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Social Network Analysis:

Bibliographic Network Analysis of the Field and its Evolution

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IMFM Ljubljana, IAM UP Koper and NRU HSE Moscow

Sredin Seminar 1282

November 21, 2018

Outline

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- ① Introduction
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- ⑦ Citation among authors / journals
- ⑧ Co-citation among authors / journals
- ⑨ Keywords co-occurrence

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Social Network Analysis (SNA) has moved from a fragmented direction represented by the works of individual scientific groups unrelated to each other, to a discipline whose representatives by 1990 have formed an “invisible college” and achieved the status of what Kuhn had labeled a “normal science” [Freeman, 2004; Hummon and Carley, 1993].

Starting from that time, the field has grown significantly, which can be seen by the number of scientific publications [Otte and Rousseau, 2002] in different scientific fields, including Natural Sciences, which lead to the so called “physicists’ invasion” into SNA [Batagelj et al., 2014] and resulted with the development of Network Science discipline.

This calls into a question whether the field remains unified and which scientific groups (by disciplines, thematic agenda, etc.) it is currently formed of. Thus, the aim of the current study is to trace the evolution of the field of Social Network Analysis using bibliographic approach.

Previous studies

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- 1 Hummon N.P., Doreian P., Freeman L.C. (1990). Analyzing the Structure of the Centrality-Productivity Literature Created Between 1948 and 1979 / *Science Communication*. 11, 4, 459 – 480.
- 2 Freeman, L. (2004). The development of social network analysis. A Study in the Sociology of Science, 1.
- 3 Hummon, N. P., Carley, K. (1993). Social networks as normal science. *Social networks*, 15(1), 71-106.
- 4 Otte, E., Rousseau, R. (2002). Social network analysis: a powerful strategy, also for the information sciences. *Journal of information Science*, 28(6), 441-453.
- 5 Borgatti, S. P., Foster, P. C. (2003). The network paradigm in organizational research: A review and typology. *Journal of management*, 29(6), 991-1013.
- 6 Leydesdorff L., Schank T., Scharnhorst A., De Nooy W. (2008). Animating the development of Social Networks over time using a dynamic extension of multidimensional scaling / *El Profesional de Informacion*, 17(6).
- 7 Lazer, D., Mergel, I., and Friedman, A. (2009). Co-citation of prominent social network articles in sociology journals: The evolving canon. *Connections*, 29(1):43:64.
- 8 Brandes, U., Pich, C. (2011). Explorative visualization of citation patterns in social network research. *Journal of social structure*, 12(8), 1-19.
- 9 Varga, A. V., Nemeslaki, A. (2012) Do organizational network studies constitute a cohesive communicative field? Mapping the citation context of organizational network research. *Journal of Sociology and Social Anthropology*, 5(64), XV, 349-364.
- 10 Batagelj, V., Doreian P., V., Ferligoj, A., Kejžar N. (2014). Understanding Large Temporal Networks and Spatial Networks: Exploration, Pattern Searching, Visualization and Network Evolution.
- 11 Groenewegen, P., Hellsten, I., Leydesdorff, L. (2015) Social Networks as a looking glass on the social networks community. International Sunbelt XXXV Conference. Hilton Metropole, Brighton, UK, June 23 – 28, 2015. Abstracts, 118.

To the Web of Science (WoS), Clarivate Analytics's multidisciplinary databases of bibliographic information, we put the query

"social network*"

Additionally, all the articles from the following journals were collected:

Social Networks, Network Science,
Social Network Analysis and Mining,
Journal of Complex Networks

Other network-related journals *are not presented* in WoS:

Computational Social Networks, Applied Network Science,
Online Social Networks and Media, Connections,
Journal of Social Structure

We limited the search to the Web of Science Core Collection because for other data bases from WoS the CR-fields (containing citation information) can not be exported. The first data set was collected in 2007, second – in June, 2018.



