

Social Network Analysis:

Bibliographic Network Analysis of the Field and its Evolution

Part 1. Basic Statistics and Citation Network Analysis

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Abstract

In this paper, we present the results of the study on the development of social network analysis (SNA) discipline and its evolution over time, using the analysis of bibliographic networks. The dataset consists of articles from the Web of Science Clarivate Analytics database and those published in the main journals in the field (70,000+ publications), created by searching for the key word “social network*.” From the collected data, we constructed several networks (citation and two-mode, linking publications with authors, keywords and journals). Analyzing the obtained networks, we evaluated the trends in the field’s growth, noted the most cited works, created a list of authors and journals with the largest amount of works, and extracted the most often used keywords in the SNA field. Next, using the Search path count approach, we extracted the main path, key-route paths and link islands in the citation network. Based on the probabilistic flow node values, we identified the most important articles. Our results show that authors from the social sciences, who were most active through the whole history of the field development, experienced the “invasion” of physicists from 2000’s. However, starting from the 2010’s, a new very active group of animal social network analysis has emerged.

Keywords: development of scientific field, social network analysis, bibliographic network, citation, search path count, main path, key-routes, probabilistic flow, island approach

1 Introduction

Social network analysis (SNA) is a rapidly developing scientific field that has appeared and grown significantly over the past 50 years. In the 1970’s the field was highly fragmented and could be represented by a set of individual scientific groups unrelated to each other; these groups existed mostly due to the significant efforts of some individuals and institutions. During 1970-80’s, the *International Network for Social Network Analysis* and *Sunbelt* conference, with specialized journals *Connections* and *Social networks* appeared. In the beginning of 1990’s the representatives of the field have already formed an “invisible college” and the field itself achieved the status of a “normal science” (Freeman, 2004; Hummon and Carley, 1993).

From that point, the field of SNA has grown significantly, both in the number of scientific publications and different disciplines involved (Otte and Rousseau, 2002; Borgatti, Foster, 2003). To a large extent, substantial increase in interest in this topic was due to the emergence of the Internet in 1990's and online social networks during the 2000's. However, if until the 2000's the field was mostly developed inside different branches of social sciences, starting from the new century it received significant attention from the researchers of the natural science disciplines. The so-called “*invasion of the physicists*” (Bonachich, 2004) resulted in development of Network Science discipline, whose representatives sometimes were reinventing and rediscovering the issues that had been developed in the social sciences for quite some time (Freeman, 2004).

The development of the SNA field was reflected in a set of studies focused both on its historiographical description (Freeman, 2004, 2011) and bibliometric analysis of publications and journals involved in the field. Several authors studied citation structures of works and journals (Hummon and Carley, 1993; Leydesdorff et al., 2008; Batagelj et al., 2014), collaboration and co-authorship structures (Otte and Rousseau, 2002; Leydesdorff et al., 2008; Batagelj et al., 2014), structures of co-citations between works, authors, and journals (Brandes and Pich, 2011), topical structures and keyword co-occurrence networks (Leydesdorff et al., 2008; Groenewegen et al., 2015). Attention was also given to different subfields (subtopics) of SNA (Hummon et al., 1990; Kejžar et al., 2010; Batagelj et al., 2014, 2019) and subdisciplines within the field (Otte and Rousseau, 2002; Borgatti, Foster, 2003; Lazer et al., 2009; Varga, Nemeslaki, 2012). These works are presented in greater details in the following section.

In general, various tools of bibliometric analysis has been proposed and extensively used to study scientific disciplines and their development over the last decades. These studies may involve research of various aspects of scientific fields' state and development in different disciplinary and regional areas, such as co-authorship trends in sociology in the USA (Moody, 2004; Hunter and Leahey, 2008), Slovenia (Mali et al., 2010), or Russia (Sokolov et al., 2012); library and information science in Argentina (Chinchilla-Rodríguez et al., 2012), economics in Poland (Lopaciuk-Gonczaryk, 2016), the field of scientometrics and informetrics (Hou et al., 2008), or comparison of different disciplines: biology, physics and mathematics (Newman, 2001, 2004), mathematics and neuroscience (Barabasi et al., 2002), or even all research disciplines in a country (Kronegger et al., 2012; Ferligoj et al., 2015; Cugmas et al., 2016). There are also studies of scientific networks in multinational (Glaenzel and Andreas, 2004) and international (Wagner and Leydesdorff, 2005) levels. The data for analysis are usually obtained from particular journals (Carley et al., 1993), thematic sets of literature (Hummon and Doreian, 1989; Batagelj et al., 2017), or the databases of bibliographic information (Kronegger et al., 2012).

The aim of our study, in line with previous research done in the area, is to implement a comprehensive approach for the identification of the main trends of the SNA field development, with a representation of various disciplinary areas, groups of scientists, and thematic agenda in the field. The applied bibliometric analysis has already shown to be productive in a set of studies of different scientific fields and topics (Kejžar et al., 2010; Batagelj et al., 2014, 2017). It allows analyzing networks of co-authorship, co-occurrence, citation and co-citation between different bibliographic entities, and identifying key publications and actors (authors, research groups, institutions, journals) in the field of SNA, main topics and scientific ideas, connections between them and their evolution in time. The study is based on the analysis of networks of articles from the *Web of Science* data base and works published in the main journals in the field.

Due to the large volume of obtained information, we had to split our results into three parts published separately: (1) basic statistics and citation network analysis (this paper), (2) analysis of co-occurrence networks, and (3) temporal network analysis. The first section of this paper presents some previous studies in the SNA field. Next, we describe the dataset and some issues of network construction. Section

four provides some statistical properties of basic networks, and Section five shows the analysis of citation network.

2 Social network analysis: the review of previous studies

One of the most comprehensive overviews of the history of SNA development was presented by Freeman in his well-known book *'The Development of Social Network Analysis'* (Freeman, 2004). Using a methodological perspective of sociology of science, Freeman patterned the links among the people who were involved into the development of the field, pointed out the main historical events, and thus presented *"the history of social network analysis written from a social network perspective"*. This qualitative study was also supported by the survey of early social network analysts (*'founding fathers'*) on the topic of their introductions to structural thinking – the scientific antecedents – and their most important works.

According to the history written by Freeman, the birth of the social network thinking can be attributed to the beginning of the 20th century. However, the first more or less consistent period that can be delineated refers to 1940-60's, which is associated with the emergence of a large number of "schools," most of which were not aware of each other and were potentially competing. That is why, **by the 1970's the field was highly fragmented**: according to the results of the "founding fathers" survey, the field's intellectual antecedents formed different groups – sociologists, on the one side (though, loosely connected to each other) and anthropologists, geographers, social psychologists, communication scientists, political scientists, historians and mathematicians (who showed more agreement about the patterns of influence) – on the other side.

Starting from 1970's, a number of attempts were made for the unification of many separate strands of SNA by a number of individuals and institutions. Among these attempts Freeman points out the organization of the *International Network for Social Network Analysis (INSNA)* in 1977, creation of *Social Networks* journal in 1979, the conferences and the regular meetings that brought separate groups together (including those connected by early version of Internet), the appearance of computer programs standardizing analysis of social network data, educational programs at the universities and "bridging" positions of some scholars travelling around different institutions. All these attempts lead to the **institutionalization of the field in 1980's**, when *'the representatives of each of these network "schools" have all joined together and organized themselves into a single coherent field'* (Freeman, 2004, p. 135). Freeman also mentions some challenges which the newly established field was facing in the beginning of the 20'th century – the confrontation between the traditional social network analysts and the physicists, discovering the network approach and *'reinventing existing tools and rediscovering established empirical results'*.

The findings of Freeman on the unification of the field are supported by the results of one of the first quantitative study on the SNA field development conducted by Hummon and Carley (1993), which was based on the citation analysis of the works published in the first 12 volumes of *Social Networks* journal and important articles that were cited by their authors. Adding some historiographic data to the results of network analysis, the authors came to the conclusion that **by the 1990's the members of SNA community have met the requirements for being an invisible college**. This notion means that until that time there has been a core active group of scientists (INSNA members), having shared paradigm (understanding of the society as a network), defining important problems, promoting common methods of analysis, and establishing criteria of accomplishment and advance, working in core substantive areas and incrementally developing the ideas. They had primary professional outlet (*Social Networks*) and regular face-to-face interaction (through the conferences). The main paths going through the citation network were few in number, densely connected, extensive in the number of articles linked together, and continuous. That is why Hummon and Carley made a conclusion that the **SNA not only acceded the**

status of a discipline, but also that the type of science engaged in within social networks field was what Kuhn had labeled a “normal science”.

Based on the analysis of the number of works related to the SNA field in databases of sociological, psychological and biomedical publications in period 1974-1999, Otte and Rousseau (2002) came to the conclusion that *‘it was only in the early 1980’s that SNA started its career’*. Interestingly, while **the fast growth of number of publications without any sign of decline was mostly seen in the sociology**, the biomedical and psychological literature showed the modest increase as well, which *‘proves that other fields, besides Sociology, have used the term and the techniques’* of SNA. Using the information from the *Sociological Abstracts* database, authors also constructed the co-authorship network and extracted the most prolific authors.

These ‘pioneer’ works were followed by a number of other studies of the field of SNA and its subtopics and subdisciplines, which used different data analysis methods. Based on the same resource – *Social Networks* journal – Leydesdorf, Schank, Scharnhorst, and De Nooy (2008) presented the temporal analysis of keywords co-occurrence and co-authorship networks, constructed out of the works published in the period 1988-2007, and extracted the most central figures, belonging to certain branches of the field, and common and specialized topics appearing in the journal’s articles through time. Studying the journal’s citation structures (in both cited and citing dimensions), authors found its **strong connection with other sociological journals**, and lower strength connections with journals from psychology, organization and management studies. They also showed that in some years the journal was also cited in a larger citation environment, including journals in physics and applied mathematics. However, *‘in spite of the fact that the citation impact of Social Networks in recent years has increased, this has not changed its disciplinary identity’*: it still *‘can be considered as a representative of sociology journals’*, rather than an *‘interdisciplinary journal’*. In a later study, Groenewegen, Hellsten, and Leydesdorff (2015) also combined social network and semantic network analyses to study the developments of content coverage of *Social Networks* and the internal consistency of its community of authors, and analysis of networks of concepts and authors to understand how the community and their interests has developed from 1978.

A comprehensive studies of the SNA field development were made by Batagelj, Doreian, Ferligoj, Kejžar, and others, who studied the collaboration networks among *social network analysts and contributors to network science*, citations between works, and citations between journals (Batagelj et al., 2014), based on the data obtained from different databases of bibliographic information. Using variety of networks, constructed out of diverse bibliometric entities (works, authors, journals, keywords, citations, publication year), the analysis of several branches of SNA field was also done on the topics of centrality measures (Batagelj et al., 2014), clustering and classification (Kejžar et al., 2010), and blockmodeling (Batagelj et al., 2019). The findings of these studies confirmed the trend of the *‘invasion to the field’* from other disciplines: while in the early period the SNA field was developed in different branches of social sciences, **starting from 2000’s, the key highly cited works in the field belonged to the authors from physics (mostly), computer science, neurosciences, and medicine**. The presence of these disciplines in the SNA topic and collaboration structures of the field became more visible. Detailed description of the physicists’ appearance in the field of SNA and their tension with social scientists was shown by Freeman (2011).

Using the dataset **SN5** (Batagelj, 2008) presented by (2014) (*Web of Science* descriptions of articles on social networks till 2007) Brandes and Pich (2011) implemented the procedure of bibliographic coupling (based on closeness of nodes according to their citing patterns) to different sets of bibliographic entities – works, authors and journals. The analysis revealed the same patterns that were observed in previous studies: **the distinction between different groups of authors – social network scientists and the representatives of Network science discipline** – with the latter forming the most cohesive groups

according to the similarity of citation patterns both in sets of works and authors. The analysis of journals similarity according to their ‘citation behavior’ supported the previous conclusions (Hummon and Carley, 1993; Leydesdorff et al., 2008) that **the field has its own specialty journal *Social Networks*, which is positioned in the group of sociological journals.**

Some authors paid attention to the development of the SNA **within different disciplines**, which in general follows the same trends. In their review of Network analysis usage in *Management and Organizational research*, Borgatti and Foster (2003) also showed the exponential growth of publications in the field indexed by *Sociological Abstracts* and containing “social network” in the abstract or title in the period of 1970-2000’s. Studying *organizational network studies* by means of bibliographic coupling and citation network analysis, Varga and Nemeslaki (2012) found the strong connection of this field to economics, management and business science, and sociology. Otte and Rousseau (2002), being interested in *social information discipline*, found the presence of SNA there as well: some of the most active information science authors also published articles in the journals from SNA field (such as *Scientometrics*, *JASIS(T)*, *Journal of Classification*). Lazer, Mergel, and Friedman (2009) studied the development of the SNA field within *sociology* – “which has served as the primary home of social network analysis over the last several decades”. Looking at the co-citation patterns of papers published in two leading general sociological journals, *the American Sociological Review* and *the American Journal of Sociology* at three time points – 1990-92, 2000 and 2005, they delineated different ‘canons’ typical for different time points and the associated authors in each. Being especially interested in the impact that works written within physics had on the study of social networks within sociology, they found the “rapid entry of the physicists into the canon between 2000 and 2005, and a possible centralization of the field around small-world networks related research”.

Thus, the previous studies done in the field of SNA development show that the institutionalization of the field reflected in the rapid increase of the yearly number of articles related to it, which was constantly growing from 1970-80’s. According to Freeman, these data show that the study of social networks is rapidly becoming one of the major areas of social science research (Freeman, 2004). On the other hand, even though the initial involvement into the field of SNA was interdisciplinary (Hummon and Carley, 1993), recently the field had to face some challenges, with *physicists’ invasion* being one of the most important (Lazer et al., 2009; Brandes and Pich, 2011; Batagelj et al., 2014; Freeman, 2011). Based on these previous findings, the current study aims to evaluate the main changes that the field came through its history and to highlight the current trends of its development.

3 Data

3.1 Data collection and cleaning

The source of data for our research was *Web of Science (WoS)*, Clarivate Analytics’s multidisciplinary databases of bibliographic information. The data set is composed of two parts. It is based on the SN5 data collected for the Vizards session at the Sunbelt 2008 (Batagelj et al., 2014), and contains all the records obtained for the query “social network*” and articles from the journal *Social Networks*, till 2007. We additionally searched for the works without full descriptions which were most frequently cited and papers on SNA of around one hundred social networkers. The final version of SN5 contained 193,376 works, 7,950 works with a description, 75,930 authors, 14,651 journals, and 29,267 keywords. The SN5 data were extended in June 2018 using the same search scheme. Starting from 2007, 576 articles from *Social Networks* journal were added. Additionally, in 2018, all the articles from the networks-related journals presented in WoS were included – such as *Network Science*, *Social Network Analysis and Mining*, *Journal of Complex Networks* (total 431 article). Other network-related journals – such as

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PT J
AU GRANOVET.MS
TI STRENGTH OF WEAK TIES
SO AMERICAN JOURNAL OF SOCIOLOGY
LA English
DT Article
C1 JOHNS HOPKINS UNIV, BALTIMORE, MD 21218 USA.
CR BARNES JA, 1969, SOCIAL NETWORKS URBA
  BECKER MH, 1970, AM SOCIOL REV, V35, P267
  BERSCHIED E, 1969, INTERPERSONAL ATTRAC
  BOISSEVAIN J, 1968, MAN, V3, P542
  BOTT E, 1957, FAMILY SOCIAL NETWORK
NR 61
TC 2156
PU UNIV CHICAGO PRESS
PI CHICAGO
PA 5720 S WOODLAWN AVE, CHICAGO, IL 60637
SN 0002-9602
J9 AMER J SOCIOL
JI Am. J. Sociol.
PY 1973
VL 78
IS 6
BP 1360
EP 1380
PG 21
SC Sociology
GA P7726
UT ISI:A1973P772600003
ER
SK IP

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Figure 1: WoS record

Computational Social Networks, Applied Network Science, Online Social Networks and Media, Journal of Social Structure, and Connections – were considered, but were not abstracted in the WoS.

Figure 1 presents an example of a record describing an article as obtained from WoS. We had to limit our search to the Web of Science Core Collection because for other databases in WoS the CR fields, which contain citation information, could not be exported.

The works, which appear only in WoS CR fields as references, do not have a full description in the collected data set, and are called *terminal* works. As such works can be highly cited and in this sense important, we additionally collected full descriptions for works with high (at least 150) citation frequencies using WoS. If a description of a work was not available in WoS, we constructed a corresponding description without CR data, searching for the work in Google Scholar (exported in RIS bibliographic format and converted into WoS with a special R function). We also included manual descriptions of important works without the CR field from the dataset BM on blockmodeling (Batagelj et al., 2019). We should note that additional influential papers, usually published earlier, could be overlooked by our search queries because they do not use the now established terminology. Finally, our data set included 70,792 WoS records with a complete description.

