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

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1 Introduction

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

Starting from that time, the field of Social network analysis has grown significantly, both in the dimentsion of 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 and online social networks during the 2000‘s. However, if untill 2000‘s the field was mostly developing inside different branches of Social sceinces, starting from the new century it got a significant attention from the representatives of other Natural science disciplines. The so-called *“physicists invasion”* (Batagelj et al., 2014) resulted in the development of a separate Network Science discipline, whose representatives sometimes were trying to reinvent and rediscover the issues that had been developed in the Social sciences for quite a long time (Freeman, 2004).

Who proposed the term?

The development of the Social network analysis field was reflected in a set of studies focused both on its historiographical description (Freeman, 2004) and bibliometric analysis of publications and journals involved to the field (of course, including the main one – *Social Networks*). Different authors studied citation structures of works and journals (Hummon and Carley, 1993; Leydesdorff et al., 2008; Batagelj et al., 2014), collaboration structures in sense of co-authorship (Otte and Rousseau, 2002; Leydesdorff et al., 2008; Batagelj et al., 2014), structures of co-citations between works, authors, and journals (Brandes, Pich, 2011), topical structures and keyword co-occurence networks (Leydesdorff et al., 2008; Groenewegen et al., 2015). Attention was also given to different subfields (subtopics) (Hummon et al., 1990; Kejžar et al., 2010; Batagelj et al., 2014), (Batagelj, new) 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 for the studies of 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 whole 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 one country (Kronegger et al., 2012; Ferligoj et al., 2015; Cugmas et al., 2016). The scientific networks in multinational (Kronegger et al., 2004) and international (Wagner and Leydesdorff, 2005) levels were also studied. The data which are usually analyzed goes from particular journals (Carley et al., 1993), thematic sets of literature (Hummon and Doreian, 1989; Batagelj et al., 2017), or whole data bases of bibliographic information (Kronegger et al., 2012). Alltogether, on the upper theoretical level these studies can be fitted to different models of science evolution, which explain the development of the fields due to the changes in paradigms, styles of thought, or modes of inquiry (Kuhn, 1962, Kaplan, 1964, Casetti, 1999), distinguish stages of scientific evolution that each discipline comes through (Shneider, 2009), or see social groups (agents) as driving forces in science (Price, 1972; Wagner, 2008).

Should we include the following?

In our study, with the respect to previous research done in the area, we aim to implement comprehensive approach for the identification of the main trends of the Social network analysis field development – in terms of the representation of various disciplinary areas, groups of scientists, and thematic agenda in the field. The applied methodology of bibliometric analysis already proved 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-occurence, citation and co-citation between different bibliographic entities, and allocating key publications and actors (authors, research groups, institutions, journals) in the field of Social network analysis, main topics and scientific ideas, connections between them and their evolution through 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.

We decided to split our results into three parts published separately: (1) basic statistics and citation network analysis, (2) analysis of co-occurence networks, (3) temporal network analysis. The first section of the current paper presents some previous studies in the field of Social network analysis. This is followed by a section describing the data set we use, and some issues of network construction. The next section provides some statistical propoerties of basic networks and analysis of Citation network.

2 Social network analysis: the review of previous studies

One of the most comprehensive overviews of the history of Social network analysis 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 (its social network), pointed out its main events and thus presented *"the history of social network analysis written from a social network perspective"*. This qualitative study was also supported by the special quantitative 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 deliniated refers to 1940-60's, which can be associated with the emergence of a large number of "schools", not aware of each other and potentially competing. That is why, **by the 1970's the field was higly fragmented**: according to the results of the "founding fathers" survey, the field's intellectual antecedents formed differnt 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 patterns of influence) – on the other side.

Starting from 1970's, a number of attempts was made for the the unification of many separate strands of network analysis, which were done by a number of individuals and institutions. Among these attempts Freeman points out organization of *International Network for Social Network Analysis (INSNA)* in 1977, creation of *Social Networks* journal in 1979, conferences and regular meetings that brought separate groups together (including those connected by early kind 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 **institutionalzation 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). At the same time, Freeman also mentions some challenges which the newly established field was facing in the beginning of 20'th century – the split between the traditional social network analysts and the physicists, discovering the network approach and *'reinventing existing tools and rediscovering established empirical results'*.

Another word

The findings of Freeman on the unification of the field are supported by the results of one of the first quantitative study on the the Social network analysis field development conducted by Hummon and Carley (Hummon and Carley, 1993), which was based on the citation analysis of the works published in 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 till that time there has been a core active group of scientists "in the know" (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 also 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's why Hummon and Carley also made a conclusion that the **SNA not only acceded the status of 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 number of works related to Social network analysis field in databases of sociological, psychological and biomedical publications in period 1974-1999, Otte and Rousseau (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 sociological database, two other analysed fields – biomedical and psychological literature – were showing the modest increase as well – which *'proves that other fields, besides Sociology, have used the term and the techniques'* of Social network analysis. 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 Social network analysis and its subtopics and subdisciplines, which used different methods of data analysis. Based on the same mentioned above resource – *Social Networks* journal – Leydesdorf, Schank, Scharnhorst, and De Nooy (Leydesdorff et al., 2008) presented the temporal analysis of keywords co-occurence and co-authorship networks, constructed out of the works published in period 1988-2007, and extracted the most central figures, belonging to sertain branches of the field, and common and specialized topics which arised in the journal's articles through time. Studying the journal's citation structures (in both cited and citing dimentsions), authors found its **strong connection with other sociological journals**, and less strong 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 is still *'can be considered as a representative of sociology journals'*, rather then an *'interdisciplinary journal'*. In a later study, Groenewegen, Hellsten, and Leydesdorff (Groenewegen et al., 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 Social network analysis field development were implemented by the group of Batagelj, Doreian, Ferligoj, Kejžar, and others, who studied the collaboration networks among *social network analysts and contributors to network science*, citations betwen works, and citations betwen journals (Batagelj et al., 2014), based on the data obtained from differnt 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 Social network field was also done – on the topics of centrality (Batagelj et al., 2014), clustering and classification (Kejžar et al., 2010), and blockmodeling (Batagelj). The findings of these studies confirmed the trend of the *'invasion to the field'* from other disciplines: while in the early period the field was developing in different branches of Social sciences, **starting from 2000's, the key – highly cited – works in the field belong to the authors from the spheres of Physics (mostly), Computer Science, Neurosciences, and Medicine**. The presence of these disciplines in the topic and collaboration structures of the field becomes more visible.

Using the dataset presented in (Batagelj et al., 2014) – *Web of Science* descriptions of articles on
URL social networks till 2007, – Brandes (Brandes, Pich, 2011) implemented the procedure of bibliographic coupling (based ob 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 scince discipline**, – with the latter forming the most cohesive groups according to the similarity of cition paterns 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 the sociological journals**.