WoS record

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PT J
AU GRANOVET.MS
TI STRENGTH OF WEAK TIES
SO AMERICAN JOURNAL OF SOCIOLOGY
LA English
DT Article
C1 JOHNS HOPKINS UNIV, BALTIMORE, MD 21218 USA.
CR BARNES JA, 1969, SOCIAL NETWORKS URBA
BECKER MH, 1970, AM SOCIOL REV, V35, P267
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



We call a *terminal* node a node without a description in the collected data set – it appears only in the WoS CR field as a reference.

We additionally collected on WoS and Google data for terminal nodes with large indegree in the citation network – highly cited works without description in the collected data set. If a description of a node was not available in WoS we manually constructed a corresponding description without CR data (using RIS bibliographic format and converting it to WoS).

As the data set of 2007 was already completed, we made this additional search only for works 2008-* in July 2018.

Types of networks and partitions

We applied the WoS2Pajek 1.5 to the collected data.

The following networks were constructed:

- ① the authorship network WA on works \times authors (from the field AU),
- ② the journalship network WJ on works \times journals (from the field CR or J9),
- ③ the keywordship network WK on works \times keywords (from the field ID or DE or TI),
- ④ the citation network $Cite$ on works (from the field CR).

We obtained also the following partitions:

- ① the partition $year$ of works by publication year,
- ② the DC partition distinguishing between works with complete description ($DC=1$) and the cited only works ($DC=0$),
- ③ the vector of number of pages NP .

ISI names

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The usual *ISI name* of a work (field CR)

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

has the following structure

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

All its elements are in upper case.

In WoS the same work can have different ISI names. To improve the precision the program WoS2Pajek supports also *short names* (similar to the names used in HISTCITE output). They have the format:

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

For example: GRANOVET_M(1985)91:481

From the last names with prefixes VAN, DE, ... the space is deleted.

Unusual names start with character * or \$.

Equivalent works, authors and journals

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BOYD_D(2007)13 | BOYD_D(2008)13:210

GRANOVET_M(1973)78:1360 | GRANOVET_M(1973)78:6

COLEMAN_J(1988)94:95 | COLEMAN_J(1988)94:S95

GRANOVET_M

GRANOVET_-

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

...

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

Equivalent works, authors and journals

There are two possibilities how to correct the data:

- to make corrections in the local copy of original data (WoS file);
- to make the equivalence partition of nodes and shrink the set of works accordingly in all obtained networks.

For the **works** with largest counts we prepared lists of possible equivalents and manually determined equivalence classes. With a program in R we produced a Pajek's partition *EQ.clu* file used for shrinking the set of works. Using the partition $p = \text{works}EQ$, we shrink using Pajek the Citation network *cite*, *WA*, *WJ*, and *WK*. We had to shrink also partitions *year*, *DC* and the vector *NP*.

The total cleaning of **journals** would require too much time. We decided to clean only the high frequency elements (cited 200 times and more) and consider bugs in low frequency elements as a noise. We got the list *journalK100.csv* with 3714 titles for inspection.

We also produced a list of frequent journal names (of length at most 5), have chosen all the cases that could be regarded as abbreviations (*CACM*, *JACM*, *JASA*), and manually searched for them.

Sizes of Original cleaned and Reduced networks

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	# 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

An important property of all these networks is that they share as the first node set the same set of works (papers, reports, books, etc.) – they are *linked*.

Cite network

Distribution of works by years

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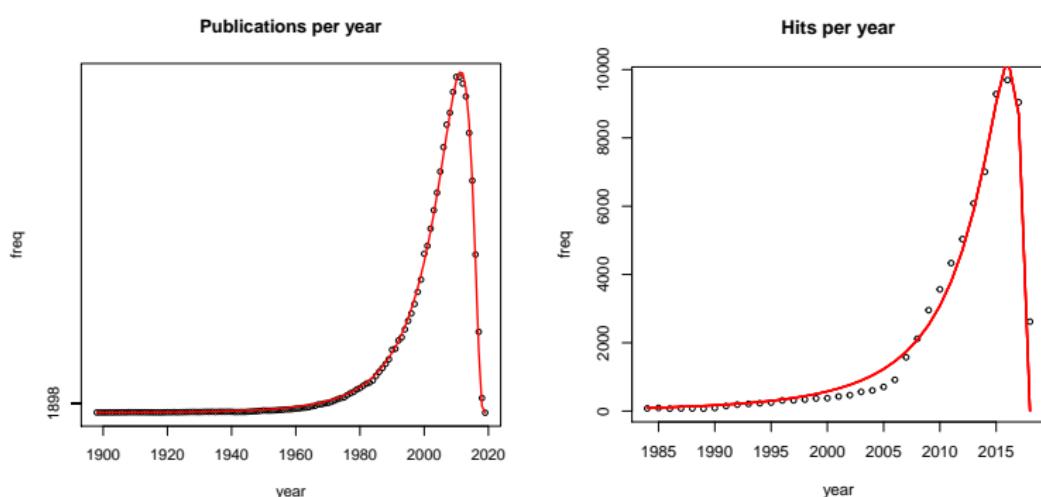
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The distributions fits the *log normal* distribution