Some comments should be given concerning the choice of the dataset for the current study. Even though for a long time *Web of Science* had a monopoly in the field of scientific work abstraction and evaluation, other sources of bibliometric data appeared – such as *Scopus*, *Google Scholar*, special citation resources and scientific social media (*SciFinder*, *Mendeley*, etc.). Previous comparison of different databases has shown that they vary significantly according to their coverage of certain scientific disciplines, and have their pros and cons. For example, *Google Scholar* is shown as providing broad coverage for most disciplines, while *Scopus* and *WoS* are found out to have less publications and weaker representation of the works in the social sciences and the humanities. At the same time the amount of works for all disciplines, especially for engineering, was found to be higher in *Scopus*, then in *WoS* (Hilbert et al., 2015; Harzing and Alakangas, 2016; Martín-Martín et al., 2018). *WoS* contains mainly publications from the *journals* with certain level of *impact factor*, while *Google Scholar* contains different types of

sources, including journals, conference papers, books, theses and reports. This can be important for the representations of those disciplines where the journals are not the only prestige sources for scientific knowledge sharing (but also conference proceedings, reports, etc.), and publications are not the only types of scientific contributions (but also software, data, patents, etc.) (Franceschet, 2009). We propose that this can lead to certain underrepresentation of some fields in our dataset, where SNA is developing – for example, *computer science*. At the same time, an important feature of *WoS* is that it provides coverage back to 1900 with descriptions including *references* (CR field); for other databases, the information on citations is included to the descriptions of publications only from 1970 (*Scopus*), or not included at all (*Google Scholar*) (Elsevier, 2018; WoS, 2018). Together with lower consistency and accuracy of data in *Google Scholar*, it makes the choice of *WoS* most appropriate for the current study. However, it should be noted that the **results are inevitably relative to the available data**.

3.2 Basic networks construction

Using **WoS2Pajek 1.5** (Batagelj, 2007), we transformed our data into a collection of networks: one-mode citation network **Cite** on works (from the field CR) and two-mode networks – the authorship network **WA** on works \times authors (from the field AU), the journalship network **WJ** on works \times journals (from the field CR or J9), and the keywordship network **WK** on works \times keywords (from the fields ID, DE or TI). An important property of all these networks is that they share the same first node set – i.e. the set of works (papers, reports, books, etc.) – which means that they are *linked* and can be easily combined using the network multiplication into new *derived* networks (Batagelj et al., 2014). The results of these networks analysis are presented in a separate paper (Part 2).

Works that appear in descriptions can be of two types: those which have full descriptions (*hits*), and those which were only cited (listed in the CR fields, but not contained in the hits). These information was stored in a partition *DC*, where $DC[w] = 1$ if a work *w* has a WoS description, and $DC[w] = 0$ otherwise. Partition *year* contains the work’s publication year from the fields PY or CR. This information is essential for the construction of temporal networks analyzed in Part 3. Also the vector *NP* was obtained, where $NP[w] =$ number of pages in a work *w*. **WoS2Pajek** also builds a CSV file *titles* with main data about *hits* (short name, WoS data file line, first author, title, journal, year), which can be used to list the results.

The usual *ISI name* of a work (its description in the field CR) has the following structure:

AU + ', ' + PY + ', ' + SO[:20] + ', V' + VL+ ', P' + BP

(first author’s surname, first letters of his/her name, the year of publication, the title of the journal, its volume and the number of starting page; + denotes concatenation), which results in such descriptions as

GRANOVETTER M, 1985, AM J SOCIOL, V91, P481

(all the elements are in the upper case). As in WoS the same work can have different ISI names, **WoS2Pajek** supports also *short names* (similar to the names used in HISTCITE output), which has the following format:

LastNm[:8] + ' ' + FirstNm[0] + '(' + PY+ ')' + VL + ':' + BP.

For example, for the mentioned work the short name is GRANOVET.M(1985)91:481. From the last names with prefixes VAN, DE, ... the spaces are deleted, and unusual names start with characters * or \$.

After all iterations of cleaning (see Appendix A for details), we finally constructed the data set used in this paper. From 70,792 hits (works with full description, $DC = 1$) we produced networks with sets of the following sizes: works $|W| = 1,297,133$, authors $|A| = 395,971$, journals $|J| = 69,146$, key words $|K| = 32,409$. We also removed multiple links and loops from the networks and labeled the

Table 1: Sizes of basic and reduced networks

	# nodes (sum)	# nodes 1	# nodes 2	# arcs
CiteN	1,297,133			2,753,633
CiteR	70,792			398,199
WAn	1,693,104	1,297,133	395,971	1,442,240
WAr	163,803	70,792	93,011	215,901
WKn	1,329,542	1,297,133	32,409	1,167,666
WKr	103,201	70,792	32,409	1,167,666
WJn	1,366,279	1,297,133	69,146	720,044
WJr	79,735	70,792	8,943	61,741

obtained basic networks **CiteN**, **WAn**, **WJn**, and **WKn** (Table 1). The statistical properties of these networks are presented in the Section 4.

3.3 Reduced networks construction

As it was already explained, for the cited only works ($DC = 0$) only partial descriptions are provided: we have information only about the *first* author, the journal and the publication year, and we have no information on the keywords (as there are no titles in ISI names and cited works). That is why for further analysis we constructed networks, which contain only works with complete description ($DC > 0$). All the link weights in the obtained networks were set to 1. We labeled these *reduced networks* **CiteR**, **WAr**, **WJr**, and **WKr**. In obtained networks, the sizes of sets are as follows: works $|W| = 70,792$, authors $|A| = 93,011$, journals $|J| = 8,943$, key words $|K| = 32,409$ (remained the same) (Table 1).

4 Statistics on basic networks

4.1 Distributions on CiteN

In Figure 2, the distributions of number of works per years are presented. The picture on the left side shows how many works from the set of **hits** (works with complete description, $DC = 1$) are published per year. If the amount of works in our dataset published in 1970 is 21, in 1991 there are already 148 works published, in 2001 - 427, and starting from 2007 the amount of works overcame the level of 1,000: they are 1,576 (2007), 2,119 (2008), 2,955 (2009), 3,564 (2010), 4,333 (2011). Starting from 2012, the amount overcame the level of 5,000: 5,035 (2012), 6,081 (2013), 7,006 (2014), 9,285 (2015), 9,693 (2016). For 2017 and 2018 the amount of works is reduced – 9,042 and 2,618, respectively – due to the incompleteness of the WoS data base for recent years. The distribution fits pretty well to the **exponential model**. The obtained values shows that the amount of works almost doubles in each 3 years ($\log(2)/\log(1.2338) = 3.299148$).

$$c \cdot a^{year-1965}, \text{ where } a = 1.2338, \text{ and } c = 0.2526.$$

The right side of Figure 2 shows the publication years for the works which are **cited only** by the hits ($DC = 0$). It is clearly seen that the majority of works which are being cited are published recently: if there are 13,202 works published in 1990, starting from 2000 the amount of works is 33,185 (2000), 50,211 (2005), 67,343 (2010). The amounts of works published after 2014 is decreasing: it is 52,074 (2014), 39,724 (2015), 23,704 (2016), 8,045 (2017), and 479 (2018), which simply means that works

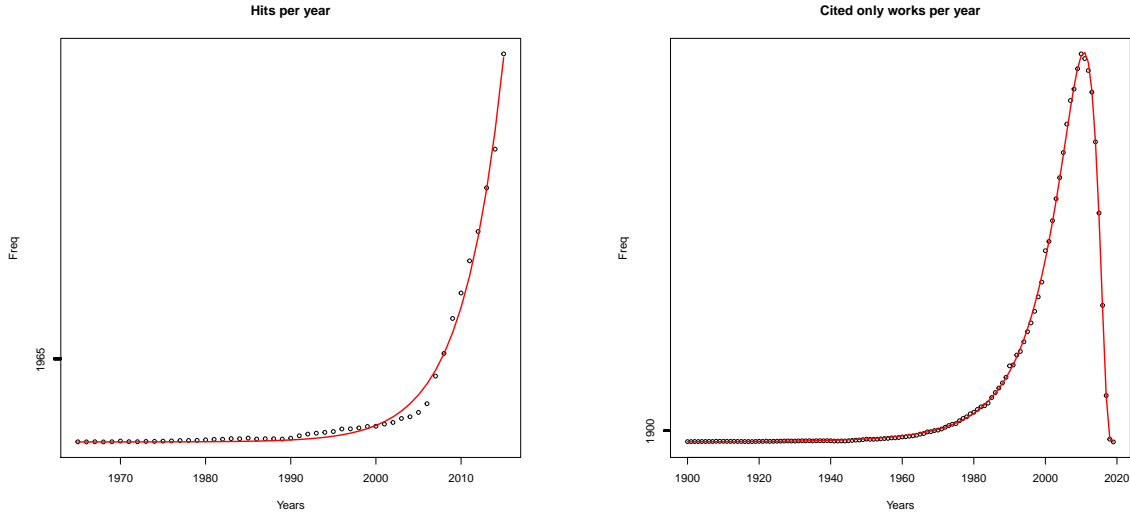


Figure 2: CiteN: Distribution of hits (left) and cited only works (right) by years

published recently could not yet get the large amount of citations. However, the presence of the most newest works shows that they are already seen and cited by the representatives of the field. We should also note that there are citations done to the works published in the first part of 20th century and even earlier – in 14th century (41 works), 15th (20), 16th (45), 17th (245), 18th (528), and 19th (2,151 works). This distribution (from 1900 to 2018) fits very well the **log normal distribution** (Batagelj et al., 2014, p. 119–121):

$$c \cdot \text{dlnorm}(2018 - \text{year}, a, b), \text{ where } a = 1.501, b = 0.9587, \text{ and } c = 7.110 \cdot 10^4.$$

In Figure 3, the indegree distribution in **CiteN** – cumulative and density – in double-logarithmic scale is shown. This distribution fits well the **power law** distribution $f = c \cdot n^{-\alpha}$, with fitted $\alpha = 2.3007$ and $c = 749338$. A small number of works attracts a large number of citations, and the large number of works attracts only small number of citations. Works with the largest indegrees are the most cited papers.

Table 2 presents 60 most *cited* works (indegree in **CiteN**). Almost half (28) of these works are published before 2000, and quarter of them (15) are books (their label ends with a colon “:”). The most cited *book* is the work of Wasserman and Faust published in 1994. Other books of networks scientists from the social sciences (marked in boldface, numbers of citations in parentheses) are: **Burt, *Structural Holes: The Social Structure of Competition*, 1992 (2333)**; **Putnam, *Bowling alone: America’s declining social capital*, 2000 (1510)**; **Scott, *Social Network Analysis: A Handbook*, 2000 (1192)**; **Coleman, *Foundations of Social Theory*, 1990 (1093)**; **Hanneman, *Introduction to social network methods*, 2005 (854)**; **Lin, *Social capital. A theory of social structure and action*, 2001 (800)**; **Rogers, *Diffusion of innovations*, 2003 (628)**; **Putnam, *Making democracy work: Civic institutions in modern Italy*, 1993 (613)**; **Zachary, *An information flow model for conflict and fission in small groups*, 1977 (583)**; **Burt, *Brokerage and closure: An introduction to social capital*, 2005 (565)**; **Rogers, *Diffusion of Innovation. 4th*, 1995 (555)**; **Fischer, *To dwell among friends: Personal networks in town and city*, 1982 (539)**. Interestingly, the a book *Ucinet for Windows: Software for Social Network Analysis*, 2002 appears twice, attributed to Everett (1171) and Borgatti (999) as the first author.

The second place is taken by a classical article of Granovetter on the *strength of weak ties* concept. Other articles of social network scientists presented in the table are (with topics in parentheses) belong to McPherson (*homophily*), Freeman and Bonachich (*centrality, betweenness*), Burt (*structural holes*),

Table 2: CuteN: The most cited works - indegree

i	freq	id	i	freq	id
1	5348	WASSERMA_S(1994):	31	734	*NEWMAN_M(2001)98:404
2	4471	GRANOVET_M(1973)78:1360	32	719	*NEWMAN_M(2010):
3	2906	*WATTS_D(1998)393:440	33	701	PORTES_A(1998)24:1
4	2614	*BARABASI_A(1999)286:509	34	687	BLEI_D(2003)3:993
5	2561	FREEMAN_L(1979)1:215	35	670	BURT_R(2004)110:349
6	2447	BOYD_D(2007)13:210	36	654	HANSEN_M(1999)44:82
7	2429	MCPHERSO_M(2001)27:415	37	639	PALLA_G(2005)435:814
8	2330	BURT_R(1992):	38	634	*CLAUSET_A(2004)70:066111
9	1886	COLEMAN_J(1988)94:95	39	629	*BONACICH_P(1987)92:1170
10	1572	*NEWMAN_M(2003)45:167	40	628	ERDOS_P(1959)6:290
11	1520	*GIRVAN_M(2002)99:7821	41	628	UZZI_B(1997)42:35
12	1510	PUTNAM_R(2000):	42	628	ROGERS_E(2003):
13	1285	*ALBERT_R(2002)74:47	43	613	PUTNAM_R(1993):
14	1240	GRANOVET_M(1985)91:481	44	593	BERKMAN_L(1979)109:186
15	1192	SCOTT_J(2000):	45	583	ZACHARY_W(1977)33:452
16	1171	EVERETT_M(2002):	46	572	BORGATTI_S(2009)323:892
17	1166	NEWMAN_M(2004)69:026113	47	569	*NEWMAN_M(2001)64:025102
18	1093	COLEMAN_J(1990):	48	565	BURT_R(2005):
19	1058	STEINFIE_C(2007)12:1143	49	561	ADLER_P(2002)27:17
20	1034	FORTUNAT_S(2010)486:75	50	559	CHRISTAK_N(2008)358:2249
21	999	BORGATTI_S(2002):	51	555	ROGERS_E(1995):
22	945	CHRISTAK_N(2007)357:370	52	554	MILGRAM_S(1967)1:61
23	867	FREEMAN_L(1977)40:35	53	553	BARON_R(1986)51:1173
24	854	HANNEMAN_R(2005):	54	550	GRANOVET_M(1978)83:1420
25	800	LIN_N(2001):	55	539	FISCHER_C(1982):
26	757	KAPLAN_A(2010)53:59	56	537	BRIN_S(1998)30:107
27	756	*BLONDEL_V(2008):P10008	57	524	MARSDEN_P(1990)16:435
28	742	NAHAPIET_J(1998)23:242	58	523	KEMP_D(2003):137
29	740	FORNELL_C(1981)18:39	59	523	KLEINBER_J(1999)46:604
30	740	*NEWMAN_M(2006)103:8577	60	517	*BOCCALET_S(2006)424:175

bold is for social scientists, * for physicists

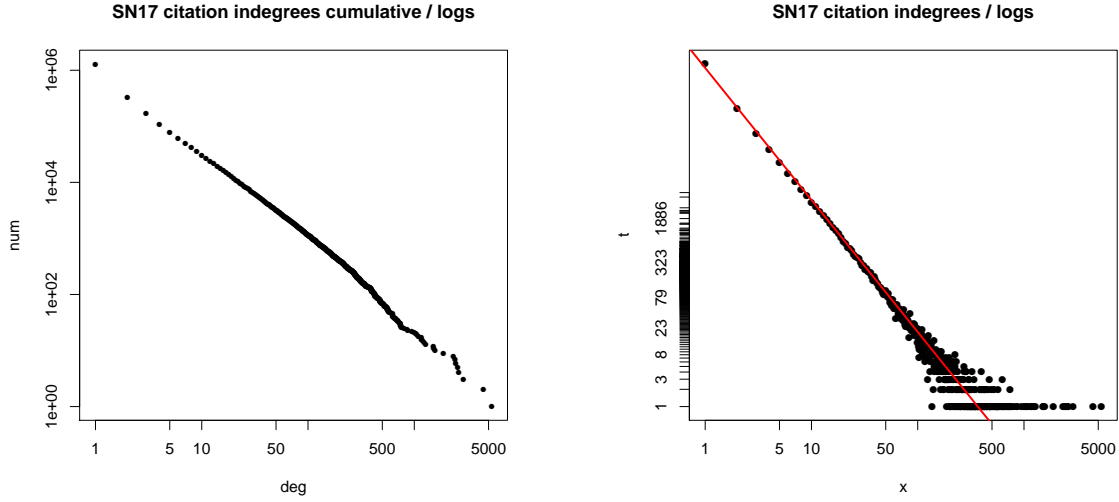


Figure 3: CiteN: Indegree distribution – cumulative (left) and density (right) in double-logarithmic scale

Coleman, Portes, Adler (social capital), Granovetter, Uzzi (embeddedness), and Milgram (small world).