Some authors paid attention to the development of the Social network analysis field **within different disciplines**, which in general follow the same trends as the field itself. In their review of Network analysis usage in *Management and Organizational research*, Borgatti and Foster (Borgatti, 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 bibliographicl coupling and citation network analysis, Varga and Nemeslaki (Varga, Nemeslaki, 2012) found the strong connection of this field to the spheres of Economics, Management and Business Science, as well as Sociology. Otte and Rousseau (Otte and Rousseau, 2002), being interested in *Social information discipline*, found the presense of Social network analysis there as well: some of the most active authors highlighted in their study also published articles in the journals from this field (such as *Scientometrics, JASIS(T), Journal of Classification*, and others). Lazer, Mergel, and Friedman (Lazer et al., 2009) studied the development of the 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 Sociology journals, *the American Sociological Review* and *the American Journal of Sociology* in three time points – 1990-92, 2000 and 2005, – they defined different 'canons' typical for different time points and the authors associated to each of them. 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 Social network analysis development shows that the institutionalization of the field reflected in the intensification of the number of the yearly number of articles related to it, which is constantly growing from 1970-80's. According to Freeman, these data shows 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 Social network analysis was interdisciplinary (Hummon and Carley, 1993), recently the field had to face some challenges, with the most imporatnt being *physicists' invasion* (Lazer et al., 2009; Brandes, Pich, 2011; Batagelj et al., 2014). Based on these previous findings, the current study is supposed to evaluate the main changes that the field came through its history and to highligth 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 Viszards session at the Sunbelt 2008 (Batagelj et al., 2014). It contains all the records obtained for the query `"social network*"`, as well as all 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 networks 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 *Computational Social Networks*, *Applied Network Science*, *Online Social Networks and Media*, *Journal of Social Structure*, and *Connections* – were considered, but turned out not to be presented in the WoS.

Figure 1 presents an example of a record describing an article as obtained from WoS. We had to limit

```
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
   BERSCHEID E, 1969, INTERPERSONAL ATTRAC
   BOISSEVAIN J, 1968, MAN, V3, P542
   BOTT E, 1957, FAMILY SOCIAL NETWOR
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
```

Figure 1: WoS record

our search to the Web of Science Core Collection because for other data bases in WoS the CR fields, which contain citation information, can not be exported.

The nodes, which are described only in WoS CR fields as references, do not have a full description in the collected data set, and are called *terminal* nodes. As such nodes can be higly cited and in this sense important, we additionally collected full descriptions for works with high (at least 150) citation frequences using WoS. If a description of a node was not available in WoS we constructed a corresponding description without CR data, searching for the work in Google Scholar (exported in RIS biblographic format and converted into WoS with a special R function). We also included manual descriptions of important works without the CR field from data set BM on blockmodeling (Batagelj, Chapter 2). We should note that such additional influental papers, usually published earlier, could be overlooked by our search queries because it could happen that they do not use the now established terminology. Finally, our data set included 70,792 records with a complete descripton.

Some comments should be done concerning the choise of the dataset for the current study. Even though for a long time *Web of Science* had a monoploy in the field of scientific work collection and evaluation, it is currently presented by other sources of bibliometric data – such as *Scopus, Google Scholar*, special citation resources and scientific social media (*SciFinder, Mendeley, etc.*). Previous comparison of different databases have shown that they vary significantly according to their coverage of certain scientific disciplines, and have their pros and cons. For example, *Google Scholar* was shown as providing broad coverage for most disciplines, while *Scopus* and *WoS* were found out to have less publications and weaker represent the works in the Social Sciences and the Humanities; a 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 *journals* with certain level of *impact factor*, while *Google Scholar* finds different types of sources, including journal and 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, patents, etc.) (Franceschet, 2009). We propose that this can lead to certain underrepresentation of some fields in our dataset, where Social network analysis 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 certain period (*Scopus*), or not included at all (*Google Scholar*). Together with lower consistency and accuracy of data in *Google Scholar*, it makes the choise of *WoS* most appropriate for the current study. However, it should be noted that its results are inevitably relative to the available data.

3.2 Basic networks construction

Using **WoSPajek 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 × authors (from the field AU), the journalship network **WJ** on works × journals (from the field CR or J9), and the keywordship network **WK** on works × 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.) – wich means that they are *linked* and can be easily combined using the network multiplication into new *derived* networks (Batagelj et al. (2014)).

Works that appear in descriptions can be of two types: those which has 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. 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 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, year of publication, title of the journal, its volume and 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 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 ISI 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 linkes and loops from the networks and named *obtained basic* networks **CiteN**, **WAn**, **WJn**, and **WKn** (Table 1). The statistical properties of these networks are presented in the Section 4.

Table 1: Sizes of Cleaned 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	1,167,670
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

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 descriptions). 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 named 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 the Figure 2, the distribution of *all works (hits + cited only)* and *hits* by years is shown. These distributions fits well the *log normal* distribution ((Batagelj et al., 2014), pp. 119–121):

$c \cdot \text{dlnorm}(2019 - year, a, b)$, where $a = 2.543$, $b = 0.7206$, and $c = 1.27810^6$.

$c \cdot \text{dlnorm}(2018 - year, a, b)$, where $a = 1.501$, $b = 0.9587$, and $c = 7.11010^4$.

In the Figure 3, the Indegree distribution in **CiteN** – cumulative and density in double-logarithmic scale – is shown. This distribution fits well the the *power law* $f = c \cdot n^{-\alpha}$, with fitted $\alpha = 2.3007$, $c = 749338$, which means that the 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. The most cited *book* is the work of *Wasserman and Faust* published in 1994. Other books of networks scientists from Social sciences (marked in boldface) are (numbers of citations in parentheses): *Burt RS, Structural Holes: The Social Structure of Competition, 1992 (2333); Putnam RD, Bowling alone: America's declining social capital, 2000 (1510); Scott J, Social Network Analysis: A Handbook, 2000 (1192); Coleman J, Foundations of Social Theory, 1990 (1093); Hanneman RA, Introduction to social network methods, 2005 (854); Lin N, Social capital. A theory of social structure and action, 2001 (800); Rogers EM, Diffusion of innovations, 2003 (628); Putnam RD, Making democracy work: Civic institutions in modern Italy, 1993 (613); Zachary WW, An*