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

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

Cite network

Indegree distribution

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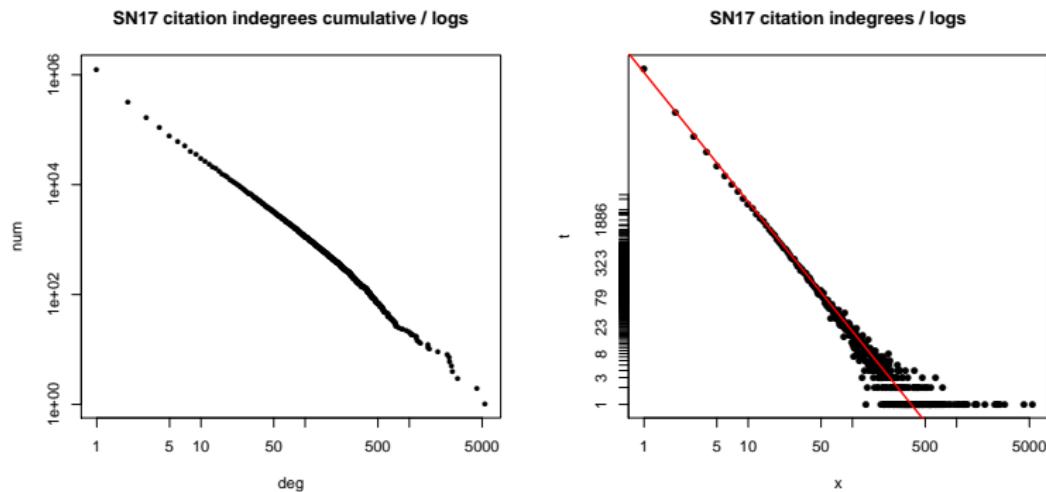
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The indegree distribution in citation network follows the *power law*
 $f = c \cdot n^{-\alpha}$.

Fitted $\alpha = 2.3007$, $c = 749338$.

The most cited works - indegree

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i	freq	id	i	freq	id
1	5348	WASSERMAN_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	MCPHERSON_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	KLEINBERG_J(1999)46:604
30	740	*NEWMAN_M(2006)103:8577	60	517	*BOCCALET_S(2006)424:175

Labels ending with : represent books



The most citing work - outdegree

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i	freq	id	i	freq	id
1	1572	CHAPMAN_C(2016):1	11	731	TSATSOU_P(2014):1
2	1406	HRUSCHKA_D(2010):5:1	12	654	GOODALE_E(2017):IX
3	1293	COWARD_F(2015):1	13	649	PEPPER_G(2017)40:S0140525X1700190X
4	1254	FITZGERALD(2008):1	14	632	STROM_R(2012):1
5	1207	DAVIES_N(2015):V	15	613	SCHACHNE_G(2015)23:49
6	1055	MARSH_C(2009):1	16	597	COSTA_L_(2011)60:329
7	942	YUS_F(2011)21:3:1	17	593	BRANDES_U(2005)34:18:1
8	929	BOCCALET_S(2006)424:175	18	586	ROBERTS_J(2014):1
9	799	REEVES_M(2017):1	19	557	GUNTER_B(2016):1
10	768	GROSS_J(2007):1	20	547	CASTELLA_C(2009)81:591

- Muijs, D., Reynolds, D., Chapman, C. (2015). Educational effectiveness and improvement research and practice: The emergence of the discipline. In The Routledge International Handbook of Educational Effectiveness and Improvement (pp. 33-56). Routledge.
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- Marsh, C. J. (2009). Key concepts for understanding curriculum. Routledge.