The list includes a lot of names of physicists working within the Network approach (marked by *): highly ranked articles of *Watts DJ – Collective dynamics of 'small-world' networks*, *Nature* 1998 (2906), as well as *Barabasi AL – Emergence of scaling in random networks*, *Science* 1999 (2614). Other works are of *Newman, Albert, Girvan, Fortunato, Blondel, Clauset* on large and complex networks, community detection and clustering. A famous work of mathematicians Erdős and Rényi *On random graphs* published in 1959 is also on the list.

There are also some representatives of the other disciplines, in topics such as social network sites and social media (including highly rated article of *Boyd D., Social network sites: Definition, history, and scholarship*, published in 2007 and having 2447 citations); medicine (including well-known works of Christakis and Fowler on spread of obesity and smoking), and management.

Works with the largest outdegree in **CiteN** are the most *citing* works. These works are books, introductory chapters of books, and review articles. Most of these works belong to the field of social sciences, they include education, human relationships, archaeology, migration, internet studies, and social media, but not exactly the topic of SNA. However, some works published in journals in physics and computer science do address the issues of network analysis (Boccaletti on complex networks, Costa on complex networks, Castellano on social physics of social dynamics, Brandes on methodological foundations of network analysis), as well as works representing – quite surprisingly – the field of Animal social networks.

4.2 Distributions on WAR

As the works with incomplete description (cited only, $DC = 0$) contain information only on the first author of works, it is correct to use **WAR** reduced network to get the information of the number of authors per work and works per author (outdegree and indegree of a network).

The distribution on the number of authors in works according to the reduced **WAR** network is presented in Figure 4, and the partition of number of authors in works according to this network in Table 3.

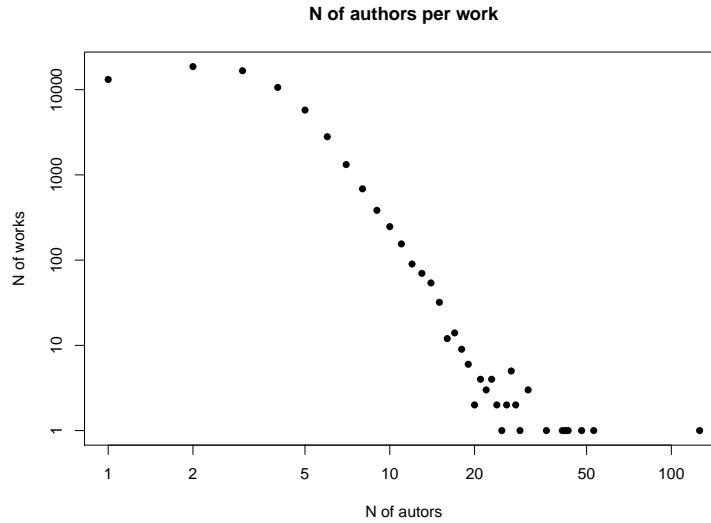


Figure 4: WAr net: Distribution of number of authors by works

The majority of works (91%) are written by 1 author (19%), or in co-authorship of 2 (26%), 3 (24%), 4 (15%), and 5 (8%) authors. In some works, however, the amount of authors is pretty high. The extreme case is the work *Sharing and community curation of mass spectrometry data with Global Natural Products Social Molecular Networking* published in *Nature Biotechnology* in 2016, which has 126 authors. Almost all the works with a large number of co-authors belong to the field of natural science (medical, health, epidemiological, and behavioral studies). For these fields, the inclusion of all authors involved in a research project is quite a frequent practice. However, the third rated article *Discussion on the paper by Handcock, Raftery and Tantrum* published in *Royal Statistical Society Journal Series A: Statistics in Society* collects 48 social networks scientists.

According to the indegree of this network, almost all of the authors with the largest number of papers have Chinese or Korean surnames (Wang, Zhang, Chen, Li, Liu, Lee, Kim, Yang, Wu, Ma). The authors with the largest numbers of works are the following (number of articles in parentheses): WANG_Y (410), WANG_X (339), ZHANG_Y (332), LIU_Y (321), CHEN_Y (317), ZHANG_J (310), LLJ (305), LI_Y (304), LLX (287). The issue of the super-productivity of these groups of authors was discussed by Harzing (2015) – this is the well-known “three Zhang, four Li” effect: 80% of people in China have one of only around 100 surnames. Thus, there is a high chance that different authors, having the same surname and first letter of the name, shrink together, creating ‘multiple personalities’. This problem could be overcome if we would use a special ID (such as ORCID) for each scientist (but this information is not provided in WoS yet).

That is why in Table 4 only those authors are presented that did not have Chinese or Korean names. After the serial number, the number from the original distribution is preserved, so that it can be seen how many authors with “multiple personalities” are presented in the data. However, with these names the authors disambiguation problem still occurs, as there are authors with such widespread surnames as Smith, Rodriguez, Johnson, etc. The table lists the well-known authors from the SNA field. The most prolific authors are Latkin (130 works), Valente (97), Dunbar (91), Newman (81), Christakis (74), Doreian (72), Carley (72), Burt (71), and others.

Table 3: WAr net: Number of authors in works – outdegree

Outdeg	Freq	Cum freq%	Outdeg	Freq	Cum freq%
0	44	0,062	19	6	0,008
1	13157	18,585	20	2	0,003
2	18635	26,324	21	4	0,006
3	16661	23,535	22	3	0,004
4	10617	14,997	23	4	0,006
5	5759	8,135	24	2	0,003
6	2802	3,958	25	1	0,001
7	1322	1,867	26	2	0,003
8	686	0,969	27	5	0,007
9	384	0,542	28	2	0,003
10	247	0,349	29	1	0,001
11	155	0,219	31	3	0,004
12	90	0,127	36	1	0,001
13	70	0,099	41	1	0,001
14	54	0,076	42	1	0,001
15	32	0,045	43	1	0,001
16	12	0,017	48	1	0,001
17	14	0,020	53	1	0,001
18	9	0,013	126	1	0,001
Sum				70792	100,000

4.3 Distributions on WJn and WJr

The distribution of number of works per journals is presented in Figure 5. It has a scale-free form. According to the indegree distribution of the **WJn** network, the majority of journals – in sum, 83% – are represented in the data set with 1 (58%), 2 (12%), 3 (6%), 4 (4%) or 5 (2.5%) works. Other 17% (11,976) journals have 6 works and more.

Table 5 shows the most used journals, which have the maximum values of the indegree distribution in networks **WJn** (journals used in all publications) and **WJr** (journals used in the publications with complete description). The journals in *social sciences* are marked in boldface.

The left side of the table presents the indegree from **WJn** ($DC = 0, DC = 1$). It contains quite a lot of journals from the social sciences – such as sociology, psychology, management and business. However, the dominant journal is *Lecture Notes in Computer Science*, which has 7,757 works, followed by *Social Science & Medicine* and *Journal of Personality and Social Psychology* with more then 3,000 works published. Other journals that have more then 2,000 works are multidisciplinary journals as *Proceedings of the National Academy of Sciences of the USA*, *Science*, *Nature*, as well as disciplinary journals *Computers in Human Behavior*, *American Journal of Public Health*, and *American Sociological Review*. These journals are followed by other top-ranked journals in different disciplines having more than 1,500 works published, such as (in descending number of works) *Physica A*, *Animal Behaviour*, *American Journal of Sociology*, *Journal of the American Medical Association*, *Lancet*, *Scientometrics*, *Academy of Management Journal*, *Lecture Notes in Artificial Intelligence*, *Journal of Applied Psychology*, *American Economic Review*. The main field’s outlet – *Social Networks* journal – is positioned on the 18th place, having 1642 works. The remaining journals cover many disciplines such as Medicine, Psychiatry, Gerontology, Psychology, Management, Marketing, Computer and Information science.

However, the situation changes quite significantly if we look at the journals with the largest amount

Table 4: WAr net: Authors with the largest number of papers – indegree

Rank	Orig rank	Author	Value	Rank	Orig rank	Author	Value
1	45	LATKIN_C	130	26	211	SCHNEIDE_J	52
2	72	VALENTE_T	97	27	212	LEYDESDO_L	51
3	84	DUNBAR_R	91	28	217	LITWIN_H	50
4	102	NEWMAN_M	81	29	228	RICE_E	48
5	121	CHRISTAK_N	74	30	232	KAWACHI_I	47
6	126	DOREIAN_P	72	31	233	BONACICH_P	46
7	127	CARLEY_K	72	32	234	PARK_Y	46
8	129	BURT_R	71	33	237	RODRIGUE_M	46
9	130	BORGATTI_S	71	34	238	NGUYEN_H	46
10	139	SNIJDE_R	67	35	239	CROFT_D	46
11	140	BARABASI_A	67	36	249	EVERETT_M	44
12	146	FOWLER_J	65	37	252	FERNANDE_M	44
13	149	KAZIENKO_P	64	38	255	CONTI_M	44
14	150	ROBINS_G	64	39	256	MORRIS_M	43
15	152	WELLMAN_B	63	40	259	CONTRACT_N	43
16	163	FALOUTSO_C	60	41	266	WHITE_H	42
17	167	RAHMAN_M	59	42	267	SKVORETZ_J	42
18	172	PATTISON_P	58	43	275	PENTLAND_A	41
19	176	TUCKER_J	58	44	276	WILLIAMS_M	41
20	181	HOSSAIN_L	56	45	280	MOODY_J	40
21	187	JOHNSON_J	54	46	289	FRIEDMAN_S	40
22	194	NGUYEN_T	54	47	290	MARSDEN_P	39
23	196	MARTINEZ_M	53	48	292	BERKMAN_L	39
24	207	GONZALEZ_M	52	49	301	KRACKHAR_D	38
25	209	RODRIGUE_J	52	50	306	MORENO_M	38

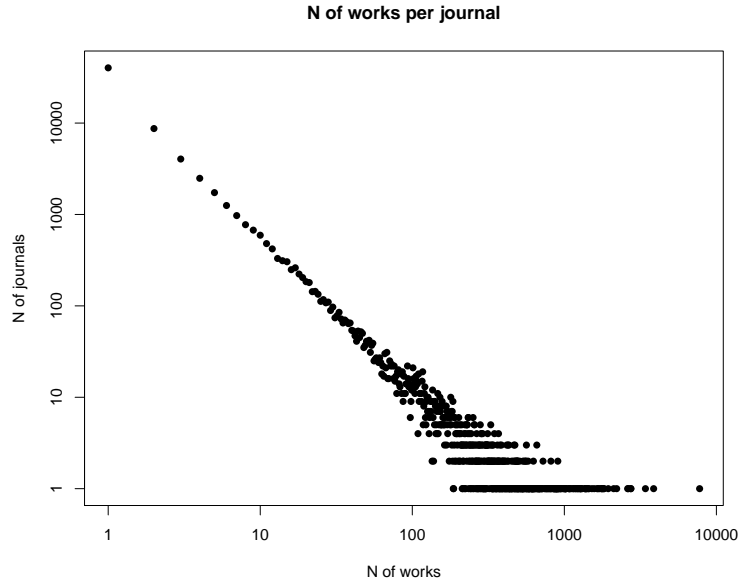


Figure 5: WJn net: Distribution of number of works by journals

of works according to the **WJr** ($DC = 1$) network indegree (right side of the table). The first place is still taken by *Lecture Notes in Computer Science* with 2,009 citations, which is followed by *Social Networks* with 1,134 citations. In this list, the amount of journals from the field of social sciences is less than at the left side. In the WAr network, some journals have shown up in the top, which were not presented in the list of top-40 works in WJn network – such as *Plos One*, *Communications in Computer and Information Science*, *Social Network Analysis and Mining*, and others. Some journals, which were on the top of WJn network indegree distribution, have lowered their positions – such as *American Journal of Sociology*, – while some journals have disappeared – such as *Nature* or *Animal Behaviour*. This means that works from these journals are cited quite intensively by the works found by the network-related search query (hits), but at the same time they are not found by this query, as they have other keywords. Thus, the right side of the table better represents the current thematic directions in the field.

4.4 Distributions on WKn

For the works with full description ($DC = 1$) the keywords are supposed to be presented in the special fields **DE** (Author Keywords) and **ID** (Keywords Plus) of the description. However, for some articles this information is not provided. In such cases the keywords are constructed by **WoS2Pajek** from the titles of works. All composite keywords were split into single words, and lemmatization was used to deal with the *word-equivalence problem*. However, the works which are cited only ($DC = 0$) do not have keywords.

The majority of works in **WKn** (95%) do not have any keywords - these are the works which do not have a complete description ($DC = 0$). The amount of keywords for 70,792 works varies from 1 to 84. The most frequent keywords are presented in Table 6. Not surprisingly, the words *social* and *network* are mentioned in the largest number of works, followed by *analysis*, which shows the relevance of the data to the topic being studied. Some other frequently used words – *model*, *community*, *graph*, *structure*, *relationship*, *tie* (marked in boldface) – are related to network analysis, while others - *datum*, *base*, *information*, *research*, *theory*, *algorithm*, *approach*, *pattern*, *effect* – to the scientific research in

Table 5: WJn and WJr nets: The most used journals – indegree

WJn – Journals used in all publications			WJr – Journals used by hits		
Rank	Value	Id	Rank	Value	Id
1	7757	LECT NOTES COMPUT SC	1	2009	LECT NOTES COMPUT SC
2	3866	SOC SCI MED	2	1134	*SOC NETWORKS*
3	3414	J PERS SOC PSYCHOL	3	806	COMPUT HUM BEHAV
4	2741	P NATL ACAD SCI USA	4	667	PLOS ONE
5	2734	COMPUT HUM BEHAV	5	531	LECT NOTES ARTIF INT
6	2631	SCIENCE	6	470	PHYSICA A
7	2609	AM J PUBLIC HEALTH	7	399	COMM COM INF SC
8	2208	NATURE	8	375	SOC SCI MED
9	2111	AM SOCIOLOG REV	9	319	PROCD SOC BEHV
10	1945	PHYSICA A	10	314	PHYS REV E
11	1825	ANIM BEHAV	11	283	PROCEDIA COMPUTER SCIENCE
12	1812	AM J SOCIOLOG	12	273	SOC NETW ANAL MIN
13	1780	JAMA-J AM MED ASSOC	13	238	ADV INTELL SYST
14	1763	LANCET	14	231	SCIENTOMETRICS
15	1759	SCIENTOMETRICS	15	225	CYBERPSYCHOL BEHAV
16	1703	ACAD MANAGE J	16	216	EDULEARN PROC
17	1668	LECT NOTES ARTIF INT	17	215	GERONTOLOGIST
18	1642	*SOC NETWORKS*	18	198	INTED PROC
19	1573	J APPL PSYCHOL	19	194	SCI REP-UK
20	1517	AM ECON REV	20	188	J MED INTERNET RES
21	1450	J MARRIAGE FAM	21	186	P NATL ACAD SCI USA
22	1441	EXPERT SYST APPL	22	180	EXPERT SYST APPL
23	1403	BRIT MED J	23	176	INFORM SCI
24	1399	CHILD DEV	24	170	BMC PUBLIC HEALTH
25	1379	RES POLICY	25	167	NEW MEDIA SOC
26	1372	COMMUN ACM	26	160	IEEE T KNOWL DATA EN
27	1365	NEW ENGL J MED	27	153	IEEE ACCESS
28	1311	PHYS REV E	28	145	AIDS BEHAV
29	1287	SOC FORCES	29	140	INFORM COMMUN SOC
30	1279	GERONTOLOGIST	30	139	STUD COMPUT INTELL
31	1278	BRIT J PSYCHIAT	31	136	IEEE ICC
32	1267	AM J PSYCHIAT	32	134	IEEE DATA MINING
33	1244	STRATEGIC MANAGE J	33	132	AM J SOCIOLOG
34	1225	MANAGE SCI	34	128	J MATH SOCIOLOG
35	1221	J BUS RES	35	120	IEEE INFOCOM SER
36	1189	ACAD MANAGE REV	36	120	ORGAN SCI
37	1188	J CONSULT CLIN PSYCH	37	119	PROC INT CONF DATA
38	1154	ORGAN SCI	38	118	KNOWL-BASED SYST
39	1150	ADDICTION	39	117	IFIP ADV INF COMM TE
40	1123	CYBERPSYCHOL BEHAV	40	114	IEEE GLOB COMM CONF

Table 6: WKn net: The most used keywords – indegree

Rank	Value	Id	Rank	Value	Id
1	51333	social	31	3485	structure
2	46191	network	32	3479	life
3	11751	analysis	33	3444	risk
4	10219	model	34	3358	research
5	8104	community	35	3143	learn
6	8090	use	36	3116	influence
7	7596	base	37	3054	student
8	7439	information	38	3054	impact
9	7061	health	39	3049	perspective
10	7023	behavior	40	3042	complex
11	6745	online	41	3024	theory
12	6087	networking	42	2859	organization
13	5833	media	43	2828	relationship
14	5404	support	44	2802	algorithm
15	5101	communication	45	2776	education
16	5013	study	46	2714	group
17	4759	datum	47	2704	mobile
18	4376	management	48	2698	tie
19	4372	internet	49	2695	adult
20	4164	knowledge	50	2633	approach
21	4126	user	51	2608	care
22	4023	facebook	52	2551	adolescent
23	3984	technology	53	2479	role
24	3907	site	54	2472	state
25	3888	web	55	2467	innovation
26	3855	self	56	2434	pattern
27	3784	graph	57	2385	effect
28	3676	performance	58	2339	people
29	3534	service	59	2333	trust
30	3512	dynamics	60	2332	family

general. There are also words related to some exact topics which are being studied in network analysis – *online, networking, facebook, internet, site, web; health, behavior; support; communication; influence; innovation; trust*. We should note that keywords can have different meanings in different contexts; however, their identification in different subgroups (of authors or works) can give us better understanding of the topic structure of the SNA field.