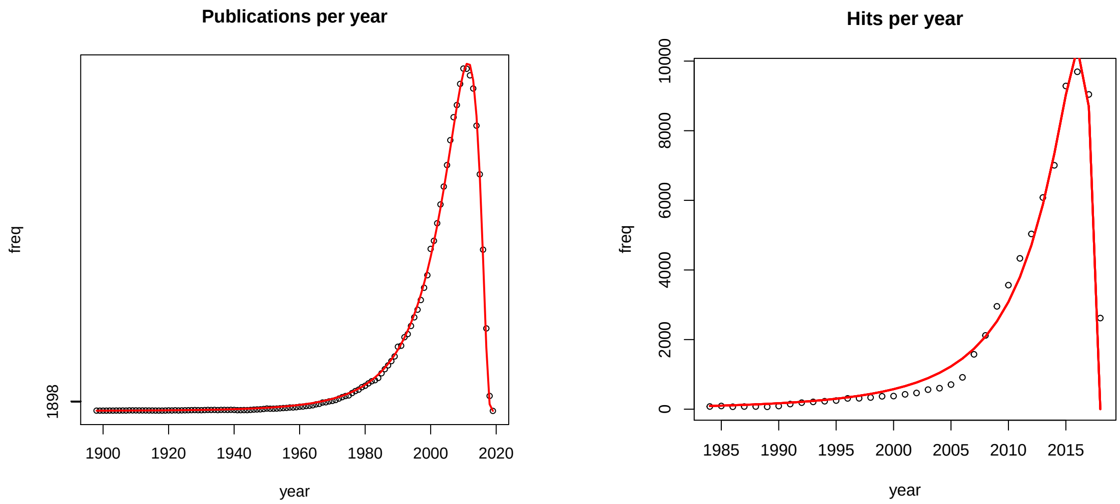

Figure 2: Citation network: Distribution of all works and hits by years

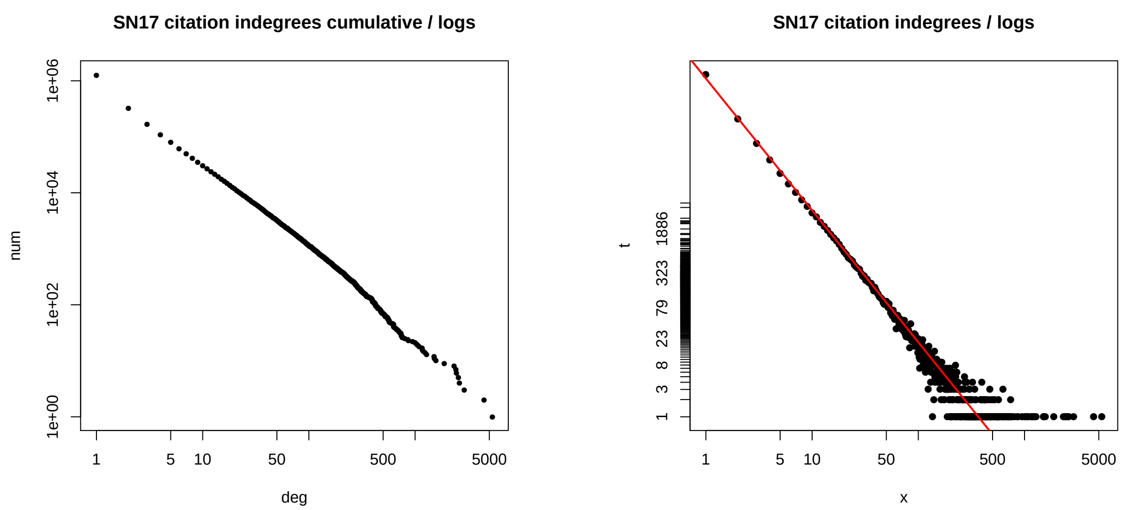

Figure 3: Citation network: Indegree distribution

Table 2: Citation net: 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

information flow model for conflict and fission in small groups, 1977 (583); Burt, RS Brokerage and closure: An introduction to social capital, 2005 (565); Rogers EM, Diffusion of Innovation. 4th, 1995 (555); Fischer CS, 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 MG (1171) and Borgatti SP (999) as the first author.

The second place is taken by a classical article of *Granovetter* on the *strenght of weak ties* concept. Other artciles 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), Coleman, Portes, Adler (social capital), Granovetter, Uzzi (embeddedness), Milgram (small world), and Borgatti*.

The list includes a lot of names of phisicists working within the Network approach (marked by *): highly ranked articles of *Watts DJ – Collective dynamics of 'small-world' networks*, appeared in NATURE in 1998 (2906), as well as *Barabasi AL – Emergence of scaling in random networks*, appeared in SCIENCE in 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 Erdős and Rényi *On random graphs* published in 1959 is also in 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 famous works of Christakis NA on spread of obesity and smoking), and management.

Works with the largest Outdegree in **CiteN** are the most *citing* works. These works are books, books introductory chapters, and review articles. Most of these works belong to the field of social sciences and cover different topics, including education, human relationships, archeology, migration, internet studies, and social media. The topic of Social network analysis is not presented separately in this type of works. However, it is presented in the works from the list published in journals in Physics and Computer Science (Bocaletti 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 WAn

remove Table 4?

Table 3 shows authors with the largest number of papers (indegree in the **WAn** network). Almost all of these names (Wang, Zhang, Chen, Li, Liu, Lee, Kim, Yang, Wu), except Newman, belong to Chinese or Korean authors. However, this is the result of the well-known "three Zhang, four Li" effect: as the 80% of surnames in China are selected among only around 100 surnames, there is a high chance that different authors, having the same surname and first letter of the name, shrink together, creating 'multiple personalities' (Harzing (2015)). This problem could be overcame if we would use a special ID (such as ORCID) for each scientist (but this information is not provided in WoS yet).

Looking at the outdegree of **WAn** network, we get the information on the number of authors in works. This distribution is presented in the Figure 4 and Table 4. The majority of works (95.5%) has only one author (however, the largest part of this group are works that are cited only, $DC = 0$, having information only on the first author). Other 4% of all the works have from 2 to 5 authors. In some works, hovever, 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 field, the inclusion of all the authors inplementing a research project to the paper 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.

remove Table 6?

4.3 Distributions on WJn

The distributuion of number of works per journals is presented on the Figure 5. It has a scale-free form. According to the Indegree distribution of the **WJsn** network, the majority of jornals – 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 general, there are quite a lot of journals from *Social sciences* – such as Sociology, Psychology, Management and Business – in the list, which are marked in boldface. However, the dominant journal is

Table 3: **WAn** network: Authors with the largest number of papers – indegree

Rank	Value	Id	Rank	Value	Id
1	1169	WANG_Y	21	552	KIM_H
2	883	ZHANG_Y	22	550	CHEN_J
3	868	CHEN_Y	23	536	LIU_X
4	847	LI_Y	24	533	WANG_L
5	838	WANG_X	25	509	LI_H
6	819	ZHANG_J	26	490	KIM_Y
7	788	WANG_J	27	485	ZHANG_Z
8	786	LIU_Y	28	474	WANG_Z
9	766	LEE_J	29	471	WANG_S
10	765	LEE_S	30	471	CHEN_X
11	749	LI_J	31	471	**NEWMAN_M**
12	708	LI_X	32	462	CHEN_L
13	696	CHEN_C	33	461	ZHANG_L
14	690	KIM_J	34	450	YANG_Y
15	620	WANG_H	35	450	ZHANG_H
16	611	ZHANG_X	36	432	WU_J
17	611	LIU_J	37	431	LEE_H
18	570	CHEN_H	38	420	LI_Z
19	557	KIM_S	39	420	WANG_W
20	554	WANG_C	40	417	LI_L