Authors with the largest number of papers - indegree

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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

The large number of Chinese authors in the list is a "three Zhang, four Li" effect. It is out of our resources to drill into this. We can only make a warning.

Number of authors in works - outdegree

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outdeg	Freq	Freq%	outdeg	Freq	Freq%
1*	1239496	95.5566	21	4	0.0003
2	18637	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
SUM				1297133	100

* In cited only works only the first author is known.

Works with the largest number of authors:

Rank	Freq	Id
1	126	WANG_M(2016)34:828
2	53	VASHISHT_R(2012)7:0039808
3	48	SNIJders_T(2007)170:322
4	43	GUSTAVSS_A(2011)21:718
5	42	DOLL_L(1992)29:1
6	41	MAGLIANO_L(2006)15:219

Sharing and community curation of mass spectrometry data with Global Natural Products Social Molecular Networking / Nature Biotechnology volume 34, pages 828–837 (2016)

Mingxun Wang, Jeremy J Carver, Vanessa V Phelan, Laura M Sanchez, Neha Garg, Yao Peng, Don Duy Nguyen, Jeramie Watrous, Clifford A Kapono, Tal Luzzatto-Knaan, Carla Porto, Amina Bouslimani, Alexey V Melnik, Michael J Meehan, Wei-Ting Liu, Max Crüsemann, Paul D Boudreau, Eduardo Esquenazi, Mario Sandoval-Calderón, Roland D Kersten, Laura A Pace, Robert A Quinn, Katherine R Duncan, Cheng-Chih Hsu, Dimitrios J Floros, Ronnie G Gavilan, Karin Kleigrewe, Trent Northen, Rachel J Dutton, Delphine Parrot, Erin E Carlson, Bertrand Aigle, Charlotte F Michelsen, Lars Jelsbak, Christian Sohlenkamp, Pavel Pevzner, Anna Edlund, Jeffrey McLean, Jörn Piel, Brian T Murphy, Lena Gerwick, Chih-Chuang Liaw, Yu-Liang Yang, Hans-Ulrich Humpf, Maria Maansson, Robert A Keyzers, Amy C Sims, Andrew R Johnson, Ashley M Sidebottom, Brian E Sedio, Andreas Klitgaard, Charles B Larson, Christopher A Boya P, Daniel Torres-Mendoza, David J Gonzalez, Denise B Silva, Lucas M Marques, Daniel P Demarque, Egle Pociute, Ellis C O'Neill, Enora Briand, Eric J N Helfrich, Eve A Granatosky, Evgenia Glukhov, Florian Ryffel, Hailey Houson, Hosein Mohimani, Jenan J Kharbush, Yi Zeng, Julia A Vorholt, Kenji L Kurita, Pep Charusanti, Kerry L McPhail, Kristian Fog Nielsen, Lisa Vuong, Maryam Elfeki, Matthew F Traxler, Niclas Engene, Nobuhiro Koyama, Oliver B Vining, Ralph Baric, Ricardo R Silva, Samantha J Mascuch, Sophie Tomasi, Stefan Jenkins, Venkat Macherla, Thomas Hoffman, Vinayak Agarwal, Philip G Williams, Jingqui Dai, Ram Neupane, Joshua Gurr, Andrés M C Rodríguez, Anne Lamsa, Chen Zhang, Kathleen Dorrestein, Brendan M Duggan, Jihad Almaliti, Pierre-Marie Allard, Prasad Phapale, Louis-Felix Nothias, Theodore Alexandrov, Marc Litaudon, Jean-Luc Wolfender, Jennifer E Kyle, Thomas O Metz, Tyler Peryea, Dac-Trung Nguyen, Danielle VanLeer, Paul Shinn, Ajit Jadhav, Rolf Müller, Katrina M Waters, Wenyuan Shi, Xuetong Liu, Lixin Zhang, Rob Knight, Paul R Jensen, Bernhard Ø Palsson, Kit Pogliano, Roger G Linington, Marcelino Gutiérrez, Norberto P Lopes, William H Gerwick, Bradley S Moore, Pieter C Dorrestein, Nuno Bandeira.