5 Citation network

5.1 Boundary problem in Citation network

The original **CiteN** network had 1,297,133 nodes. Considering the indegree distribution in this network we got the following counts for the lowest number of received citations: 0 (41,954), 1 (933,315), 2 (154,895), 3 (58,141), and 4 (29, 885), which all together cover 94% of citations. Thus, most of the works were terminal ($DC = 0$) or were referenced only once or twice (indegree = 1 or 2). Therefore,

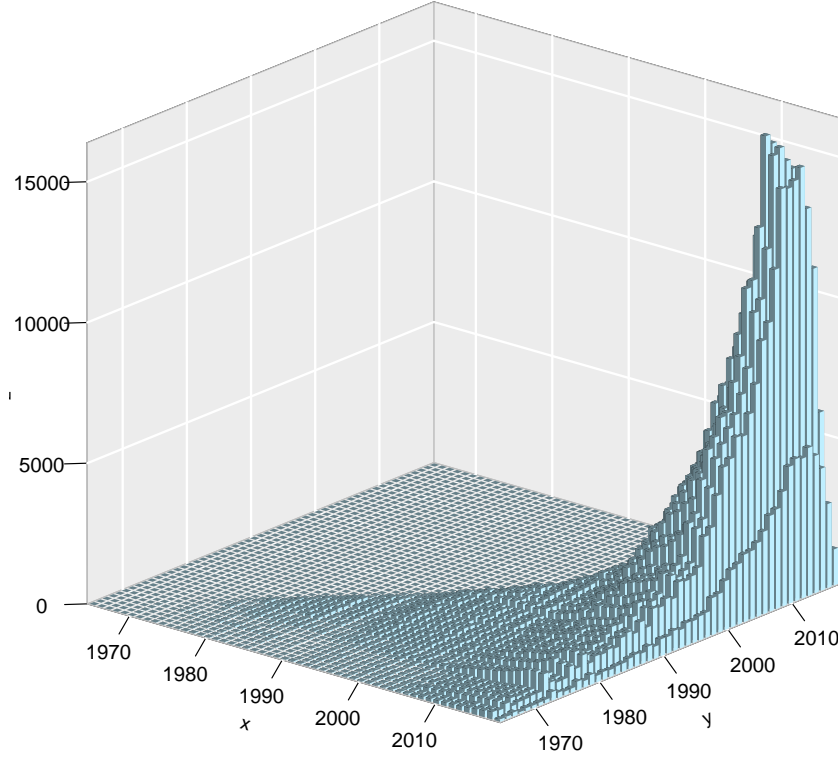


Figure 6: Citations between years

we decided to remove all the ‘cited only’ nodes with indegree smaller than 3 ($DC = 0$ and $\text{indeg} < 3$) – the *boundary problem* (Batagelj et al., 2014). We also removed all the nodes starting with string [ANON. Finally, we got a subnetwork **CiteB** with 222,086 nodes and 1,521,434 arcs.

5.2 Analysis of Citation network

It is interesting to observe how many citations are per years. We combined **CiteB** network with partition on years **Years.clu** of publications and constructed the network of **citations between years**, where the values of lines are equal to the number of times that all works published in one year were cited in all works published in another year (the network is directed, only later years can cite previous years). Figure 6 presents the distribution of citations between years in a three-dimensional space. The majority of citations in recent works are done to the recent works as well. The years having the largest amount of citations from other years are 2010 (88,840), 2009 (82,294), 2007 (80,129), 2011 (79,843), 2008 (77,595). Among top-20 years, there are only several years which do not belong to the 2000’s: 1999 (39,629), 1998 (36,649), 1997 (27,667), and 1996 (26,216). The largest line weights are from 2015 and 2016 to 2010 (16,384 and 15,755, respectively) and 2011 (16,026 and 15,944).

Figure 7 presents the curves of **normalized values of citations per each year** in the period 1985–2018 (54 years in total). It clearly shows that the yearly citation patterns do not vary significantly from year to year – there are always noticeably more citations done to the recent works, then to works published previously. This effect was already observed in the analysis of large bibliographic data sets from WoS (Šubelj and Fiala, 2017).

A citation network is usually (almost) acyclic; however, it can include some small cyclic parts, which

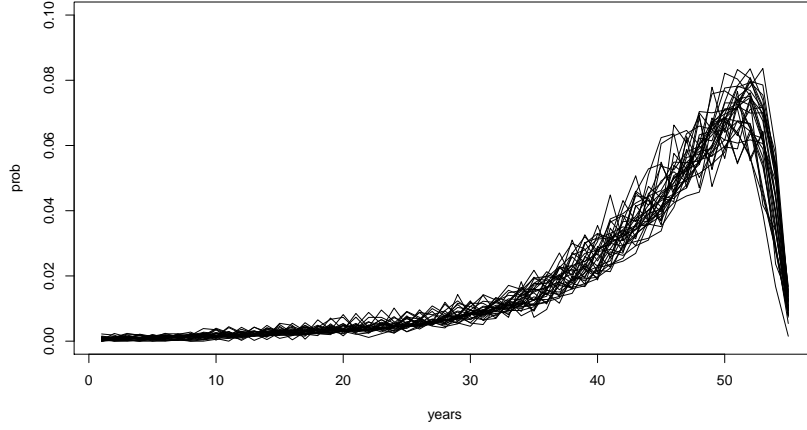


Figure 7: Citations between years – normalized

can be identified as nontrivial strong components of the network (with the minimum size 2). First we searched for nontrivial strong components (see Appendix B for details). To get an acyclic network, as required by the SPC weights algorithm, we applied the *preprint transformation* to CiteB. The preprint transformation function replaces each work u from a strong component by pair of nodes – published work u and its preprint version u' . Node u' is labeled by the label of node u preceded by a character “=”. Published work can cite only preprints. Each strong component was replaced by a corresponding complete bipartite graph on pairs (Batagelj et al., 2014). The resulting network **CiteT** has 222,189 nodes and 1,521,658 arcs.

We computed the **SPC weights** on **CiteT** network arcs (Batagelj et al., 2014; Batagelj, 2014). The normalized SPC weight of an arc is equal to the probability that a random path through the network is passing through this arc. We identified main paths (CPM main path and Key-route paths) in this network, and then used **Link islands approach** (Batagelj et al., 2014) to find the most “important” parts of this network. To find the most “important” nodes in the network this approach was supplemented by the **Node islands approach**; we also computed **probabilistic flow** for the network **CiteT**.

5.3 CPM main path and Key Routes

Figure 8 displays the CPM Main path through the SNA literature (which is the same to the one obtained with the Main path procedure), which includes 59 nodes. We divided this CPM Main path to three parts, according to the disciplinary of the works that are presented.

The first group, composed of the works published in 1944 – 1996, present the works of network scientists from the social sciences. These works appeared (see Appendix C) in journals *Social networks*, *Administrative Science Quarterly*, *Annual Review of Sociology*, *American Sociological Review*, *Social Forces*, *Sociological Methods & Research*, *Journal of Mathematical Psychology*, *Psychological Review*, *The Journal of Psychology*, recalling the history of SNA field formation. In this group, 6 out of 20 works belong to R. Burt.

However, since 1999, the initiative in the field goes to the physicists, whose works appear in journals *Physical Review E*, *Journal of Statistical Physics*, *Reviews of Modern Physics*, *European Physical Jour-*

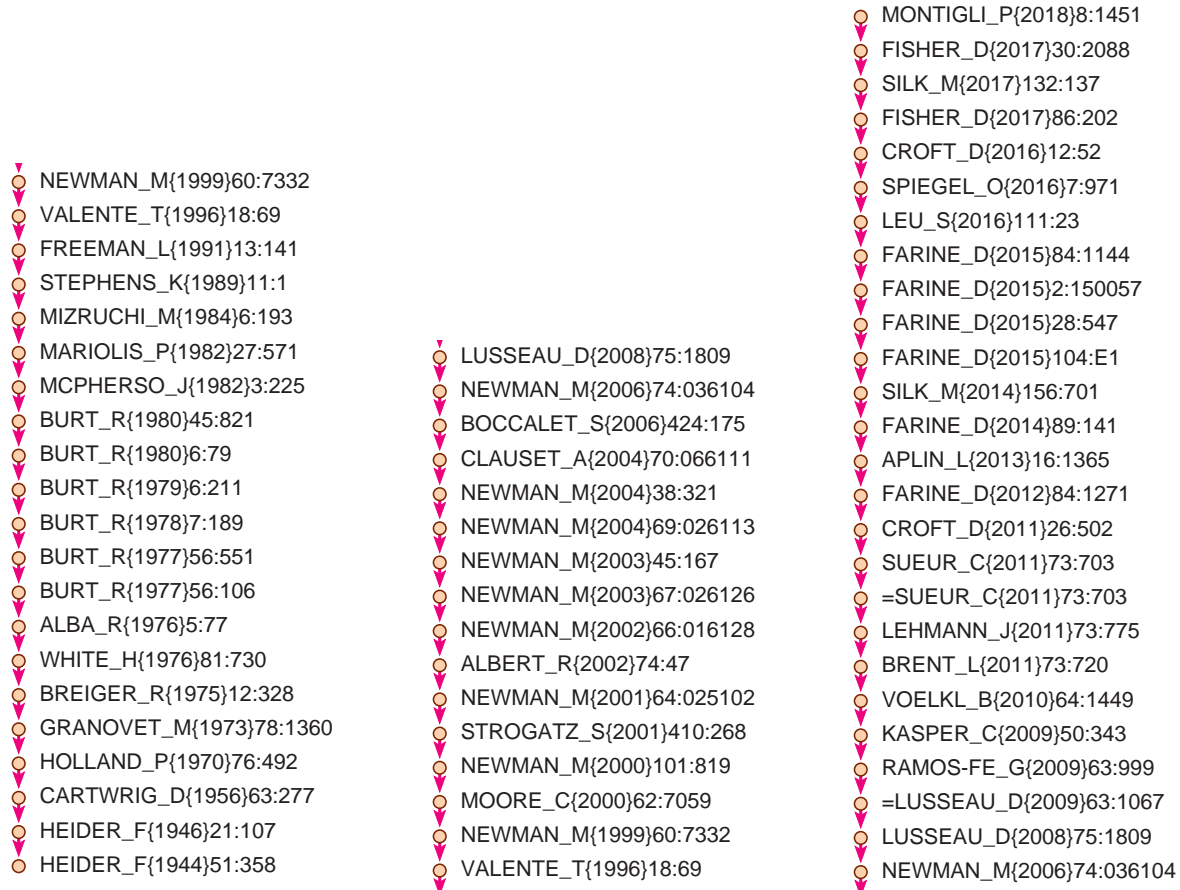


Figure 8: SPC net: Main path by fragments – sociology, physics, biology
 (2nd and 3rd parts starts with two works from the previous group)

nal B, *Physics Reports*, *Nature*, and *SIAM Review*. In this part of network, 9 out of 14 works belong to M. Newman.

The third part of the Main path, which contains works from 2008 to 2018, is devoted to completely another topic – animal social networks. The works appear in journals *Animal Behaviour*, *American Journal of Primatology*, *Primates*, *Journal of Evolutionary Biology*, *Journal of Animal Ecology*, *Journal of Evolutionary Biology*, *Trends in Ecology & Evolution*, and others. The most active author in this group is D. Farine, who has 6 out of 25 works. While the *invasion of physics* into the SNA field was already shown in other studies (Lazer et al., 2009; Brandes and Pich, 2011), the appearance of the third group in the Main path is quite surprising. For the centrality literature analysis it was shown that the trend goes from physics to neuroscience (Batagelj et al., 2014) and for network clustering literature it consists only of social and physical parts (Batagelj et al., 2019)

The procedure of Key-route paths (Batagelj et al., 2014) produces a more nuanced image of most important paths in the SNA literature, as it contains some deviations from the structure of the network, identified with the CPM Main path method. Figure 9 shows the obtained Key-route paths, which contain 127 nodes. Basically, we still get the division into three previously mentioned groups.

Key-route paths **the first period (1944–1999)** includes 50 works of the SNA from the social scientists. It starts with two works of Heider on his *theory of social perception and cognitive organization*

(1944, 1946), which form the basis for the work of Cartwright (1956) on *structural balance*. Later, two works of Holland on *structural models* follow, published in 1970–1971. Next comes the classical paper of Granovetter on *strength of weak ties* (1973), which is a basis for the works of Breiger on *clustering relational data* and White on *blockmodels*, followed by Alba on the *measure based on social proximity* in networks, and Boorman on *role structures in multiple networks*, published in 1975–76. Then there are 6 works of Burt on *positions in multiple networks (stratification and prestige)*, *structural equivalence and networks subgroups*, published from 1977 to 1981, which have connections to the works of Holland on *social structure*, Breiger, Lauman, and Wellman on communities structures, Breiger on *social roles*, and Faust on *structural and general equivalences*, published at about the same time period. Summing up, this group of works is dealing with **network and community structures, positions, structural equivalence, and blockmodels**.

These works are followed by works on **measurement and different network metrics**: of Romney and Bernard (1982) on *recalled data for networks construction*, and Stephenson on *centrality* (1989). The last work is also connected to the works of Mizruchi on *measures of influence*, Bonacich on *power and centrality measures*, and Burt, Mariolis, Mizruchi on *interlock networks*. This is followed by the work of Freeman on the *measures of centrality*, which was published in 1991, and it is very strongly connected to the work of Valente on *social network thresholds in the diffusion of innovations* (1996). Another strong connection of Valente goes to the previous work of Michaelson (1993) on the *development of a scientific specialty as a diffusion through social relations*.

The work of Valente is the one bridging the first group of scientists from the social science with the **group of physicists**, which includes 28 works from the Network science discipline published in the **second period (1999–2008)**. Valente's work was cited by Newman in the work on the *small-world network model*, appeared in 1999. This work is followed by others on the same topic (small-world networks), written by Moore, Newman, as well as by the work of Callaway on *random graphs* (2000). Then both directions meet at the work of Strogatz on *complex networks*. Then this topic continues, including *clustering and preferential attachment in growing networks and spread of epidemic diseases on networks* (Newman, 2001, 2002). Since 2003 to 2006, this topic goes to the direction of *community structures detection in large networks*.

We should note, however, that there is also an **epidemiological turn** in the observed network, which starts from the works of Stephens and Freeman, followed by Milardo, Neaigus, and Rothenberg in the works on the *diseases transmission* (1992–98), and Potterat in the *infections transmission* (1999). These works are cited by Ferguson (disease transmission), and then the route comes back to the main path to the Newman's work on the structure and function of complex networks (2003).

Since that time, the topics of the obtained Key-routes network change significantly. The work of Newman on community structures is strongly connected to the work of Lusseau (2009) on **animal social networks**, which starts the **third period (2008–2018)** with 49 works of the behavioural ecologists. This work is followed by many others, on the same topic: Krause, James (2009) with *general works* on animal SNA, and Ramos-Fernandez, Kasper, Voell, Lehmann, Brent, Sueur (2009–2011), working with *social networks of Nonhuman Primates* (monkeys, baboons). These works are followed by Croft (2011), which represent a practical guide on *hypothesis testing* in Animal social networks. This work is cited by others presenting the research on *mixed-species groups* (Farine), *killer whales* (Foster), *sharks* (Mourier), *dolphins* (Cantor), published in 2012, and *birds* (Silk) and *starlings* (Boogert), published in 2014. There are also some more works on the *methodological issues* – of Hobson (*An analytical framework for quantifying and testing patterns of temporal dynamics in social networks*), Castels (*Social networks created with different techniques are not comparable*), and Pinter-Wollman (*The dynamics of animal social networks: analytical, conceptual, and theoretical advances*), published in 2013–2014. These works are followed

by four works of Farine, published in 2015, on both *methodological issues on constructing, conducting and interpreting animal SNA*, and study of the *wild birds territory acquisition*. We should also note that there are some works connected to the main path, which represents the *social personality and phenotype* (Wilson, Alpin, Farine), published in 2013-2014.

