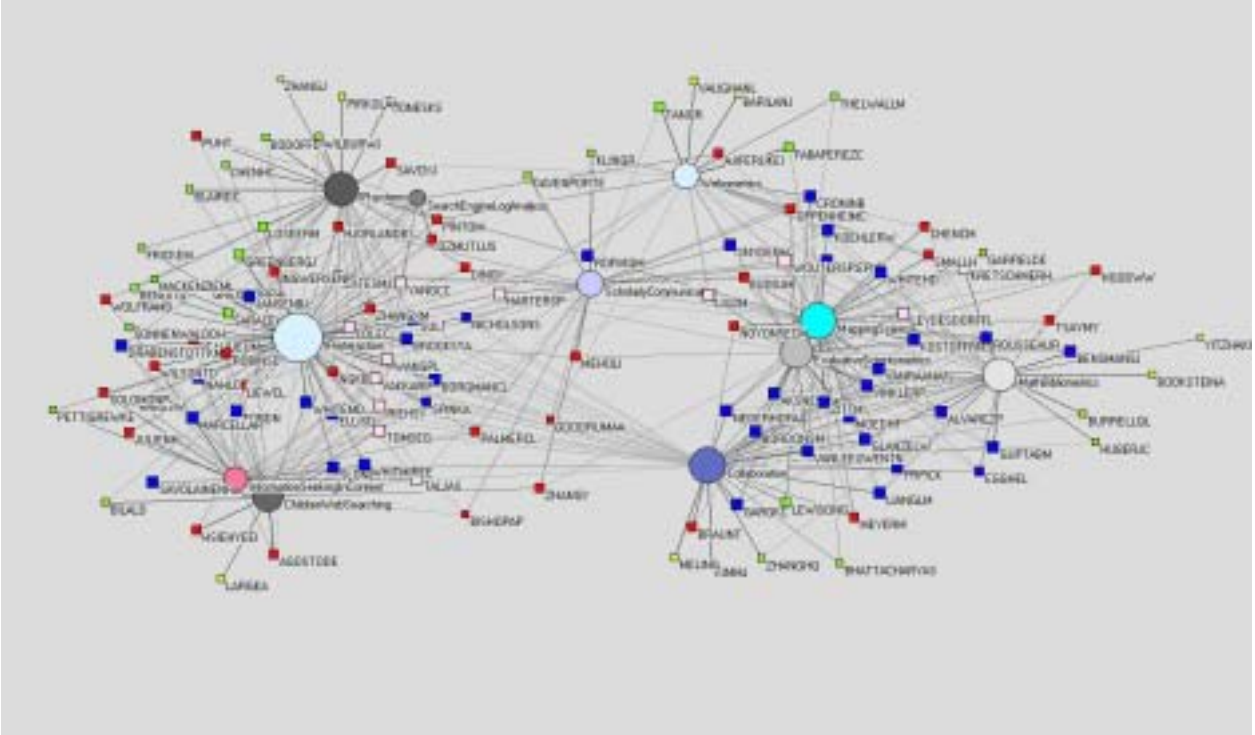

Figure 2: Structure matrix of factor analysis with oblique rotation

Clearly, the largest or most active research area in the IS field during 1996-2005 was user-centered information retrieval, labelled here as IR interaction – 36 (or 30%) of the 121 authors have primary loadings in this research area, 29 of whom have loadings higher than 0.6. The second largest research area, Mapping of Science, includes primary loadings from 15 authors, followed by Collaboration, Mathematical bibliometrics, and system-oriented IR, labelled here as IR systems, each of which includes 11-12 authors with primary loadings. The remaining research areas range from 4 to 8 authors each. The factor labelled Search engine log analysis has a primary loading from only one author.

While most research areas are quite clear in nature as indicated by the common themes in the oeuvres belonging to the corresponding factors, we found it difficult to label the factor that we tentatively labelled as Scholarly communication. E. Davenport, R. Kling, and A.P. Bishop have primary loadings higher than 0.6 in this factor. Although the common theme of their articles appears to be scholarly communication, Davenport, who loads highest in this factor (0.86), also has several articles on knowledge management.

The research areas are clearly grouped into two camps (Figure 2): the literatures camp, which includes Collaboration, Mapping of Science, Mathematical bibliometrics, Webometrics, and Evaluative citation analysis, and the IR camp, which includes IR interaction, IR systems, Children's web searching behaviour, and Information seeking in context. The connections between these two camps are mostly through the Scholarly communication and Webometrics research areas, and to a lesser degree through the many low co-loadings on the Collaboration research area in the literature camp from authors whose primary loadings are in the IR interaction research area. The two research areas Mapping of Science and Evaluative citation analysis are more closely related within the literatures camp, so are the two research areas Children's web searching behaviour and Information seeking in context within the IR camp. The Webometrics research area is clearly very different from the rest of the literatures camp as it is clearly quite separate from the rest of that camp with quite strong connections to IR.