The most used journals - indegree

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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

The most used keywords - indegree

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Keywords were extracted also from titles. Phrases were split to component words. Stop words were removed.
 Words were lemmatized.

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

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indeg	Freq	Freq%	CumFreq	CumFreq%
0	41954	3.2344	41954	3.2344
1	933315	71.9521	975269	75.1865
2	154895	11.9413	1130164	87.1278
3	58141	4.4823	1188305	91.6101
4	29885	2.3039	1218190	93.9140
5	17651	1.3608	1235841	95.2748

Most of nodes are terminal ($DC = 0$) or nodes cited only once (indegree=1). We decided (*boundary problem*) to include in our networks nodes with $DC > 0$ or $\text{indeg} > 2$. They determine a subnetwork **CiteB** with 222,086 nodes and 1,521,434 arcs.

Cite net

Components

The citation network CiteB has 41 nontrivial strong components. To get an acyclic network we applied the *preprint transformation* to CiteB. The resulting network **CiteT** has 222,189 nodes and 1,521,658 arcs.

We computed the SPC weights on network arcs, and determined

- CPM path / Main path = 59 nodes
- Key-routes = 127 nodes
- SPC link islands [weights] of sizes [20, 200] = 5 islands of 138, 65, 13, 12, and 11 nodes
- SPC node islands [weights] of sizes [20, 200] = 1 island of 200 nodes

We computed the Probabilistic flow, and determined Node islands [weights] of sizes [10, 200] = 1 island of 200 nodes

Strong components from SPC network

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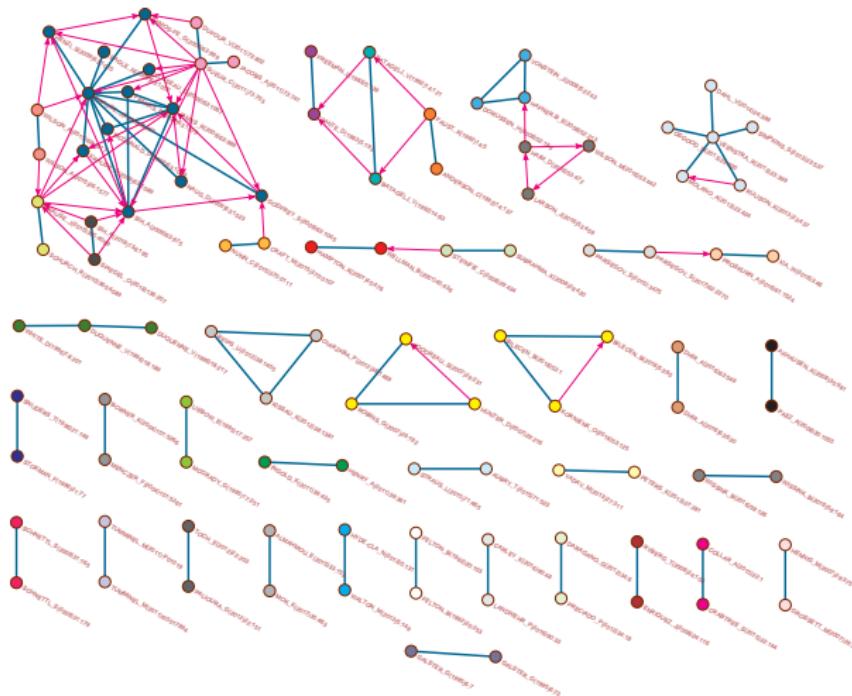
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Main path, Key Routes, and Island 4 from SPC network