The upper part of the network contains of works published in the last years, 2016–2018. It presents studies on *disease transmission* (Adelman, Sah, Silk, Dougherty), and the studies of *animal paths tracking* (Leu, Spiegel). Also it contains works on *theoretical issues* (*Current directions in animal social networks* by Croft, *Social traits, social networks and evolutionary biology* by Fisher) and *implementation of different models of network analysis to Animal behaviour research*: exponential random graph models and statistical network models (Silk), the potential of stochastic actor-oriented models (Fisher), dynamic vs. static SNA (Farine).

The full information on the papers (first author, title, journal, year of publication) included into the Main path and Key-route paths is presented in Table 7 in the Appendix C. It is also relevant for our analysis of the islands, presented in the following subsections. In this table, the second column (code) describes in which analysis the work appears: 1- Key-routes, 2- Main Path (CPM), 3- Island 5, 4 - Island 4, 5 - Node Island, 6 - Probabilistic Flow Island.

5.4 Link Islands

Using Islands approach, we searched for SPC link islands (on link weights) (Batagelj et al., 2014, p. 55–57) with the number of nodes between 10 and 200, and found 5 islands of 138, 65, 13, 12, and 11 nodes. The obtained largest Island 4 with 138 nodes is presented in Figure 10. Its structure reminds the structure of the Key-route paths - there are 89 overlapping nodes in two networks. The majority of the works presented in this island (from bottom to the work of Valente, published in 1996) belong to the social network scientists, whose works were already discussed in previous subsection. In comparison to the Key-routes, this network includes more evident group of *works on blockmodeling* – by Faust, Doreian, and Batagelj, published in 1992–1997. In the physicists part (from Newman, 1999 to Newman, 2006 on the main route) the topic of *evolving networks* is also presented (Bianconi, Yook, 2001, Jeong, 2003). The third, behavioural ecologists' part is pretty short and finishes by the works on animal social networks published in 2010.

However, this group is fully presented in another Island 5 containing 65 nodes (Figure 10). It has 39 overlapping nodes with the Key-routes. 'New' works in the island also belong to the topics on animal social networks described above. However, there are some works devoted to the methodological issues of Network analysis itself – *reconstructing animal social networks from independent small-group observations* (Perreault, 2010), *temporal dynamics and network analysis* (Blonder, 2012), *mining of animal social systems* (Krause, 2013), *animal social network inference and permutations for ecologists in R* (Farine, 2013), *estimating uncertainty and reliability of social network data using Bayesian inference* (Farine, 2015). It is interesting that this group form a separate subnetwork, even though it is connected to the upper part of Island 4 by topic. It may mean that the works included into this subnetwork are more connected to each other, while social animal network works in Island 4 are more strongly connected to the previous works of physicists.

Other obtained islands are presented in Figure 12. For the purpose of better visibility of the picture, the weights were multiplied by 100. The left Island 2 consists of 12 works in the field of social networks in *education*, including issues of leadership, teachers and students communication and collaboration. Another very coherent group is presented in the same figure on the bottom left. These are 11 works in *Neuropsychiatrie* written by Austrian authors. The left upper island presents 13 works of *physicists* with the strongest links between the work of Boccaletti published in 2014 on the structure and dynamics of

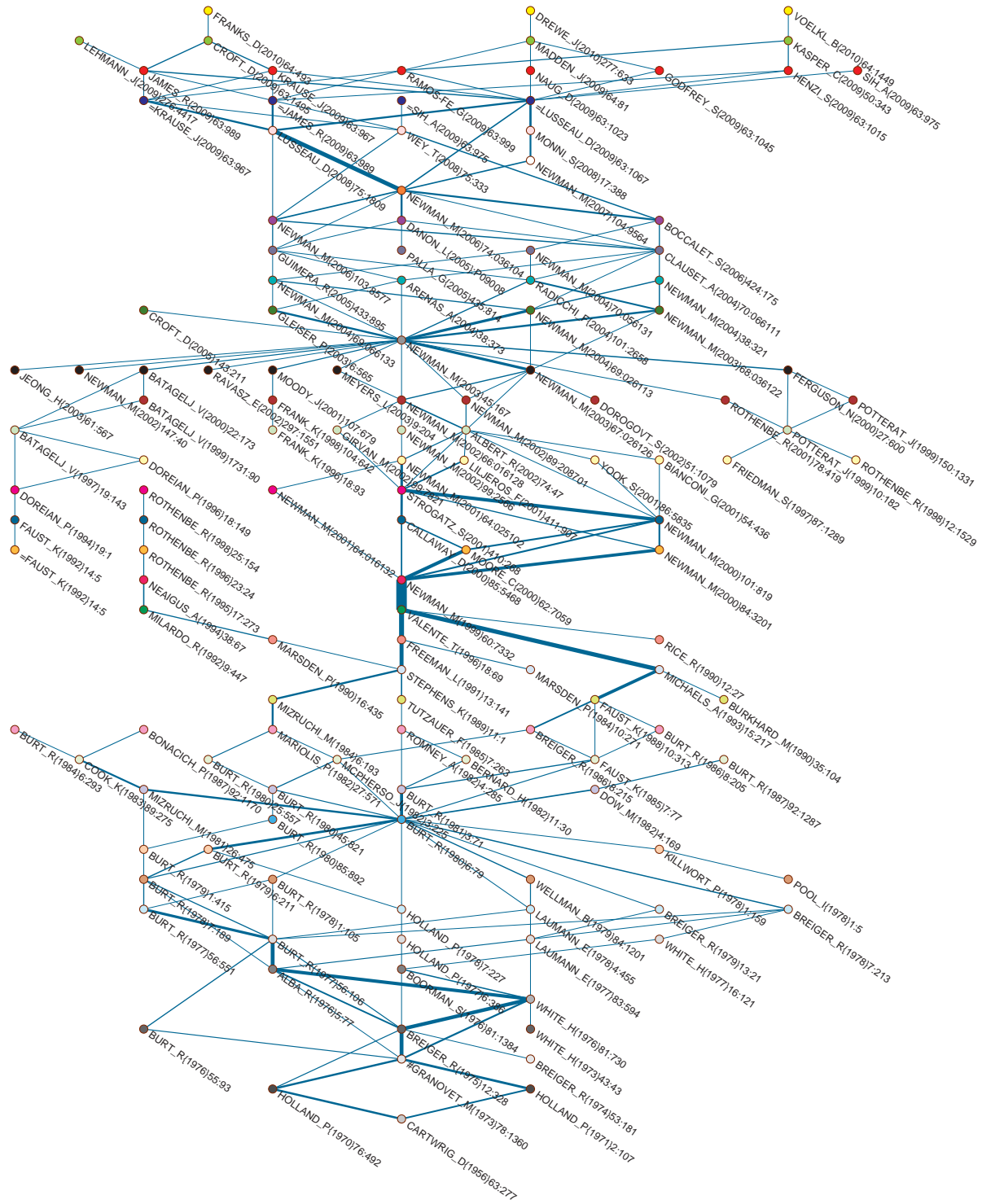


Figure 10: SPC net: Island 4

multilayer networks and others on the topics of complex, multilayer, dynamic, and temporal networks, as well as spreading processes in these networks.

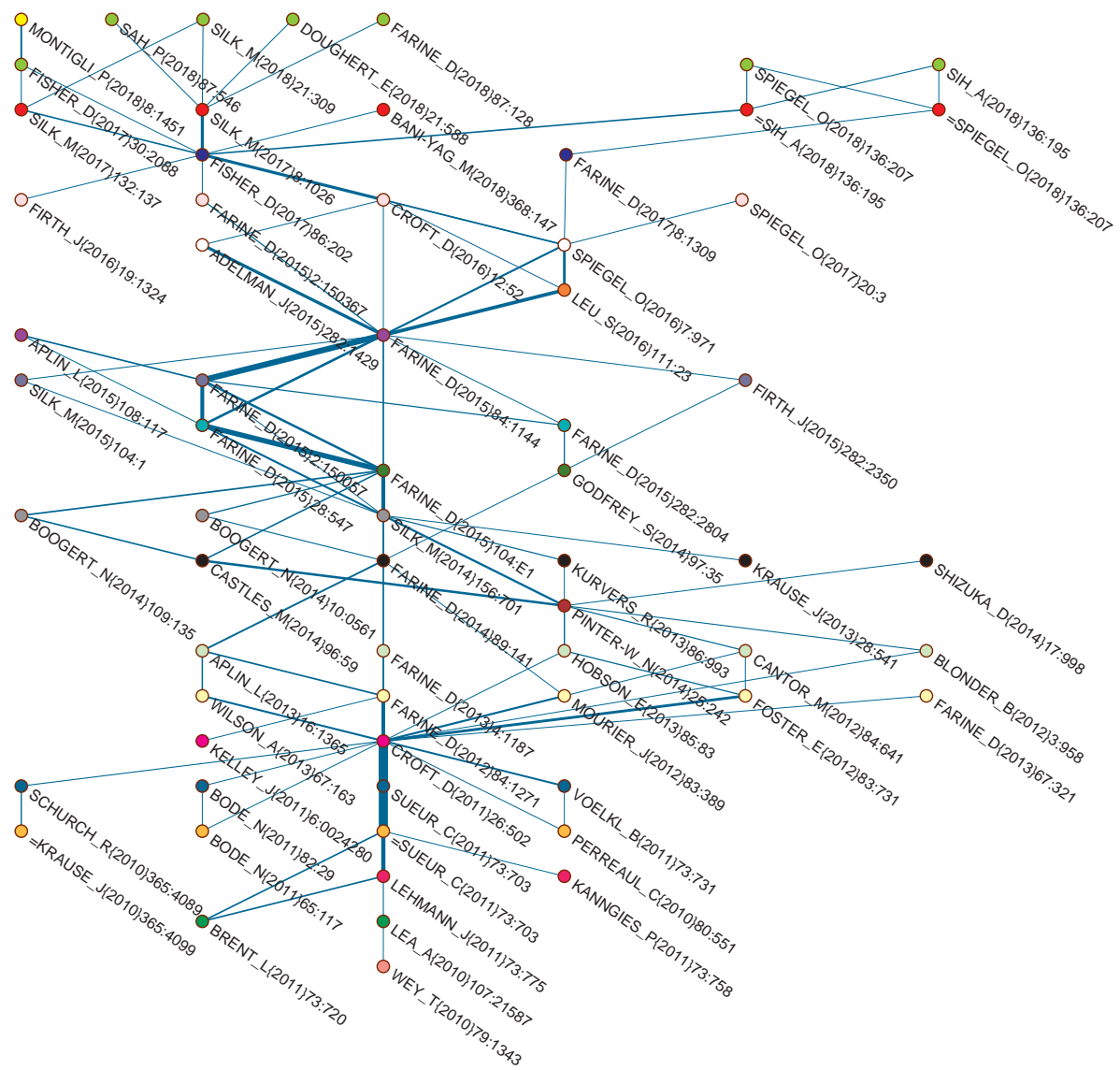


Figure 11: SPC net: Island 5

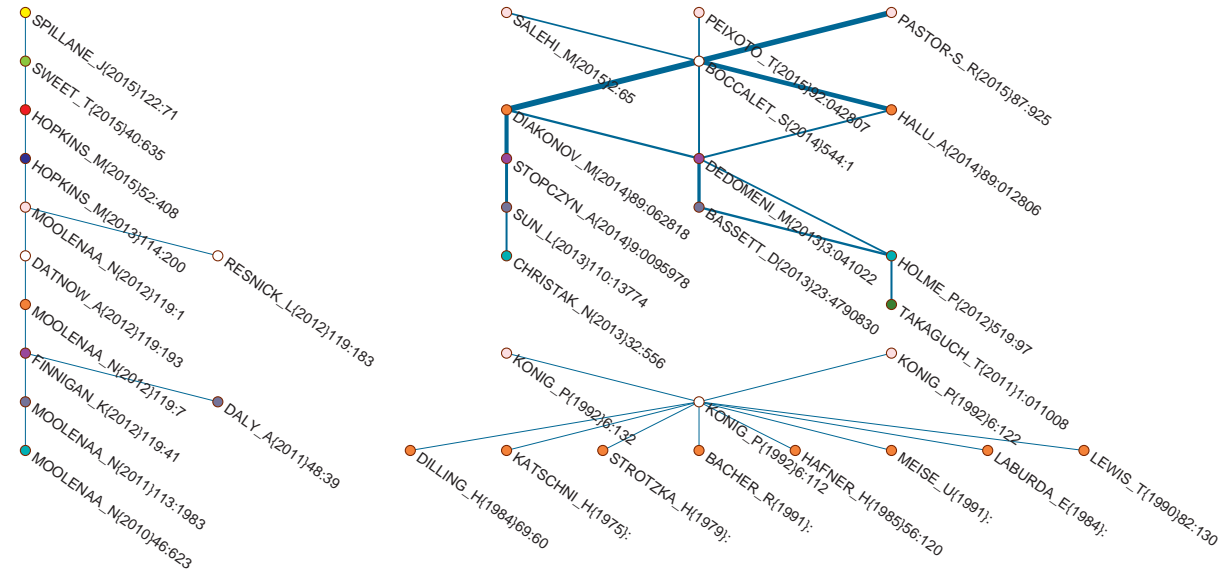


Figure 12: SPC net: Islands 1-3

Using **Node islands approach** we searched for the node islands in SPC network of size [10, 200], and got one island of size 200. The works appeared in that island in large part overlap with the works from Islands 4 and 5. These works are listed with the code 5 in the Table 7.

5.5 Probabilistic flow

The Probabilistic flow algorithm determines a node index (and a link weight). The node value is equal to the probability that a random path starting in some initial node reaches this node. We computed the Probabilistic flow (Batagelj et al., 2014, p. 81–82) on the **CiteT** network, and determined the 200 nodes with the largest values of the probabilistic flow index. They are presented in Table 7.

39 works out of the first 60 works from the obtained table overlap with the works from the table of 60 works with the largest indegree values of **CiteN** network (Table 2). Half of the listed works with the largest weights in Probabilistic flow network (except O'REILLY_T(2005) on web 2.0, and ALBERT_R(1999) 401:130 on world-wide web) are presented in the most cited works list. The largest values of probabilistic flow are already presented in the indegree distribution of **CiteN** network: works of Wasserman and Faust (1994), Watts (1998), Granovetter (1973), Boyd (2007), Barabasi (1991), Freeman (1979), Burt (1992), Milgram (1967). There are also physicists in the top of this distribution are Watts (1998), Barabasi (1999), Girvan (2002), Newman (2003), Albert (2002). Works appeared in the list of probabilistic flow, which are not in the list of the most cited works, are works of physicists (Strogatz, Watts, Albert), computer scientists (Brin), mathematicians (Bollobas), scientometricians (Page, Redner), and social scientists (Katz, Mitchell, Glaser).

By contrast, the obtained set of works is quite different from the lists of most “important” works obtained with SPC algorithm (main path and key-routes) and islands approach. However, there are some intersections of the works from the Probabilistic flow list with works which are included to the subnetworks of main path, key-route, and islands 5 and 4 (see Table 7, Appendix C). The 14 works which appear in the maximum subnetworks, including probabilistic flow, are works of several social scientists – Granovetter (1973) on strenght of weak ties, White (1976) on the blockmodels of roles and positions, and Cartwright (1956) on structural balance and generalization of Heider theory, – while

the majority of works belongs to physicists: *Newman, Albert, Strogatz, Clauset, Boccaletti on complex networks and community detection*.

6 Conclusions

Our study uses the bibliometric approach for studying the field of SNA. In this paper we presented only the first part of the study – the analysis of the basic networks constructed out of the collected dataset and their reduced versions, including only the works with the full WoS description. In general, we can make a conclusion on the relevance of the obtained data to the research objects: the lists of most cited works, most used journals and, especially, keywords (with top words *social*, *network* and *analysis*) do not contradict our basic knowledge of the SNA field. These data were used for more complex analysis.

The results show that starting from its institutionalization in the 1980-1990's, SNA field has grown significantly both in terms of the number of publications and the amount of disciplines involved into the research using SNA approach. The number of publications shows the constant growth, and on average it doubles every 3 years.