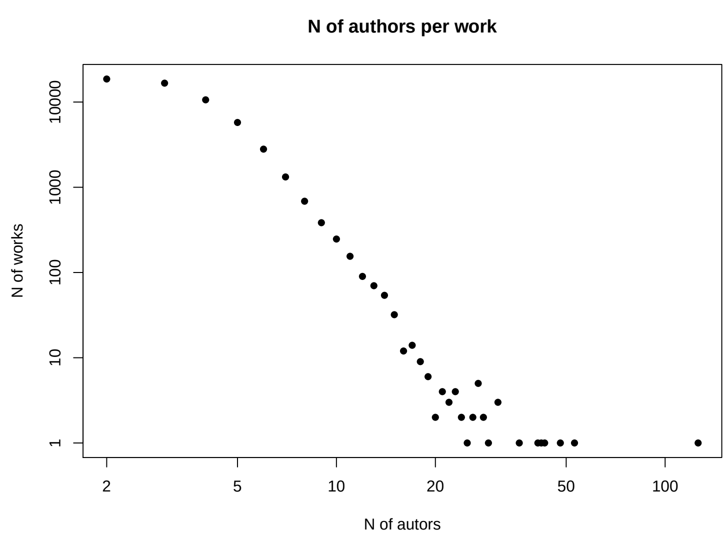

Figure 4: WAsn network: Distribution of number of authors by works

Table 4: WA net: Number of authors in works – outdegree

outdeg	Freq	Freq%	outdeg	Freq	Freq%
1	1239498	95.5566	21	4	0.0003
2	18635	1.4368	22	3	0.0002
3	16661	1.2844	23	4	0.0003
4	10617	0.8185	24	2	0.0002
5	5759	0.4440	25	1	0.0001
6	2802	0.2160	26	2	0.0002
7	1322	0.1019	27	5	0.0004
8	686	0.0529	28	2	0.0002
9	384	0.0296	29	1	0.0001
10	247	0.0190	31	3	0.0002
11	155	0.0119	36	1	0.0001
12	90	0.0069	41	1	0.0001
13	70	0.0054	42	1	0.0001
14	54	0.0042	43	1	0.0001
15	32	0.0025	48	1	0.0001
16	12	0.0009	53	1	0.0001
17	14	0.0011	126	1	0.0001
18	9	0.0007			
19	6	0.0005			
20	2	0.0002			
SUM				1297133	100

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 *Proceedings of the National Academy of Sciences of the USA, Science, Nature*, as well as such disciplinary journals as *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 Social network analysis field‘s outlet *Social Networks* journal is also in this list, on the18th place, having 1642 works. The remaining journals cover many disciplines such as Medicine, Psychiatry, Gerontology, Epidemiology, Psychology, Management, Marketing, Computer and Information science.

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 some 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.

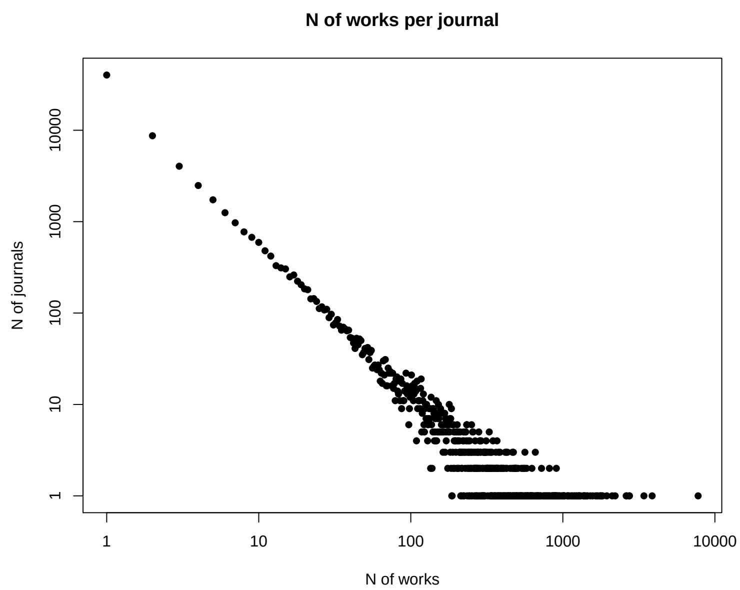

Figure 5: WJsn network: Distribution of number of works by journals

Table 5: WJ net:The most used journals – indegree

Rank	Value	Id	Rank	Value	Id
1	7757	LECT NOTES COMPUT SC	31	1278	**BRIT J PSYCHIAT**
2	3866	SOC SCI MED	32	1267	**AM J PSYCHIAT**
3	3414	**J PERS SOC PSYCHOL**	33	1244	**STRATEGIC MANAGE J**
4	2741	P NATL ACAD SCI USA	34	1225	**MANAGE SCI**
5	2734	COMPUT HUM BEHAV	35	1221	**J BUS RES**
6	2631	SCIENCE	36	1189	**ACAD MANAGE REV**
7	2609	AM J PUBLIC HEALTH	37	1188	**J CONSULT CLIN PSYCH**
8	2208	NATURE	38	1154	**ORGAN SCI**
9	2111	**AM SOCIOL REV**	39	1150	ADDICTION
10	1945	PHYSICA A	40	1123	CYBERPSYCHOL BEHAV
11	1825	ANIM BEHAV	41	1092	COMPUT EDUC
12	1812	**AM J SOCIOL**	42	1087	**J GERONTOL B-PSYCHOL**
13	1780	JAMA-J AM MED ASSOC	43	1075	PEDIATRICS
14	1763	LANCET	44	1067	AM J EPIDEMIOL
15	1759	SCIENTOMETRICS	45	1024	**DEV PSYCHOL**
16	1703	**ACAD MANAGE J**	46	1022	**PSYCHOL BULL**
17	1668	LECT NOTES ARTIF INT	47	1020	INFORM SCI
18	1642	***SOC NETWORKS***	48	1016	J ADOLESCENT HEALTH
19	1573	**J APPL PSYCHOL**	49	1009	ARCH GEN PSYCHIAT
20	1517	AM ECON REV	50	997	**J MARKETING**
21	1450	**J MARRIAGE FAM**	51	994	AIDS BEHAV
22	1441	EXPERT SYST APPL	52	972	PERS INDIV DIFFER
23	1403	BRIT MED J	53	949	**PERS SOC PSYCHOL B**
24	1399	CHILD DEV	54	947	J BUS ETHICS
25	1379	**RES POLICY**	55	939	**J MARKETING RES**
26	1372	COMMUN ACM	56	925	**HARVARD BUS REV**
27	1365	NEW ENGL J MED	57	915	IEEE T KNOWL DATA EN
28	1311	PHYS REV E	58	914	DRUG ALCOHOL DEPEN
29	1287	**SOC FORCES**	59	908	J ADV NURS
30	1279	GERONTOLOGIST	60	906	MIS QUART

Table 6: WK 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

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 other 70,792 works varies from 1 to 84. The most frequent keywords are presented in the Table 6. Not surprisingly, the words *social* and *network* are mentioned in the larges number of works, followed (with a large margin) 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 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 differnt subgroups (of authors or works) can bring us better understading of the topic structure of the field.

Idea: loolk at moda, or average?

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 recieved citations: 0 (41,954), 1 (933,315), 2 (154,895), 3 (58,141), and 4 (29, 885), which alltogether 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, we decided to remove all the 'cited only' nodes with indegree smaller then 3 ($DC = 0$ and 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

We restricted the original citation network **CiteN** to its 'boundary' – **CiteB** with 222,086 nodes and 1,521,434 arcs. A citation network is usually (almost) acyclic; however, it can include some small cyclic parts, which can be identified as strong components of the network (with the minimum size 2). At first we searched for nontrivial strong components (see Appendix B for details). To get an acyclic network, as required by the SPC weights algorithm used in its analysis, 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'. Published work could cite only preprints. Each strong component was replaced by a corresponding complete bipartite graph on pairs (Batagelj et al., 2014). The resulting network **CiteT** had 222,189 nodes and 1,521,658 arcs. The increase in the number of works is due to some of them appearing twice with one name starting with an $=$ sign indicating the "preprint" version of a paper.