Most authors have conducted research in two to four research areas, as indicated by the square nodes in green, red or blue. A few authors focused on a single research area (yellow nodes), and a few others have shown interest in five research areas (pink nodes). Examples of highly focused authors include Bookstein, Melin, Vaughan, and Bar-Ilan in the literatures camp, and Jones, J. Zhang, Pirkola, and Large in the IR camp. Examples of authors with wide interests include Leydesdorf and Kretschmer within the literatures camp, and Vakkari, Cole, PL. Wang, Harter, Wouters, and ZM. Liu bridging the two camps.

A few observations can be made when we compare these results with those from our ACA study (Zhao & Strotmann, 2008).

(a) Most research areas identified in the two studies are the same. All but one of the research areas identified here were also seen in the ACA study. The only exception is the area of research on collaboration patterns in science (often through co-authorship analysis), which suggests that this area mostly draws on foundations that it has in common with other research areas, and that it has not produced its own influential authors yet. Research areas that were identified from the ACA study but are missing here include User’s judgments of relevance and Metadata & digital resources, which indicates that these areas of research have not attracted sufficient number of currently active authors although they have had impact on research in other research areas.

(b) One of the research areas that were identified in both studies showed different foci. Users’ interaction with IR systems is the common theme of oeuvres in the IR interaction research area in the current study. The corresponding group in the ACA study was, however, on user studies in general, not limited to information searching behaviours. That means that IR interaction has been the focus of user-related research in the ten-year period studied, but also that it has drawn on research on all aspects of information behaviour.

(c) As was to be expected given the natures of ACA and BC analyses, scholars from outside the IS field and historical figures only appeared in the ACA study but not here in the BC analysis. In fact, none of the authors in the Science communication specialty in the ACA study (e.g., Merton, Garvey, Line, and A.J. Meadows) appears here, and neither do the computer scientists in the IR systems specialty (e.g., K.L. Kwok, C. Buckley, M.F. Porter, and C.J. van Rijsbergen) or in the Webometrics specialty (e.g., S. Brin, J. Kleinberg, and S. Lawrence) – one reason why each of these two research areas here is about half the size of the corresponding specialty in the ACA study. This suggests that studies in these three areas in the IS field have been drawing heavily on research outside of IS, and that BC analysis appears to provide a more realistic picture of the state of research within the IS field whereas ACA reveals the structure of both internal and external influences on IS research.

(d) Some authors have membership in different research areas in these two studies. A good example is the three authors in the Scholarly communication research area here. Two of them (i.e., Davenport and Kling) loaded high and solely in the Webometrics specialty in the ACA study and the other one (Bishop) had low loadings in two other specialties. This suggests that an author's citation identity as shown in author BC analysis is often different from her citation image as seen from ACA. An author's citation identity is defined by herself through works that she perceives as most influential to her research, whereas an author's citation image is largely defined by citers of her works through her mostly influential works as perceived by the citers.

Conclusion

Based on each author's research areas that have attracted a sufficient number of other authors, an author BC analysis of the IS field in this preliminary study provided a realistic picture of the state of research in the IS field. In this picture, the two-camp structure with strong connections within camps and sparse links between camps was quite clear, and the area of research that we tentatively labelled as Scholarly communication appeared to have strong connections to both camps. Research on IR interaction was by far the most active area of the IS field. The Mapping of science area was quite active as well, followed by the research areas on Collaboration, Mathematic bibliometrics, and IR systems.

This picture of the IS field's intellectual structure is quite similar overall to that revealed from ACA as both author BC analysis and ACA are based on intellectual links manifested in citation networks. There are also visible differences in results from these two approaches as author BC analysis focuses on the recent research by currently active scholars within the IS field whereas ACA reveals the structure of the influences on this field, some of which are from outside the field or from founding figures who are no longer active. Research on collaboration patterns was an active research area in this decade, but did not have high impact on the IS field during this period. Active research on information behaviour was mostly focused on IR interaction but was influenced by a wider literature. Research on children's Web searching behaviour or on information seeking in context appears to have been both active and influential in this IS field.

Author BC analysis thus appears to be an effective approach to the study of author knowledge networks, and provides important insights into the intellectual structure of a research field, which are sufficiently different from those from ACA that it can improve our ability to obtain a more thorough view of the structure and the networks of a research field.

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