The analysis confirmed the previous studies on the SNA field development using citation network analysis. Up to the middle of 1990's the most "important" works belong to the authors from the *social sciences*, and starting from 2000's the field experience the "invasion of physicists". To our surprise, from 2010's both groups experience the "invasion" of scientists from a completely another field – *animal SNA*. The presence of this group is also seen in other results: we identified the journal *Animal Behaviour*, as well as some active authors, having large amount of works. This does not mean that either social scientists or physicists are not presented in the field anymore – it means that the newly appeared group is quite active both in number of publications and citations of each other. According to the analysis of journals, another active field of SNA research goes from the field of *Computer science*, with *Lecture notes in Computer Science* being the journal with the largest amount of works published. One can argue, however, that this is more a *series* of different publications on Computer Science, including conference proceedings, but not a single journal.

However, in spite of all "invasions" the most cited works still belong to the social scientists – with Wasserman, Faust, and Granovetter on the top. Other highly cited works are intermixed between social scientists (Freeman, McPherson, Burt, Coleman, Putnam, Scott, Everett and Borgatti, and others) and physicists (Newman, Watts, Barabasi, Albert, Girvan, and others). *Social networks*, the main journal in the SNA field, occupies a very high position among the journals where the works from our data set were published. It has lower position in terms of citations from the whole data set.

Possible explanation of some groups appearance can be due to the nature of algorithms used for identification of main subgroups of the observed citation networks. Main path algorithm *forces* to connect the nodes in the network, even if the line weight between some of them can be low. Islands approach identify locally important part of the network, which should be *distinct* from their neighbourhood. We can propose that the works on some topics could not form a separate island, as they are embedded to the subgroup of main island. More detailed explanation of the different groups in SNA field appearance and coexistence should be provided with the further analysis of derived networks, such as networks of co-authorship and co-citation between journals and authors (Part 2), and temporal analysis of these networks (Part 3).

Once again, we should highlight that for the results of bibliographic network analysis the coverage of bibliographic database used in the research is extremely important. We can propose that for future analysis a combination of different data bases (such as *WoS*, *Scopus*, *Google Scholar*, and others) can be used. However, the problem of identification of different entities (journals and authors) can still occur,

that is why we can state the need of standardization of information published in bibliographic data bases.

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A Appendix: Synonyms

Some problems associated with names recognition can occur in the data base. It can happen that the same work is named by different short names. For example, the short names `BOYD_D (2007) 13` and `BOYD_D (2008) 13:210` referencing the same work of Danah Boyd, are originally published in 2007,

but in many cases referenced as being published in 2008. There were also cases when the short names were different due to the discrepancies in the descriptions – such as `GRANOVET_M(1973) 78:1360` and `GRANOVET_M(1973) 78:6`, or `COLEMAN_J(1988) 94:95` and `COLEMAN_J(1988) 94:S95`. Also the names of some authors were presented in a different way – for example, `GRANOVET_M` and `GRANOVET_`. We identified these cases for all works with the large (at least 3) indegree frequencies in the Cite network.

To resolve these problems, we have to correct the data. There are two possibilities: (1) to make corrections in the local copy of original data (WoS file); and (2) to make an equivalence partition of nodes and shrink the set of works accordingly in all obtained networks. We used the second option (Batagelj et al., 2014). For the works with the large frequencies we prepared lists of possible equivalents and manually determined equivalence classes. With a function in R we produced a **Pajek**’s partition of equivalent work names representing the same work. We used this partition to shrink the networks **Cite**, **WA**, **WJ**, and **WK**. The partitions **year**, **DC** and the vector **NP** were also shrunk.

Similar problem was also with journals titles. The network **WJ** had 70,425 journals. Due to the inconsistencies in titles writing in different descriptions, it contained sets of nodes denoting *the same journal*. To get the list of these nodes, we constructed for each journal title a short code, which was formed out of the first two letters of each word in the journal’s title, – such as `SONEANMI` for `SOCIAL NETWORK ANALYSIS AND MINING`, – and then sorted so that the journals with the same code were grouped together. We decided to manually inspect all journals with at least one of their names cited at least 200 times. To get these counters we computed in Pajek the 2-mode network **Cite*WJc** and determined the vector **wIndegJ.vec** with weighted indegrees for journals. We obtained a list of candidates for inspection with 5,482 titles. To additionally reduce the number of titles to inspect we decided to consider only titles that appeared in at least 3 citations. Finally, we got the list **journalK100.csv** with 3,714 titles, that were manually inspected. After manually checking this list was reduced to 1,688 titles. Some examples of the journal titles grouped according to their codes are presented in the Figure 13.

However, some journal titles can appear also in an abbreviated form based on initials – for example, the *Journal of the American Statistical Association* could be coded as `JAMSTAS` according to its short title `J AM STAT ASS` and as `JA` according to its abbreviation `JASA`. That is why we also produced a list of frequent journals names of length at most 5, have chosen all the cases that could be considered as abbreviations, such as `CACM`, `JACM`, `JASA`, `LNCS`, `NIPS`, `JASSS`, `IJCAI`, `BMJ`, `JOSS`, and others, and performed a manual search for the abbreviations of these journals in the original list of 70,425 journals. We grouped all the journal titles which included the same abbreviations – an example is presented on the Figure 14 (it is seen that there were different codes generated to different titles). The results of the search were added to the first obtained list, and finally the list and the corresponding partition for network shrinking were produced.

B Appendix: Strong components

The citation network **CiteB** has 41 nontrivial strong components of different sizes, which are presented in the Figure 15. The reciprocal (cycle) links are marked with the blue colour, while directed pink lines also show the connections of these nodes with others. In the majority of cases, mutual referencing between the works is a characteristic of papers published in the same issue of the journal. For example, the first large cycle is combined of 12 works published in a special issue named *Social Networks: new perspectives* in the journal *Behavioral Ecology and Sociobiology* (Volume 63, Issue 7, May 2009). Another example are the works `BATAGELJ_V(1992) 14:63` and `BATAGELJ_V(1992) 14:121`, and

```

63656 1312696 10849 SONEANMI | SOCIAL NETWORK ANAL
63657 1330776 3 SONEANMI | SOCIAL NETWORKS ANAL
63658 1311789 645 SONEANMI | SOC NETW ANAL MIN
63659 1313366 7 SONEANMI | SOCIAL NETW ANAL MIN
63660 1315722 7 SONEANMI | SOC NETW ANAL MINING
...
25340 1297450 195 HUREMA | HUM RESOURCE MANAGE
25341 1298839 189 HUREMA | HUMAN RESOURCE MANAG
25343 1304542 3 HUREMA | HUMAN RESOURCES MANA
25344 1305503 67 HUREMA | HUM RESOUR MANAGE
25345 1312370 222 HUREMA | HUM RESOUR MANAGE-US
25352 1301632 189 HUREMAR | HUM RESOUR MANAGE R
25353 1303129 5 HUREMAR | HUM RESOUR MANAG R
...
4188 1299141 391 AMJGEPS | AM J GERIAT PSYCHIAT
4189 1299905 23 AMJGEPS | AM J GERIATRIC PSYCH
4190 1302259 12 AMJGEPS | AMER J GERIATR PSYCHIATR
4191 1304932 14 AMJGEPS | AM J GERIATR PSYCHIA
4192 1314551 7 AMJGEPS | AM J GERIATR PSYCHIATRY

```

Figure 13: An example of different journals titles writing

```

10524 1297183 50 5912 COAC | COMMUN ACM
10525 1311274 14141 6 COAC | COMMUNICATIONS ACM
10062 1309889 12756 61 CA | CACM
...
55366 1351847 54714 1 PSPOSC | PS POLITICAL SCIENCE
55768 1320199 23066 5 POSC | POLITICAL SCI
55769 1320573 23440 3 POSC | POLIT SCI
56082 1297982 849 224 PSSCPO | PS-POLIT SCI POLIT
56083 1298064 931 110 PSSCPO | PS-POLITICAL SCI POL
...
33087 1299216 2083 1617 JAC | J ACM
33550 1355703 58570 2 JACJA | J ACM JACM
32955 1302464 5331 17 JA | JACM

```

Figure 14: An example of different titles journals writing with abbreviations

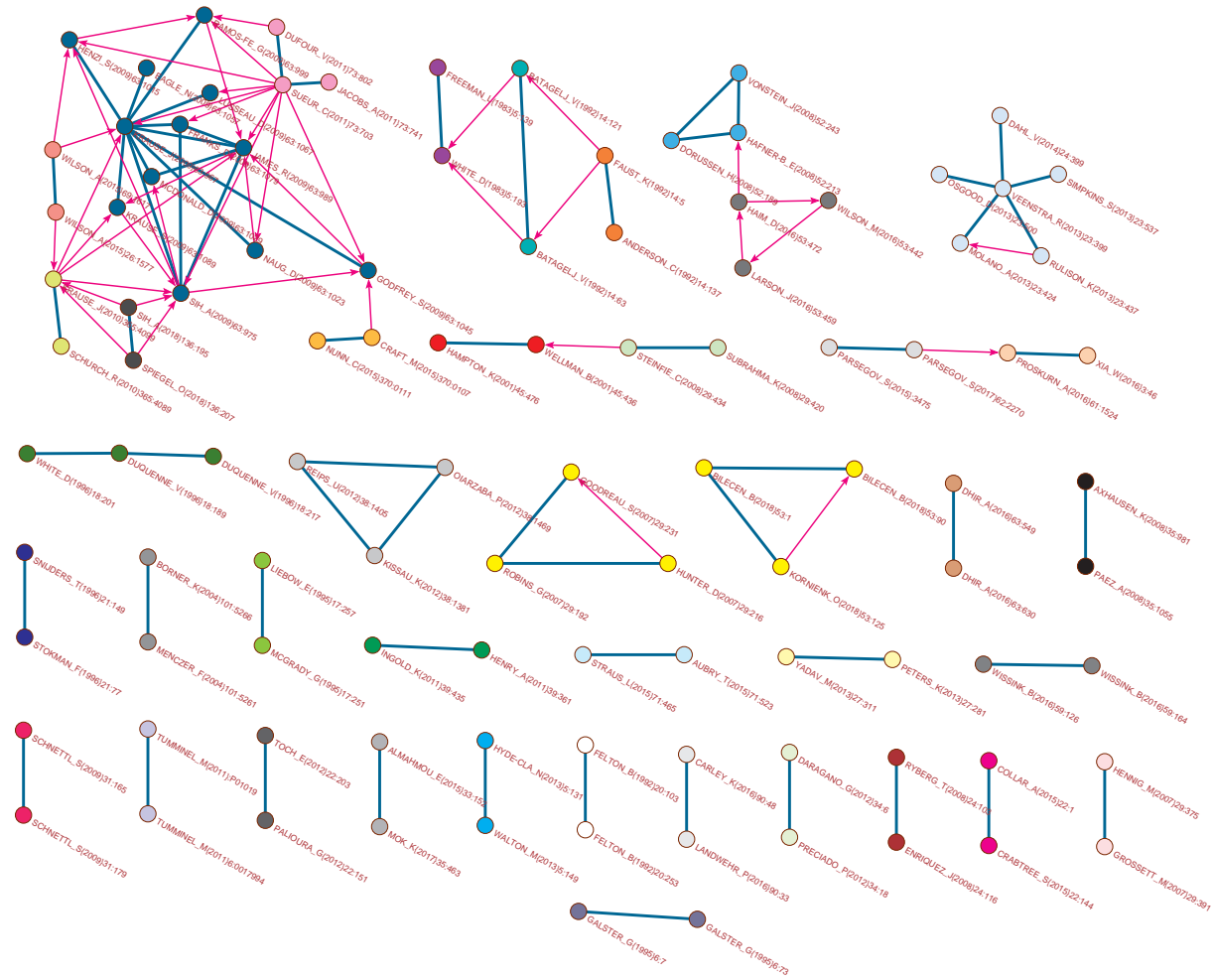


Figure 15: SPC net: Strong components

FAUST_K(1992)14:5 and ANDERSON_C(1992)14:137 in the special issue on *Blockmodels* in the journal *Social networks* (Volume 14, Issues 1–2, March–June 1992).

Other cases are connections due to the same author (TUMMINEL_M(2011) : P01019 and TUMMINEL_M(2011) 6:0017994, WILSON_A(2015) 69:1617 and WILSON_A(2015) 26:1577, PARSEGOV_S(2015) : 3475 and PARSEGOV_S(2017) 62:2270) or journal (VEENSTRA_R(2013) 23:399 and DAHL_V(2014) 24:399). However, there are cases when the authors and journals of publications are different (ALMAHMOU_E(2015) 33:152 and MOK_K(2017) 35:463, XIA_W(2016) 3:46 and PROSKURN_A(2016) 61:1524).

C Appendix: Main publications

Table 7: Citation CiteT net: Overlapping of components: (1-Key Routes, 2-CPM Main Path, 3-Island 5, 4-Island 4, 5-Node Island, 6-Probabilistic Flow)

year	code	author	title	jour or book
1934	6	Moreno JL	Who Shall Survive: A New Approach to the Problem of Human Interrelations	book
1941	6	Davis A	Deep South: A Social Anthropological Study of Caste and Class	book
1944	12	Heider F	Social perception and phenomenal causality	psychol rev
1946	12	Heider F	Attitudes and cognitive organization	j psychol
1948	6	Bavelas A	A mathematical model for group structure	hum organ
1950	6	Homans GC	The human group	book
1951	6	Leavitt HJ	Some effects of certain communication patterns on group performance	j abnorm soc psych
1953	6	Katz L	A new status index derived from sociometric analysis	psychometrika
1954	6	Barnes JA	Class and committees in a norwegian island parish	hum relat
1955	6	Katz E	Personal influence	book
1956	12456	Cartwright D	Structural balance - a generalization of Heider theory	psychol rev
1957	6	Bott E	Family and social network: roles	book
1958	6	Heider F	The psychology of interpersonal relations	book
1959	6	Goffman E	The presentation of self in everyday life	book
1959	6	Erdos P	On random graphs I	book
1960	6	Erdos P	On the evolution of random graphs	publ mat inst has
1962	6	Rogers EM	Diffusion of innovations	book
1965	6	Price DJD	Networks of scientific papers	science
1965	6	Harary F	Structural models: an introduction to the theory of directed graphs	book
1965	6	Hubbell CH	An input-output approach to clique identification	sociometry
1966	6	Sabidussi G	The centrality of a graph	book
1966	6	Coleman JS	Equality of educational opportunity	book
1967	6	Glaser BG	The discovery of grounded theory: strategies for qualitative theory	book
1967	6	Milgram S	The small world problem	psychol today
1967	6	Milgram S	The small world problem	book
1969	6	Travers J	An experimental study of the small world problem	book
1969	6	Kauffman S	Metabolic stability and epigenesis in randomly constructed genetic nets	theoret biol
1969	6	Mitchell JC	Social networks in urban situations: analyses of personal relationships in central african towns	book
1970	1245	Holland PW	Method for detecting structure in sociometric data	amer j sociol
1970	5	White HC	Search parameters for small world problem	soc forces
1970	6	Kernighan BW	An efficient heuristic procedure for partitioning graphs	book
1971	145	Holland PW	Transitivity in structural models of small groups	comp group stud
1971	6	Lorrain F	Structural equivalence of individuals in social networks	book
1972	6	Bonacich P	Factoring and weighting approaches to status scores and clique identification	j math sociol
1973	12456	Granovetter MS	Strength of weak ties	amer j sociol
1973	4	White HC	Everyday life in stochastic networks	sociol inq
1973	5	Holland PW	Structural implications of measurement error in sociometry	j math sociol
1973	6	Laumann EO	Bonds of pluralism: the form and substance of urban social networks	book