Then we computed the **SPC weights** on **CiteT** network arcs. The normalized SPC weight of an arc is equal to a probability that a random path through the network is passing through this arc. The total flow

write total flow

is [xx] . 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 connected components of this network. For the same network, we also computed the **probabilistic flow**, and used the **Vertex islands approach** to get its components.

5.3 CPM main path and Key Routes

Figure 6 shows the CPM Main path through the Social network analysis literature (which is the same to the one obtained with Main path procedure), which includes 59 nodes. We devided 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 field of Social sciences. These works appeared in such journals as *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 Social network analysis field formation. In this group, 6 of 20 works belong to R. Burt.

However, since 1999, the initiative in the field goes to the physicists, whose works appears in such journals as *Physical Review E, Journal of Statistical Physics, Reviews of Modern Physics, European Physical Journal B, Physics Reports, Nature*, and *SIAM Review*. In this part of network, 9 of 14 works belong to M. Newman.

Figure 6: Main path by fragments – sociology, physics, biology

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 at such journals as *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 Social network analysis field was already shown in other studies (Lazer et al., 2009; Brandes, Pich, 2011), the appearance of the third group in the Main path is quite surprising, because previously it was shown that the trend goes from Physics to Neuroscience (Batagelj et al., 2014).

The procedure of Key-route paths (Batagelj et al., 2014) produces a more nuanced image of most important paths in the Social network analysis literature, as it implies some deviations from the structure of the network, identified with the CPM Main path method. Figure 7 shows the obtained Key-route paths, which contain 127 nodes. Basically, we can see the division into three previously mentioned groups.

The first period (1944–1999) includes 50 works of the Social network analysis discipline's representatives. It starts with two works of Heider on his *theory of social perception and cognitive organization* of 1944 and 1946, which form the basis for the work of Cartwright of 1956 on *structural balance*. Then, with some marin, two works of Holland on *structural models* follows, published in 1970–1971. Next comes a 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 the one 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 the main path on the topics of *positions in multiple networks (stratifiction and prestige), structural equivalence and networks subgoups*, 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 strcutures, 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 constructin*, 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 *measure 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 speciality as a diffusion through social relations*.

The work of Valente is the one bridging the first group of social network scientists with the **group of physicists**, which includes 28 works from the Network science discipline published in the **second period (1999–2008)**. It is 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*, and 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 identification 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 *deseases transmission* (1992–98), and Potterat in the *infections transmission* (1999). These works are cited by Ferguson (desease transmission), and then the route comes back to the main path - 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 stractures 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, at the same topic – Krause, James (2009) with *general works* on animal social network analysis, and Ramos-Fernandez, Kasper, Voell, Lehmann, Brent, Sueur (2009–2011), working with *social networks of Nonhuman Primates* (monkeys, baboons). These works are followed by the one of 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 social network analysis*, 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 phenotypic types* (Wilson, Alpin, Farine), published in 2013-2014.

The upper part of the network contains works published in the last years, 2016–2018. It presents studies on *desease 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 social network analysis (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 on the Table 8. It is also relevant for our analysis on the islands, presented in the following subsections. In this table, the second column (code) describes in which analysis the work appeared (1- Key-routes, 2- Main Path (CPM), 3- Island 5, 4 - Island 4, 5 - Node Island, 6 - Probilistic Flow Island).

5.4 Link Islands

Using Islands approach, we searched for SPC link islands (on line weights) with the number of nodes between 20 and 200, and found 5 islands of 138, 65, 13, 12, and 11 nodes. The obtained largest Island 4 of 138 nodes is presented on the Figure 8. 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 alreday discussed upper. 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 and presented on the Figure 8. It has 39 overlapping nodes with the Key-routes. ‘New’ works presented in the island also belong to the topics on animal social networks described above. Howver, there are some more 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 ineteresting 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 the Island 4 are more stongly connected to the previous works of phisicists.

Three other obtained islands are presented on the Figure 10. For the purpose of better visibility of the picture, the weights were maximized by 100. The left Island 2 consitst of 12 work in the field of social networks in *education*, imcluding 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 presenets 13 works of *physicists* with the strongest links between the work of Bocaletti published in 2014 on the structure and dynamics of multilayer networks and others on the topics of complex, multilayer, dynamic, and temporal networks, as well as spreading processes in these networks.

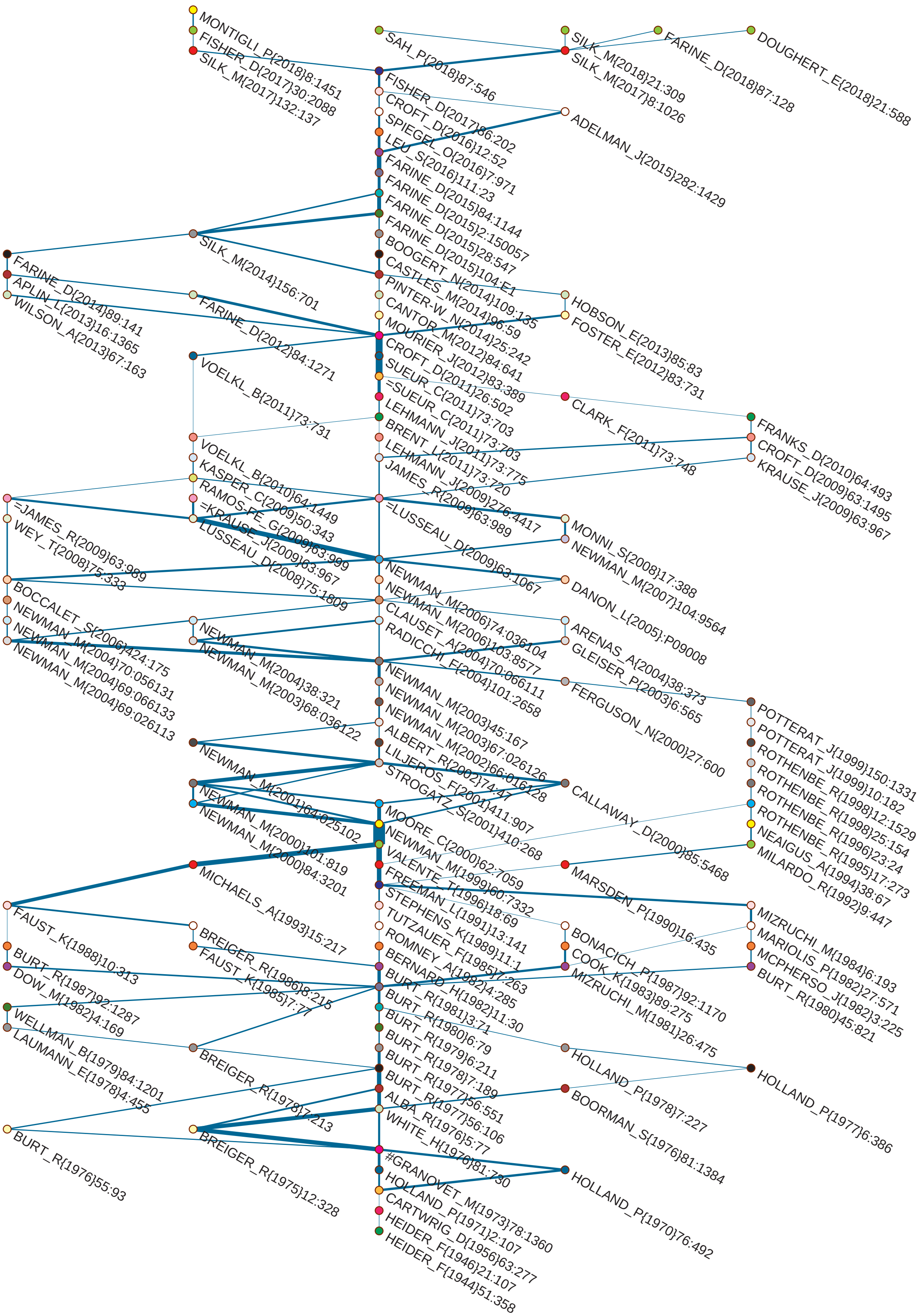

Figure 7: Key Routes

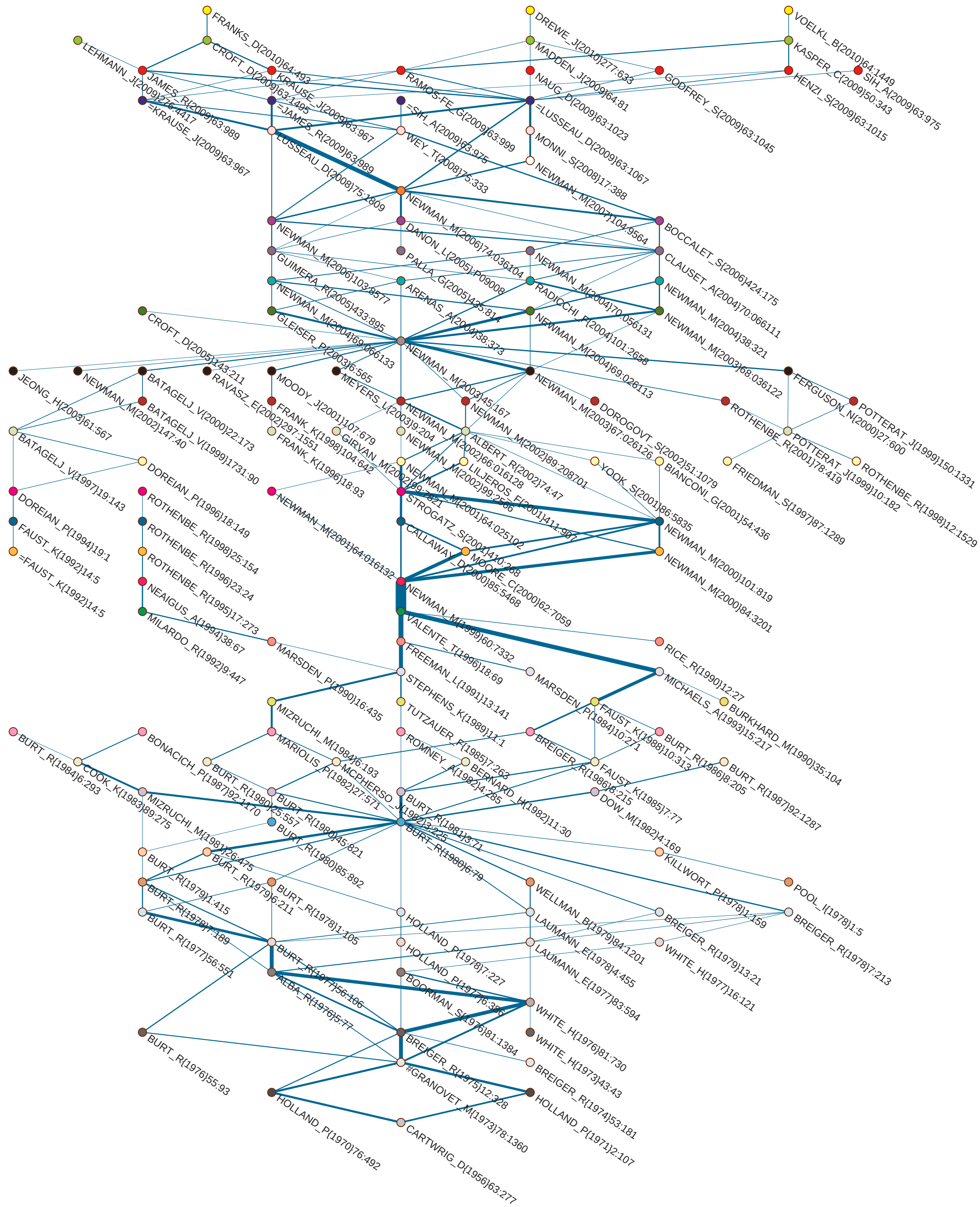

Figure 8: Island 4, from SPC network

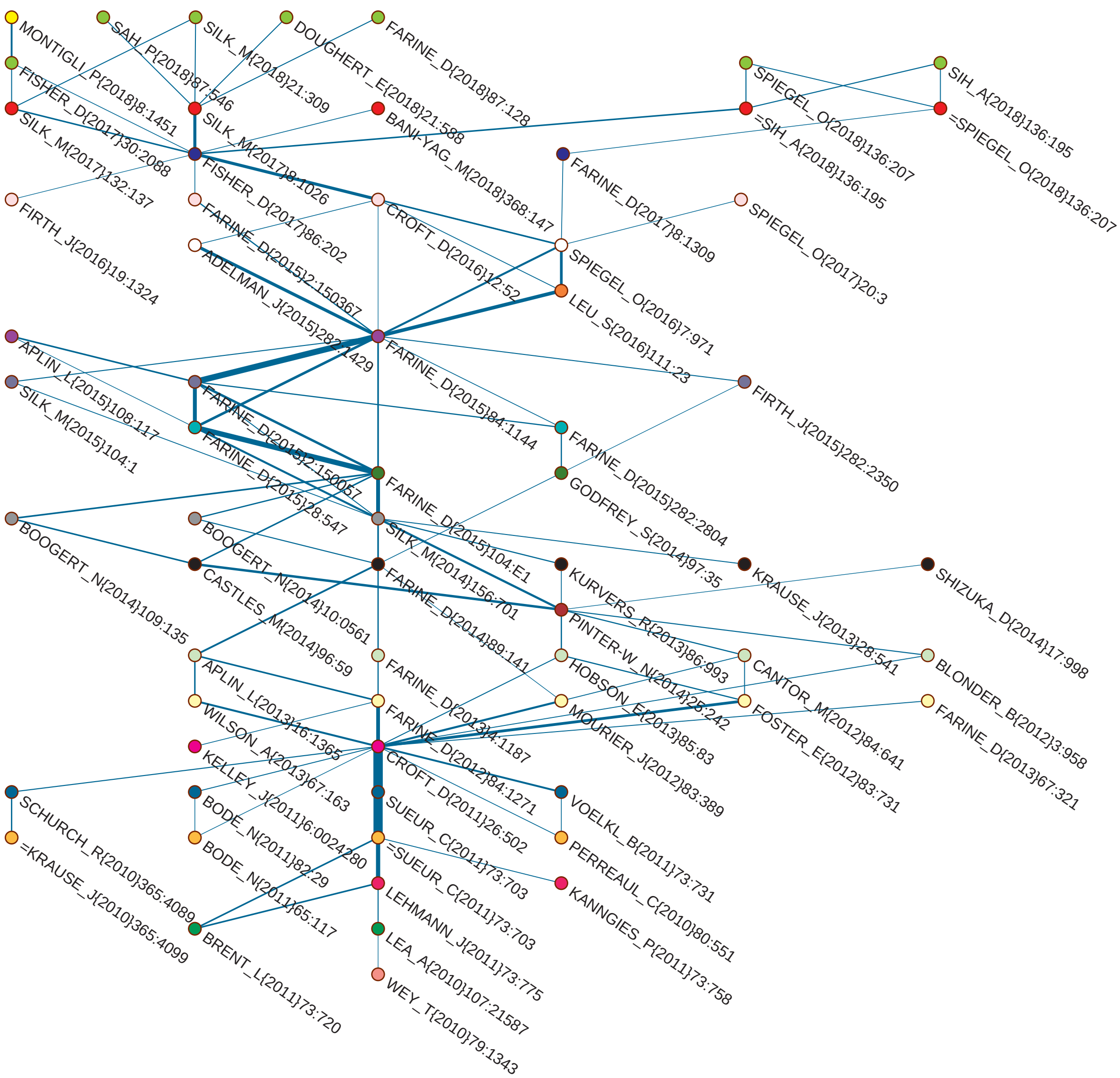

Figure 9: Island 5, from SPC network

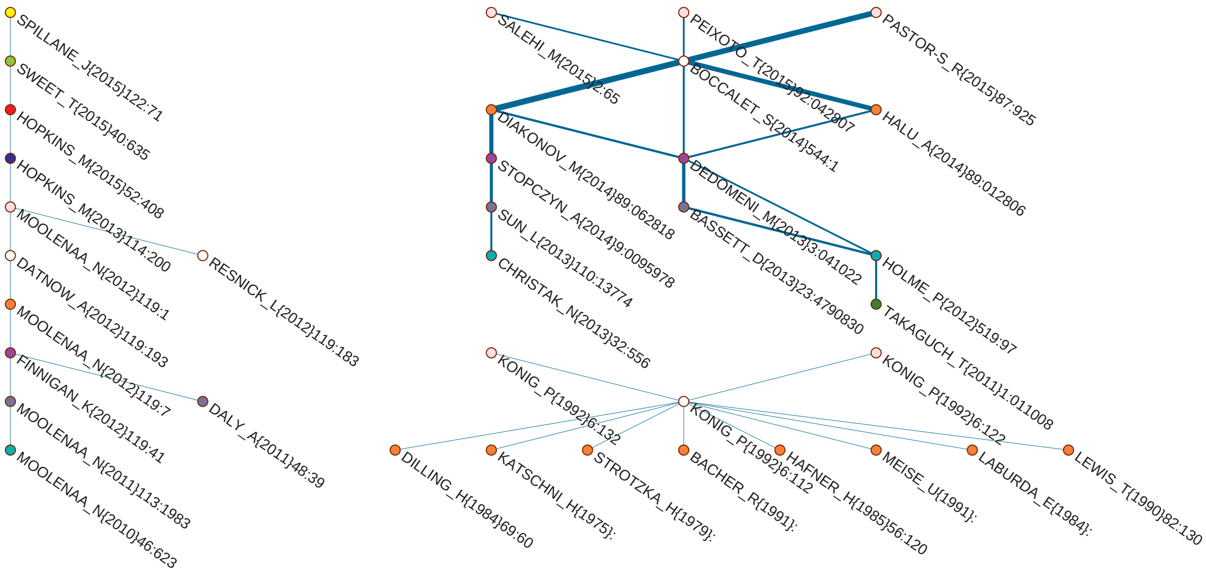

Figure 10: Islands 1-3, from SPC network

5.5 Probabilistic flow

We computed the Probabilistic flow on weighted network, and determined Node islands (on vertex weights) with the number of nodes between 10 and 200 and got one island with the size of 200 nodes.

Table 7 present the list of the most important works, which have the highest indegree values of Probabilistic flow network. For the purposes of visibility, the values were maximized by 1,000,000. 39 works from this list overlap with the table containing the highest Indegree values of **CiteN** network. First 30 works in the list, except `BLEI_D(2003)3:993` on latent dirichlet allocation, `O'REILLY_T(2005)` on web 2.0, and `ALBERT_R(1999)401:130` on world-wide web are also presented in the most cited works list. Works appeared in the top list of this island, which are not in the list of the most cited works, are works of physicists (Strogatz, Watts, Albert), computer scientists (Brin), mathematics (Bollobas), scientometricians (Page, Redner), and social scientists (Katz, Mitchell, Glaser).

6 Conclusions

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Table 7: Most important works from Probabilistic Flow network

Rank	Value	Id	Rank	Value	Id
1	4691	WASSERMA_S(1994):	31	545	BLONDEL_V(2008):P10008
2	2941	WATTS_D(1998)393:440	32	527	KATZ_L(1953)18:39
3	2676	GRANOVET_M(1973)78:1360	33	526	NEWMAN_M(2010):