Table 7: Citation CiteT net: Overlapping of components: (1-Key Routes, 2-CPM Main Path, 3-Island 5, 4-Island 4, 5-Node Island, 6-Probabilistic Flow)

year	code	author	title	jour or book
1974	45	Breiger RL	Duality of persons and groups	soc forces
1974	6	Granovetter MS	Getting a job: a study of contacts and careers	book
1975	1245	Breiger RL	Algorithm for clustering relational data with applications to SNA and comparison with multidimensional-scaling	j math psychol
1975	6	Fishbein M	Intention and behavior: an introduction to theory and research	book
1976	12456	White HC	Social-structure from multiple networks 1 Blockmodels of roles and positions	amer j sociol
1976	1245	Alba RD	Intersection of social circles - new measure of social proximity in networks	sociol method res
1976	145	Burt RS	Positions in networks	soc forces
1976	145	Boorman SA	Social-structure from multiple networks 2 Role structures	amer j sociol
1977	1245	Burt RS	Positions in multiple network systems 1 General conception of stratification and prestige in a system of actors cast as a social topology	soc forces
1977	1245	Burt RS	Positions in multiple network systems 2 Stratification and prestige among elite decision-makers in community of altneustadt	soc forces
1977	145	Holland PW	Social-structure as a network process	z soz
1977	45	Laumann EO	Community-elite influence structures - extension of a network approach	amer j sociol
1977	45	White HC	Probabilities of homomorphic mappings from multiple graphs	j math psychol
1977	6	Freeman LC	Set of measures of centrality based on betweenness	sociometry
1977	6	Zachary WW	An information flow model for conflict and fission in small groups	book
1978	1245	Burt RS	Cohesion versus structural equivalence as a basis for network subgroups	sociol method res
1978	145	Holland PW	Omnibus test for social-structure using triads	sociol method res
1978	145	Laumann EO	Community structure as interorganizational linkages	annu rev sociol
1978	145	Breiger RL	Joint role structure of 2 communities elites	sociol method res
1978	456	Pool ID	Contacts and influence	soc networks
1978	45	Killworth PD	Reversal small-world experiment	soc networks
1978	45	Burt RS	Stratification and prestige among elite experts in methodological and mathematical sociology circa 1975	soc networks
1978	6	Granovetter M	Threshold models of collective behavior	am j sociol
1979	1245	Burt RS	Relational equilibrium in a social topology	j math sociol
1979	145	Wellman B	Community question - intimate networks of east yorkers	amer j sociol
1979	45	Breiger RL	Toward an operational theory of community elite structures	qual quant
1979	45	Burt RS	Structural theory of interlocking corporate directorates	soc networks
1979	6	Freeman LC	Centrality in social networks conceptual clarification	soc networks
1979	6	Berkman LF	Social networks, host-resistance, and mortality - 9-year follow-up-study of alameda county residents	amer j epidemiol
1979	6	Garey MR	Computers and intractability: a guide to the theory of NP-completeness	book
1980	1245	Burt RS	Models of network structure	annu rev sociol
1980	1245	Burt RS	Testing a structural theory of corporate cooptation - interorganizational directorate ties as a strategy for avoiding market constraints on profits	amer sociol rev
1980	45	Burt RS	Coaptive corporate actor networks - a reconsideration of interlocking directorates involving American manufacturing	admin sci quart
1980	45	Burt RS	Autonomy in a social topology	amer j sociol
1981	145	Mizruchi MS	Influence in corporate networks - an examination of 4 measures	admin sci quart

Table 7: Citation CiteT net: Overlapping of components: (1-Key Routes, 2-CPM Main Path, 3-Island 5, 4-Island 4, 5-Node Island, 6-Probabilistic Flow)

year	code	author	title	jour or book
1981	145	Burt RS	A note on inferences regarding network subgroups	soc networks
1981	6	Holland PW	An exponential family of probability-distributions for directed-graphs	j amer statist assn
1981	6	Feld SL	The focused organization of social ties	am j sociol
1982	1245	Mcpherson JM	Hypernetwork sampling - duality and differentiation among voluntary organizations	soc networks
1982	1245	Mariolis P	Centrality in corporate interlock networks - reliability and stability	admin sci quart
1982	145	Bernard HR	Informant accuracy in social-network data 5 An experimental attempt to predict actual communication from recall data	soc sci res
1982	145	Romney AK	Predicting the structure of a communications network from recalled data	soc networks
1982	145	Dow MM	Network auto-correlation - a simulation study of a foundational problem in regression and survey-research	soc networks
1982	6	Fischer CS	To dwell among friends: personal networks in town and city	book
1982	6	Burt RS	Toward a structural theory of action: network models of social structure, perception and action	book
1983	145	Cook KS	The distribution of power in exchange networks - theory and experimental results	am j sociol
1983	6	Granovetter M	The strength of weak ties: a network theory revisited	sociol theory
1983	6	Salton G	introduction to modern information retrieval	book
1984	1245	Mizruchi MS	Interlock groups, cliques, or interest-groups - comment	soc networks
1984	45	Burt RS	Network items and the general social survey	soc networks
1984	45	Marsden PV	Mathematical ideas in social structural-analysis	j math sociol
1984	6	Lazarus R	Stress, appraisal, and coping	book
1984	6	Axelrod R	The evolution of cooperation	book
1984	6	Kuramoto Y	Chemical oscillations, waves, and turbulence	book
1985	145	Faust K	Does structure find structure - a critique of burt use of distance as a measure of structural equivalence	soc networks
1985	145	Tutzauer F	Toward a theory of disintegration in communication-networks	soc networks
1985	6	Cohen S	Stress, social support, and the buffering hypothesis	psychol bull
1985	6	Granovetter M	Economic-action and social-structure - the problem of embeddedness	amer j sociol
1985	6	Bollobas B	Random graphs	book
1986	145	Breiger RL	Cumulated social roles - the duality of persons and their algebras	soc networks
1986	45	Burt RS	A cautionary note	soc networks
1986	6	Bourdieu P	The forms of capital	book
1986	6	Baron RM	The moderator mediator variable distinction in social psychological-research - conceptual, strategic, and statistical considerations	j personal soc psychol
1986	6	Bandura A	Social foundations of thought and action: a social cognitive theory	book
1987	1456	Bonacich P	Power and centrality - a family of measures	amer j sociol
1987	145	Burt RS	Social contagion and innovation - cohesion versus structural equivalence	amer j sociol
1988	145	Faust K	Comparison of methods for positional analysis - structural and general equivalences	soc networks
1988	6	House JS	Social relationships and health	science
1988	6	Coleman JS	Social capital in the creation of human capital	am jour soc
1988	6	Wellman B	Social structures: a network approach	*book
1989	1245	Stephenson K	Rethinking centrality - methods and examples	soc networks

Table 7: Citation CiteT net: Overlapping of components: (1-Key Routes, 2-CPM Main Path, 3-Island 5, 4-Island 4, 5-Node Island, 6-Probabilistic Flow)

year	code	author	title	jour or book
1989	6	Kamada T	An algorithm for drawing general undirected graphs	inform process lett
1989	6	Davis FD	Perceived usefulness, perceived ease of use, and user acceptance of information technology	mis quart
1989	6	Kochen M	The small world	book
1990	1456	Marsden PV	Network data and measurement	annu rev sociol
1990	4	Burkhardt ME	Changing patterns or patterns of change - the effects of a change in technology on soc. netw. structure and power	admin sci quart
1990	4	Rice RE	Individual and network influences on the adoption and perceived outcomes of electronic messaging	soc networks
1990	6	ColemanJ.	Foundations of social theory	book
1990	6	Guare J	Six degrees of separation: a play	book
1990	6	Deerwester S	Indexing by latent semantic analysis	j am soc inf sci tec
1991	1245	Freeman LC	Centrality in valued graphs - a measure of betweenness based on network flow	soc networks
1991	6	Ajzen I	The theory of planned behavior	organ behav hum dec
1991	6	Scott J	Social network analysis: a handbook	book
1991	6	Lave J	Situated learning: legitimate peripheral participation	book
1991	6	Fruchterman TMJ	Graph drawing by force-directed placement	software pract exper
1992	145	Milardo RM	Comparative methods for delineating social networks	j soc person relat
1992	45	Faust K	Blockmodels - interpretation and evaluation	soc networks
1992	5	Batagelj V	Direct and indirect methods for structural equivalence	soc networks
1992	5	Batagelj V	An optimizational approach to regular equivalence	soc networks
1992	6	Burt RS	Structural holes: the social structure of competition	book
1992	6	Nowak MA	Evolutionary games and spatial chaos	nature
1993	145	Michaelson AG	The development of a scientific specialty as diffusion through social-relations - the case of role analysis	soc networks
1993	6	Putnam RD	Making democracy work: civic institutions in modern italy	book
1993	6	Padgett JF	Robust action and the rise of the medici, 1400-1434	amer j sociol
1993	6	Manski CF	Identification of endogenous social effects - the reflection problem	rev econ stud
1993	6	Ahuja RK	Network flows: theory, algorithms, and applications	book
1994	145	Neaigus A	The relevance of drug injectors social and risk networks for understanding and preventing hiv-infection	soc sci med
1994	45	Doreian P	Partitioning networks based on generalized concepts of equivalence	j math sociol
1994	6	Wasserman S	Social network analysis: methods and applications	book
1995	145	Rothenberg RB	Choosing a centrality measure - epidemiologic correlates in the colorado-springs study of social networks	soc networks
1995	6	Molloy M	A critical-point for random graphs with a given degree sequence	random struct algor
1995	6	Rogers EM	Diffusion of Innovation. 4th	book
1995	6	Granovetter MS	Getting a Job: A Study of Contacts and Careers	book
1995	6	Nonaka I	The knowledge creation company: how Japanese companies create the dynamics of innovation	book
1995	6	Putnam RD	Bowling Alone: America's Declining Social Capital. An Interview with Robert Putnam	j democr
1996	1245	Valente TW	Social network thresholds in the diffusion of innovations	soc networks
1996	145	Rothenberg R	The relevance of social network concepts to sexually transmitted disease control	sex transm dis
1996	45	Doreian P	A partitioning approach to structural balance	soc networks
1996	4	Frank KA	Mapping interactions within and between cohesive subgroups	soc networks

Table 7: Citation CiteT net: Overlapping of components: (1-Key Routes, 2-CPM Main Path, 3-Island 5, 4-Island 4, 5-Node Island, 6-Probabilistic Flow)

year	code	author	title	jour or book
1996	6	Wasserman S	Logit models and logistic regressions for social networks 1. An introduction to Markov graphs and p	psychometrika
1996	6	Kretzschmar M	Measures of concurrency in networks and the spread of infectious disease	math biosci
1997	45	Friedman SR	Sociometric risk networks and risk for HIV infection	amer j public health
1997	45	Batagelj V	Notes on blockmodeling	soc networks
1997	6	Uzzi B	Social structure and competition in interfirm networks: The paradox of embeddedness	admin sci quart
1998	145	Rothenberg RB	Social network dynamics and HIV transmission	aids
1998	14	Rothenberg RB	Using social network and ethnographic tools to evaluate syphilis transmission	sex transm dis
1998	45	Frank KA	Linking action to social structure within a system: Social capital within and between subgroups	amer j sociol
1998	6	Watts DJ	Collective dynamics of 'small-world' networks	nature
1998	6	Portes A	Social Capital: Its origins and applications in modern sociology	annu rev sociol
1998	6	Nahapiet J	Social capital, intellectual capital, and the organizational advantage	acad manage rev
1998	6	Redner S	How popular is your paper? An empirical study of the citation distribution	book
1998	6	Wenger E	Communities of practice: Learning, meaning, and identity	book
1998	6	Page L	The pagerank citation ranking: Bringing order to the web.	book
1998	6	Brin S	The anatomy of a large-scale hypertextual Web search engine	comput networks isdn
1998	6	Huberman B	Strong regularities in world wide web surfing	science
1999	1245	Newman MEJ	Scaling and percolation in the small-world network model	phys rev e
1999	145	Potterat JJ	Chlamydia transmission: Concurrency, reproduction number, and the epidemic trajectory	amer j epidemiol
1999	145	Potterat JJ	Network structural dynamics acid infectious disease propagation	int j std aids
1999	45	Batagelj V	Partitioning approach to visualization of large graphs	lect note comput sci
1999	6	Barabasi AL	Emergence of scaling in random networks	science
1999	6	Hansen MT	The search-transfer problem: The role of weak ties in sharing knowledge across organization subunits	admin sci quart
1999	6	Faloutsos M	On power-law relationships of the internet topology	book
1999	6	Watts DJ	Small Worlds: The Dynamics of Networks Between Order and Randomness	book
1999	6	Barabasi AL	Mean-field theory for scale-free random networks	physica a
1999	6	Albert R	Internet - Diameter of the World-Wide Web	nature
1999	6	Banavar JR	Size and form in efficient transportation networks. Nature,	nature
1999	6	Kleinberg JM	Authoritative sources in a hyperlinked environment	j acm
1999	6	Haberman B	Internet: growth dynamics of the world-wide web	nature
1999	6	Lawrence S	Accessibility of information on the Web.	nature
1999	6	Barthélemy M	Small-world networks: Evidence for a crossover picture	phys rev lett
2000	1245	Newman MEJ	Models of the small world	j statist phys
2000	1245	Moore C	Exact solution of site and bond percolation on small-world networks	phys rev e
2000	145	Callaway DS	Network robustness and fragility: Percolation on random graphs	phys rev lett
2000	145	Newman MEJ	Mean-field solution of the small-world network model	phys rev lett
2000	145	Ferguson NM	More realistic models of sexually transmitted disease transmission dynamics - Sexual partnership networks, pair models, and moment closure	sex transm dis
2000	45	Batagelj V	Some analyses of Erdos collaboration graph	soc networks

Table 7: Citation CiteT net: Overlapping of components: (1-Key Routes, 2-CPM Main Path, 3-Island 5, 4-Island 4, 5-Node Island, 6-Probabilistic Flow)

year	code	author	title	jour or book
2000	6	Putnam RD	Bowling alone: America's declining social capital	book
2000	6	Jeong H	The large-scale organization of metabolic networks	nature
2000	6	Berkman LF	From social integration to health: Durkheim in the new millennium	soc sci med
2000	6	Albert R	Error and attack tolerance of complex networks	nature
2000	6	Amaral LAN	Classes of small-world networks	proc nat acad sci usa
2000	6	Broder A	Graph structure in the Web	comput netw
2000	6	Scott J	Social Network Analysis: A Handbook	book
2000	6	Shi JB	Normalized cuts and image segmentation	ieee t pattern anal
2001	12456	Newman MEJ	Clustering and preferential attachment in growing networks	phys rev e
2001	12456	Strogatz SH	Exploring complex networks	nature
2001	145	Liljeros F	The web of human sexual contacts	nature
2001	456	Newman MEJ	Scientific collaboration networks. II. Shortest paths, weighted networks, and centrality	phys rev e
2001	45	Moody J	Race, school integration, and friendship segregation in America	amer j sociol
2001	45	Rothenberg R	The risk environment for HIV transmission: Results from the Atlanta and Flagstaff network studies	j urban health
2001	4	Yook SH	Weighted evolving networks	phys rev lett
2001	4	Bianconi G	Competition and multiscaling in evolving networks	europophys lett
2001	6	Mcpherson M	Birds of a feather: Homophily in social networks	annu rev sociol
2001	6	Newman MEJ	The structure of scientific collaboration networks	proc nat acad sci usa
2001	6	Lin N	Social capital. A theory of social structure and action.	book
2001	6	Brandes U	A faster algorithm for betweenness centrality	j math sociol
2001	6	Domingos P	Mining the network value of customers	book
2001	6	Goldenberg J	Talk of the network: A complex systems look at the underlying process of word-of-mouth	mark lett
2001	6	Pastor-Satorras R	Epidemic spreading in scale-free networks	phys rev lett
2002	12456	Albert R	Statistical mechanics of complex networks	rev mod phys
2002	12456	Newman MEJ	Spread of epidemic disease on networks	phys rev e
2002	456	Girvan M	Community structure in social and biological networks	proc nat acad sci usa
2002	456	Newman MEJ	Assortative mixing in networks	phys rev lett
2002	45	Dorogovtsev SN	Evolution of networks	adv phys
2002	45	Newman MEJ	Random graph models of social networks	proc nat acad sci usa
2002	4	Ravasz E	Hierarchical organization of modularity in metabolic networks	science
2002	4	Newman MEJ	The structure and function of networks	comput phys commun
2002	6	Watts DJ	Identity and search in social networks	science
2002	6	Barabasi AL	Linked: The New Science Of Networks	book
2002	6	Barabasi AL	Evolution of the social network of scientific collaborations	physica a
2002	6	Adler PS	Social capital: Prospects for a new concept	acad manage rev
2002	6	Otte E	Social network analysis: a powerful strategy, also for the information sciences	j inform sci
2002	6	Richardson M	Mining knowledge-sharing sites for viral marketing	book
2003	12456	Newman MEJ	The structure and function of complex networks	siam rev

Table 7: Citation CiteT net: Overlapping of components: (1-Key Routes, 2-CPM Main Path, 3-Island 5, 4-Island 4, 5-Node Island, 6-Probabilistic Flow)

year	code	author	title	jour or book
2003	12456	Newman MEJ	Mixing patterns in networks	phys rev e
2003	145	Newman MEJ	Why social networks are different from other types of networks	phys rev e
2003	145	Gleiser PM	Community structure in jazz	adv complex syst
2003	45	Meyers LA	Applying network theory to epidemics: Control measures for Mycoplasma pneumoniae outbreaks	emerg infect dis
2003	4	Jeong H	Measuring preferential attachment in evolving networks	europphys lett
2003	56	Guimera R	Self-similar community structure in a network of human interactions	phys rev e
2003	6	Rogers EM	Diffusion of innovations	book
2003	6	Borgatti SP	The network paradigm in organizational research: A review and typology	j manage
2003	6	Dorogovtsev SN	Evolution of Networks: From Biological Nets to the Internet and WWW	book
2003	6	Watts DJ	Six Degrees: The Science of a Connected Age	book
2003	6	Blei DM	Latent Dirichlet allocation	j mach learn res
2003	6	Adamic LA	Friends and neighbors on the Web	soc networks
2003	6	Lusseau D	The bottlenose dolphin community of Doubtful Sound features a large proportion of long-lasting associations - Can geographic isolation explain this unique trait?	behav ecol sociobiol
2003	6	Venkatesh V	User acceptance of information technology: Toward a unified view	mis quart
2003	6	Kempe D	Maximizing the spread of influence through a social network	acm sigkdd conf
2003	6	Kempe D	Maximizing the spread of influence through a social network	acm sigkdd conf
2004	12456	Newman MEJ	Finding and evaluating community structure in networks	phys rev e
2004	12456	Newman MEJ	Detecting community structure in networks	eur phys j b
2004	12456	Clauset A	Finding community structure in very large networks	phys rev e
2004	1456	Radicchi F	Defining and identifying communities in networks	p natl acad sci usa
2004	1456	Newman MEJ	Fast algorithm for detecting community structure in networks	phys rev e
2004	145	Arenas A	Community analysis in social networks	eur phys j b
2004	145	Newman MEJ	Analysis of weighted networks	phys rev e
2004	6	Cross RL	The hidden power of social networks: Understanding how work really gets done in organizations	book
2004	6	Freeman LC	The development of social network analysis. A Study in the Sociology of Science	book
2004	6	Eubank S	Modelling disease outbreaks in realistic urban social networks	nature
2004	6	Burt RS	Structural holes and good ideas	amer j sociol
2005	145	Danon L	Comparing community structure identification	j stat mech-theory e
2005	456	Guimera R	Functional cartography of complex metabolic networks	nature
2005	456	Palla G	Uncovering the overlapping community structure of complex networks in nature and society	nature
2005	4	Croft DP	Assortative interactions and social networks in fish	oecologia
2005	6	Burt RS	Brokerage and closure: An introduction to social capital	book
2005	6	Adomavicius G	Toward the next generation of recommender systems: A survey of the state-of-the-art and possible extensions	book
2005	6	Carrington P	Models and Methods in Social Network Analysis	book
2005	6	Borgatti SP	Centrality and network flow	soc networks
2005	6	Gross R	Information revelation and privacy in online social networks	book
2006	12456	Boccaletti S	Complex networks: Structure and dynamics	phys rep-rev sect phys lett

Table 7: Citation CiteT net: Overlapping of components: (1-Key Routes, 2-CPM Main Path, 3-Island 5, 4-Island 4, 5-Node Island, 6-Probabilistic Flow)

year	code	author	title	jour or book
2006	12456	Newman MEJ	Finding community structure in networks using the eigenvectors of matrices	phys rev e
2006	1456	Newman MEJ	Modularity and community structure in networks	proc nat acad sci usa
2006	6	Kossinets G	Empirical analysis of an evolving social network	science
2006	6	Newman M	The Structure and Dynamics of Networks	book
2006	6	Eagle N	Reality mining: sensing complex social systems	pers ubiquit comput
2007	145	Newman MEJ	Mixture models and exploratory analysis in networks	proc nat acad sci usa
2007	5	Krause J	Social network theory in the behavioural sciences: potential applications	behav ecol sociobiol
2007	6	Onnela JP	Structure and tie strengths in mobile communication networks	proc nat acad sci usa
2007	6	Palla G	Quantifying social group evolution	nature
2007	6	Christakis NA	The spread of obesity in a large social network over 32 years	n engl j med
2007	6	Mazer JP	I'll see you on Facebook: The effects of computer-mediated teacher self-disclosure on student motivation, affective learning, and classroom climate	book
2007	6	Liben-Nowell D	The link-prediction problem for social networks	j am soc inf sci technol
2007	6	Robins G	An introduction to exponential random graph (p^*) models for social networks	soc networks
2007	6	Fortunato S	Resolution limit in community detection	proc nat acad sci usa
2007	6	Boyd DM	Social network sites: Definition, history, and scholarship	j comput-mediat comm
2007	6	Raghavan UN	Near linear time algorithm to detect community structures in large-scale networks	phys rev e
2007	6	Mislove A	Measurement and Analysis of Online Social Networks	book
2007	6	Leskovec J	Cost-effective Outbreak Detection in Networks	book
2007	6	Josang A	A survey of trust and reputation systems for online service provision	decis support syst
2007	6	Steinfeld C	The benefits of Facebook friends: Social capital and college students' use of online social network sites.	j comput-mediat comm
2007	6	Dwyer C	Trust and privacy concern within social networking sites: A comparison of Facebook and MySpace.	amcis 2007 proc
2007	6	Lenhart A	Teens, Privacy and online social networks: how teens manage their online identities and personal information in the age of Myspace	book
2007	6	Ellison NB	The benefits of Facebook "friends:" Social capital and college students' use of online social network sites	j comput-mediat comm
2008	1245	Lusseau D	Incorporating uncertainty into the study of animal social networks	anim behav
2008	145	Wey T	Social network analysis of animal behaviour: a promising tool for the study of sociality	anim behav
2008	145	Monni S	Vertex clustering in random graphs via reversible jump Markov chain Monte Carlo	j comput graph stat
2008	6	Blondel VD	Fast unfolding of communities in large networks	j stat mech-theory e
2008	6	Smith KP	Social networks and health	annu rev sociol
2008	6	Gonzalez MC	Understanding individual human mobility patterns	nature
2008	6	Christakis NA	The collective dynamics of smoking in a large soc.l netw.	new engl j med
2008	6	Fowler JH	Dynamic spread of happiness in a large soc. netw.: longit. analysis over 20 years in the Framingham Heart Study	brit med j
2009	1245	Kasper C	A social network analysis of primate groups	primates
2009	1245	Ramos-FernandezG	Association networks in spider monkeys (<i>Ateles geoffroyi</i>)	behav ecol sociobiol
2009	1245	Lusseau D	The emergence of unshared consensus decisions in bottlenose dolphins	behav ecol sociobiol
2009	145	Croft DP	Behavioural trait assortment in a social network: patterns and implications	behav ecol sociobiol
2009	145	James R	Potential banana skins in animal social network analysis	behav ecol sociobiol

Table 7: Citation CiteT net: Overlapping of components: (1-Key Routes, 2-CPM Main Path, 3-Island 5, 4-Island 4, 5-Node Island, 6-Probabilistic Flow)

year	code	author	title	jour or book
2009	145	Krause J	Animal social networks: an introduction	behav ecol sociobiol
2009	145	James R	Potential banana skins in animal social network analysis	behav ecol sociobiol
2009	145	Krause J	Animal social networks: an introduction	behav ecol sociobiol
2009	14	Lehmann J	Network cohesion, group size and neocortex size in female-bonded Old World primates	p roy soc b-biol sci
2009	45	Godfrey SS	Network structure and parasite transmission in a group living lizard, the gidgee skink, <i>Egernia stokesii</i>	behav ecol sociobiol
2009	45	Sih A	Social network theory: new insights and issues for behavioral ecologists	behav ecol sociobiol
2009	45	Naug D	Structure and resilience of the social network in an insect colony as a function of colony size	behav ecol sociobiol
2009	45	Madden JR	The social network structure of a wild meerkat population: 2. Intragroup interactions	behav ecol sociobiol
2009	45	Henzi SP	Cyclicity in the structure of female baboon social networks	behav ecol sociobiol
2009	45	Sih A	Social network theory: new insights and issues for behavioral ecologists	behav ecol sociobiol
2009	5	Mcdonald DB	Young-boy networks without kin clusters in a lek-mating manakin	behav ecol sociobiol
2009	6	Pempek TA	College students' social networking experiences on Facebook	j appl dev psychol
2009	6	Borgatti SP	Network Analysis in the Social Sciences	science
2009	6	Chen W	Efficient Influence Maximization in Social Networks	book
2009	6	Clauset A	Power-Law Distributions in Empirical Data	siam rev
2009	6	Eagle N	Inferring friendship network structure by using mobile phone data	p natl acad sci usa
2010	1245	Voelkl B	Simulation of information propagation in real-life primate networks: longevity, fecundity, fidelity	behav ecol sociobiol
2010	145	Franks DW	Sampling animal association networks with the gambit of the group	behav ecol sociobiol
2010	45	Drewe JA	Who infects whom? Social networks and tuberculosis transmission in wild meerkats	p roy soc b-biol sci
2010	35	Lea AJ	Heritable victimization and the benefits of agonistic relationships	p natl acad sci usa
2010	35	Wey TW	Social cohesion in yellow-bellied marmots is established through age and kin structuring	anim behav
2010	35	Schurch R	The building-up of social relationships: behavioural types, social networks and cooperative breeding in a cichlid	philos t r soc b
2010	35	Perreault C	A note on reconstructing animal social networks from independent small-group observations	anim behav
2010	35	Krause J	Personality in the context of social networks	philos t r soc b
2010	6	Fortunato S	Community detection in graphs	phys rep
2010	6	Kaplan AM	Users of the world, unite! The challenges and opportunities of Social Media	bus horizons
2010	6	Centola D	The Spread of Behavior in an Online Social Network Experiment	science
2010	6	Roblyer MD	Findings on Facebook in higher education: A comparison of college faculty and student uses and perceptions of social networking sites	internet high educ
2011	1235	Croft DP	Hypothesis testing in animal social networks	trends ecol evol
2011	1235	Brent LNJ	Social Network Analysis in the Study of Nonhuman Primates: A Historical Perspective	am j primatol
2011	1235	Sueur C	How Can Social Network Analysis Improve the Study of Primate Behavior?	am j primatol
2011	1235	Lehmann J	Baboon (<i>Papio anubis</i>) Social Complexity-A Network Approach	am j primatol
2011	1235	Sueur C	How Can Social Network Analysis Improve the Study of Primate Behavior?	am j primatol
2011	135	Voelkl B	Network Measures for Dyadic Interactions: Stability and Reliability	am j primatol
2011	1	Clark FE	Space to Choose: Network Analysis of Social Preferences in a Captive Chimpanzee Community, and Implications for Management	am j primatol
2011	35	Bode NWF	Soc.l netw. and models for collective motion in animals	behav ecol sociobiol

Table 7: Citation CiteT net: Overlapping of components: (1-Key Routes, 2-CPM Main Path, 3-Island 5, 4-Island 4, 5-Node Island, 6-Probabilistic Flow)

year	code	author	title	jour or book
2011	35	Kanngiesser P	Grooming Network Cohesion and the Role of Individuals in a Captive Chimpanzee Group	am j primatol
2011	35	Bode NWF	The impact of social networks on animal collective motion	anim behav
2011	6	Kietzmann JH	Social media? Get serious! Understanding the functional building blocks of social media	bus horizons
2011	3	Kelley JL	Predation Risk Shapes Social Networks in Fission-Fusion Populations	plos one
2012	1235	Farine DR	Social network analysis of mixed-species flocks: exploring the structure and evolution of interspecific social behaviour	anim behav
2012	135	Mourier J	Evidence of social communities in a spatially structured network of a free-ranging shark species	anim behav
2012	135	Cantor M	Disentangling social networks from spatiotemporal dynamics: the temporal structure of a dolphin society	anim behav
2012	135	Foster EA	Social network correlates of food availability in an endangered population of killer whales, Orcinus orca	anim behav
2012	35	Blonder B	Temporal dynamics and network analysis	methods ecol evol
2013	1235	Aplin LM	Individual personalities predict social behaviour in wild networks of great tits (Parus major)	ecol lett
2013	135	Wilson ADM	Network position: a key component in the characterization of social personality types	behav ecol sociobiol
2013	135	Hobson EA	An analytical framework for quantifying and testing patterns of temporal dynamics in social networks	anim behav
2013	35	Farine DR	Animal social network inference and permutations for ecologists in R using asnipe	methods ecol evol
2013	35	Krause J	Reality mining of animal social systems	trends ecol evol
2013	35	Kurvers RHJM	Contrasting context dependence of familiarity and kinship in animal social networks	anim behav
2013	35	Farine DR	Social organisation of thornbill-dominated mixed-species flocks using social network analysis	behav ecol sociobiol
2014	1235	Farine DR	Measuring phenotypic assortment in animal social networks: weighted associations are more robust than binary edges	anim behav
2014	1235	Silk MJ	The importance of fission-fusion social group dynamics in birds	ibis
2014	135	Pinter-Wollman N	The dynamics of animal social networks: analytical, conceptual, and theoretical advances	behav ecol
2014	135	Castles M	Social networks created with different techniques are not comparable	anim behav
2014	135	Boogert NJ	Perching but not foraging networks predict the spread of novel foraging skills in starlings	behav process
2014	35	Boogert NJ	Developmental stress predicts social network position	biol letters
2014	35	Godfrey SS	A contact-based social network of lizards is defined by low genetic relatedness among strongly connected individuals	anim behav
2014	3	Shizuka D	Across-year social stability shapes network structure in wintering migrant sparrows	ecol lett
2015	1235	Farine DR	Constructing, conducting and interpreting animal social network analysis	j anim ecol
2015	1235	Farine DR	Selection for territory acquisition is modulated by social network structure in a wild songbird	j evolution biol
2015	1235	Farine DR	The role of social and ecological processes in structuring animal populations: a case study from automated tracking of wild birds	roy soc open sci
2015	1235	Farine DR	Proximity as a proxy for interactions: issues of scale in social network analysis	anim behav
2015	135	Adelman JS	Feeder use predicts both acquisition and transmission of a contagious pathogen in a North American songbird	p roy soc b-biol sci
2015	35	Silk MJ	The consequences of unidentifiable individuals for the analysis of an animal social network	anim behav
2015	35	Aplin LM	Consistent individual differences in the social phenotypes of wild great tits, Parus major	anim behav
2015	35	Farine DR	Estimating uncertainty and reliability of social network data using Bayesian inference	roy soc open sci
2015	35	Firth JA	Experimental manipulation of avian social structure reveals segregation is carried over across contexts	p roy soc b-biol sci
2015	35	Farine DR	Interspecific social networks promote information transmission in wild songbirds	p roy soc b-biol sci

Table 7: Citation CiteT net: Overlapping of components: (1-Key Routes, 2-CPM Main Path, 3-Island 5, 4-Island 4, 5-Node Island, 6-Probabilistic Flow)

year	code	author	title	jour or book
2016	1235	Spiegel O	Socially interacting or indifferent neighbours? Randomization of movement paths to tease apart social preference and spatial constraints	methods ecol evol
2016	1235	Croft DP	Current directions in animal social networks	curr opin behav sci
2016	1235	Leu ST	Environment modulates population social structure: experimental evidence from replicated social networks of wild lizards	anim behav
2016	35	Firth JA	Social carry-over effects underpin trans-seasonally linked structure in a wild bird population	ecol lett
2016	5	Jacoby DMP	Emerging Network-Based Tools in Movement Ecology	trends ecol evol
2017	1235	Fisher DN	Analysing animal social network dynamics: the potential of stochastic actor-oriented models	j anim ecol
2017	1235	Silk MJ	Understanding animal social structure: exponential random graph models in animal behaviour research	anim behav
2017	1235	Fisher DN	Social traits, social networks and evolutionary biology	j evolution biol
2017	135	Silk MJ	The application of statistical network models in disease research	methods ecol evol
2017	35	Farine DR	A guide to null models for animal social network analysis	methods ecol evol
2017	5	Formica V	Consistency of animal social networks after disturbance	behav ecol
2017	5	Mourier J	Does detection range matter for inferring social networks in a benthic shark using acoustic telemetry?	roy soc open sci
2017	3	Spiegel O	What's your move? Movement as a link between personality and spatial dynamics in animal populations	ecol lett
2018	1235	Montiglio PO	Social structure modulates the evolutionary consequences of social plasticity: A social network perspective on interacting phenotypes	ecol evol
2018	135	Dougherty ER	Going through the motions: incorporating movement analyses into disease research	ecol lett
2018	135	Silk MJ	Contact networks structured by sex underpin sex-specific epidemiology of infection	ecol lett
2018	135	Farine DR	When to choose dynamic vs. static social network analysis	j anim ecol
2018	135	Sah P	Disease implications of animal social network structure: A synthesis across social systems	j anim ecol
2018	35	Spiegel O	Where should we meet? Mapping social network interactions of sleepy lizards shows sex-dependent social network structure	anim behav
2018	35	Sih A	Integrating social networks, animal personalities, movement ecology and parasites: a framework with examples from a lizard	anim behav
2018	35	Spiegel O	Where should we meet? Mapping social network interactions of sleepy lizards shows sex-dependent social network structure	anim behav
2018	35	Sih A	Integrating social networks, animal personalities, movement ecology and parasites: a framework with examples from a lizard	anim behav
2018	5	Blaszczyk MB	Consistency in social network position over changing environments in a seasonally breeding primate	behav ecol sociobiol
2018	3	Bani-Yaghoub M	A methodology to quantify the long-term changes in social networks of competing species	ecol model