4	2445	BOYD_D(2007)13:210	34	520	STROGATZ_S(2001)410:268
5	2241	BARABASI_A(1999)286:509	35	517	PALLA_G(2005)435:814
6	1926	FREEMAN_L(1979)1:215	36	499	CLAUSET_A(2004)70:066111
7	1396	GIRVAN_M(2002)99:7821	37	497	ERDOS_P(1960)5:17
8	1299	NEWMAN_M(2003)45:167	38	488	ROGERS_E(2003):
9	1227	MCPHERSO_M(2001)27:415	39	485	NEWMAN_M(2006)103:8577
10	1158	ALBERT_R(2002)74:47	40	481	COLEMAN_J(1990):
11	1105	SCOTT_J(2000):	41	478	BRIN_S(1998)30:107
12	1098	BURT_R(1992):	42	477	AMARAL_L(2000)97:11149
13	1045	MILGRAM_S(1967)1:61	43	475	ERDOS_P(1959)6:290
14	1013	NEWMAN_M(2004)69:026113	44	465	WATTS_D(1999):
15	928	KAPLAN_A(2010)53:59	45	462	LAVE_J(1991):
16	878	FREEMAN_L(1977)40:35	46	460	KLEINBER_J(1999)46:604
17	852	PUTNAM_R(2000):	47	449	SCOTT_J(1991):
18	847	COLEMAN_J(1988)94:95	48	446	BOLLOBAS_B(1985):
19	835	BLEI_D(2003)3:993	49	442	PAGE_L(1999):
20	742	GRANOVET_M(1985)91:481	50	440	NEWMAN_M(2001)64:025102
21	731	CHRISTAK_N(2007)357:370	51	436	NEWMAN_M(2004)69:066133
22	727	EVERETT_M(2002):	52	431	REDNER_S(1998)4:131
23	726	NEWMAN_M(2001)98:404	53	429	CHRISTAK_N(2008)358:2249
24	719	ALBERT_R(1999)401:130	54	424	ADOMAVIC_G(2005)17:734
25	701	O'REILLY_T(2005):	55	424	KEMP_D(2003):137
26	669	BORGATTI_S(2002):	56	423	DOMINGOS_P(2001):57
27	667	FORTUNAT_S(2010)486:75	57	423	MITCHELL_J(1969):
28	633	HANNEMAN_R(2005):	58	415	ALBERT_R(2000)406:378
29	569	STEINFIE_C(2007)12:1143	59	415	GLASER_B(1967):
30	549	ZACHARY_W(1977)33:452	60	410	ROGERS_E(1995):

Barabâsi, A. L., Jeong, H., Néda, Z., Ravasz, E., Schubert, A., Vicsek, T. (2002). Evolution of the social network of scientific collaborations. Physica A: Statistical mechanics and its applications, 311(3-4), 590-614.

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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` were referencing the same work of Danah Boyd, 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 the equivalence partition of nodes and shrink the set of works accordingly in all obtained networks. We used the second option (Batagelj, Chapter 2). For the works with the large frequences 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 $\mathbf{Cite}$, $\mathbf{WA}$, $\mathbf{WJ}$, and $\mathbf{WK}$. The partitions $\mathbf{year}$, $\mathbf{DC}$ and the vector $\mathbf{NP}$ 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, for each journal title we constructed a short code, which was formed out of the first two letters of each word in the journals‘ titles, – such as `SONEANMI` for `SOCIAL NETWORK ANALYSIS AND MINING`, – and then sorted so that the journals with the same codes 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 the list of candidates for inspection with 5,482 titles. To additinally 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 manual checking this list was reduced to 1,688 titles. Some examples of the journals titles grouped according to their codes are presented on the Fig 11.

However, some jurnal 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 jornals in the original list of 70,425 journals, where the values of weighted indegree of the journals were also presented. We grouped all the jornals titles which included the same abbreviations – an example is presented on the Fig 12 (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.

A Appendix: Srong components

The citation network **CiteB** has 41 nontrivial strong components of different sizes, which are presented in the Figure 13. The reciprocal (cycle) links are marked with the bluse colour, while directed pink

```
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 11: An example of different 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 12: An example of different titles writing with abbreviations

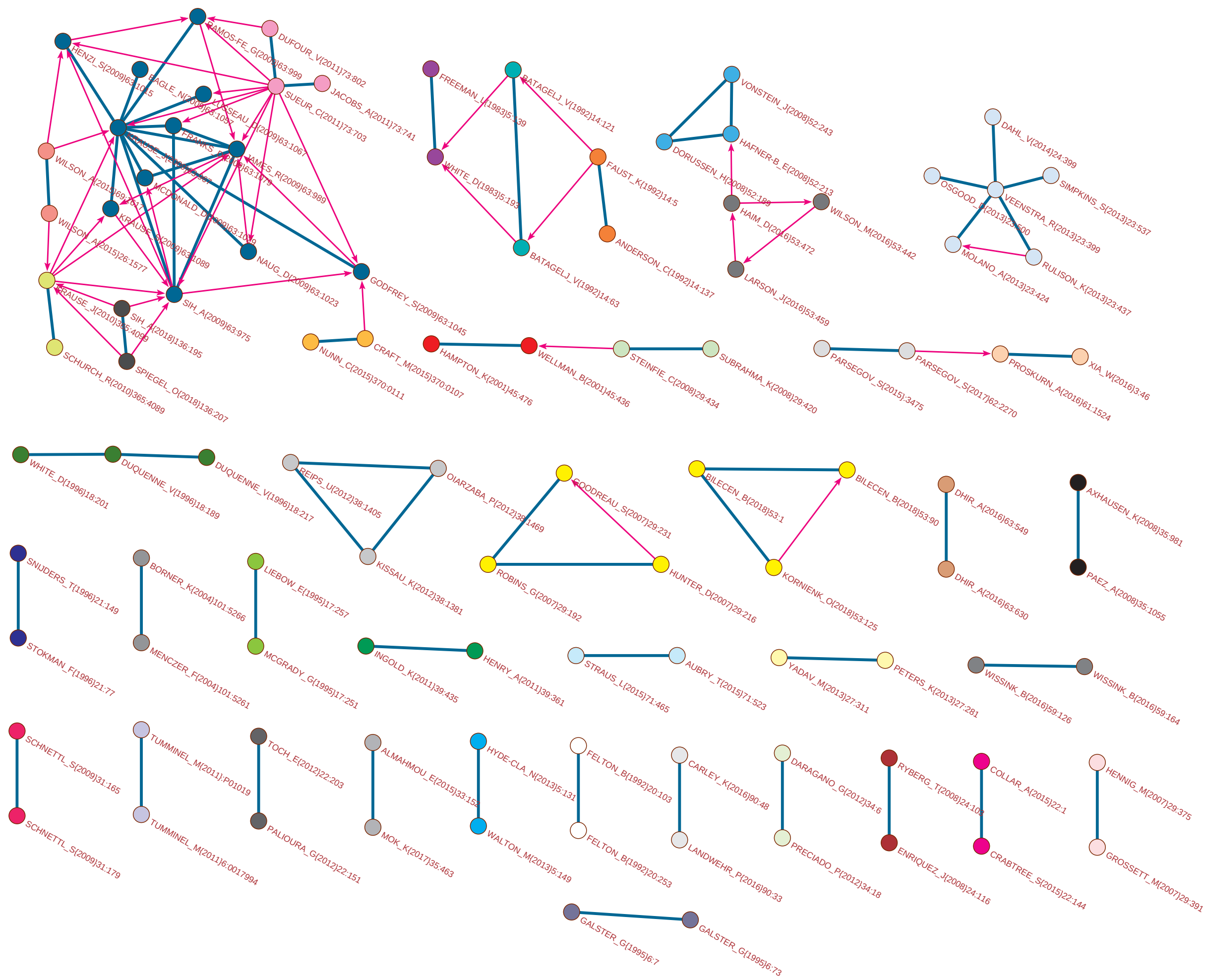

Figure 13: Strong components from SPC network

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 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).

A Appendix

Table 8: Cite net: Overlapping of components: (1- Key Routes, 2- Main Path (CPM), 3- Island5, 4 - Island 4, Node Island, 5 - Prob Flow Island)

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 8: Cite net: Overlapping of components: (1- Key Routes, 2- Main Path (CPM), 3- Island5, 4 - Island 4, Node Island, 5 - Prob Flow Island)

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	Cooptive 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 8: Cite net: Overlapping of components: (1- Key Routes, 2- Main Path (CPM), 3- Island5, 4 - Island 4, Node Island, 5 - Prob Flow Island)

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 8: Cite net: Overlapping of components: (1- Key Routes, 2- Main Path (CPM), 3- Island5, 4 - Island 4, Node Island, 5 - Prob Flow Island)

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 8: Cite net: Overlapping of components: (1- Key Routes, 2- Main Path (CPM), 3- Island5, 4 - Island 4, Node Island, 5 - Prob Flow Island)

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 ofpractice: 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	Barthélémy 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 8: Cite net: Overlapping of components: (1- Key Routes, 2- Main Path (CPM), 3- Island5, 4 - Island 4, Node Island, 5 - Prob Flow Island)

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	europhys 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 8: Cite net: Overlapping of components: (1- Key Routes, 2- Main Path (CPM), 3- Island5, 4 - Island 4, Node Island, 5 - Prob Flow Island)

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	europhys 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

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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	Steinfield 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 reversihle 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 (Ateles geoffroyi)	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

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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, Egernia stokesii	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 LJN	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 (Papio anubis) 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

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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

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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