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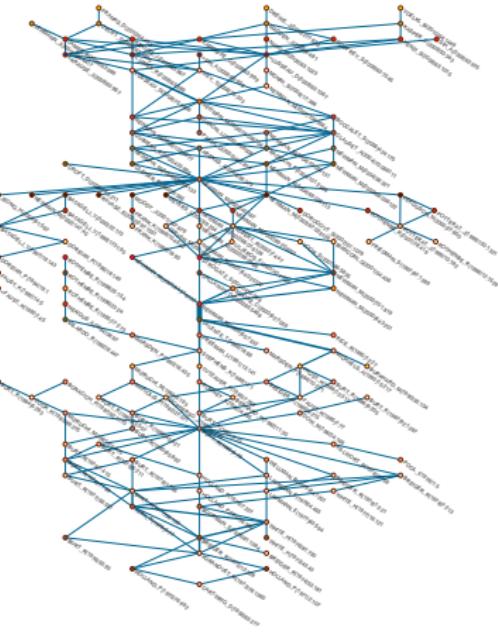
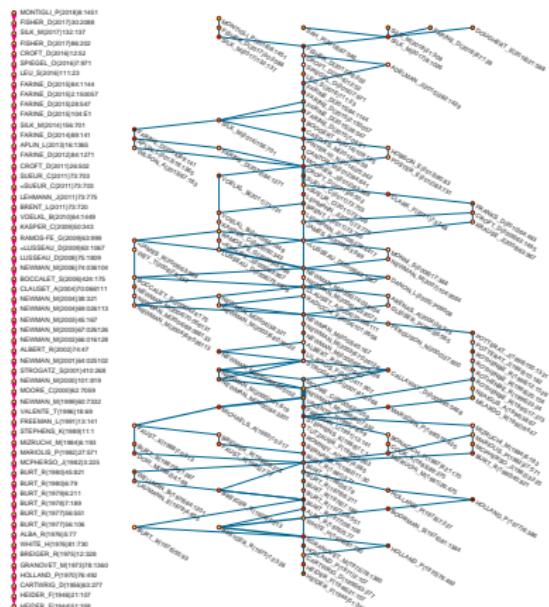
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Main path from SPC network

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- ① 1944–1996: 20 works from the field of Social Science in journals *Social networks*, *Administrative Science Quarterly*, *Annual Review of Sociology*, *American Sociological Review*, *Social Forces*, *Sociological Methods & Research*, *Journal of Mathematical Psychology*, *Psychological Review*, *The Journal of Psychology*
- ② 1999–2007: 14 works from Physics in journals *Physical Review E*, *Journal of Statistical Physics*, *Reviews of Modern Physics*, *European Physical Journal B*, *Physics Reports*, *Nature*, and *SIAM Review*
- ③ 2008–2018: 25 works from Animal social networks in journals *Animal Behaviour*, *American Journal of Primatology*, *Primates*, *Journal of Evolutionary Biology*, *Journal of Animal Ecology*, *Journal of Evolutionary Biology*, *Trends in Ecology & Evolution*

Key-routes from SPC network

Third period (2008–2018): 49 works of behavioural ecologists.

- ① Krause, James (2009): *general works on animal social network analysis*
- ② Ramos-Fernandez, Kasper, Voell, Lehmann, Brent, Sueur (2009–2011): *social networks of Nonhuman Primates* (monkeys, baboons).
- ③ Croft (2011): practical guide on *hypothesis testing* in animal social networks
- ④ 2014: research on *mixed-species groups* (Farine), *killer whales* (Foster), *sharks* (Mourier), *dolphins* (Cantor), published in 2012, and *birds* (Silk) and *starlings* (Boogert)
- ⑤ 2013-2014: *methodological issues* – 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*), Pinter-Wollman (*The dynamics of animal social networks: analytical, conceptual, and theoretical advances*)

Key-routes from SPC network

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- ① Farine (2015): *methodological issues on constructing, conducting and interpreting animal social network analysis, study of the wild birds territory acquisition.*
- ② 2013-2014: *social personality and phenotypic types* (Wilson, Alpin, Farine).
- ③ 2016–2018: studies on *desease transmission* (Adelman, Sah, Silk, Dougherty), *animal paths tracking* (Leu, Spiegel); works on *theoretical issues* (*Current directions in animal social networks* by Croft, *Social traits, social networks and evolutionary biology* by Fisher); *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).

Islands 1-3, 5 from SPC network

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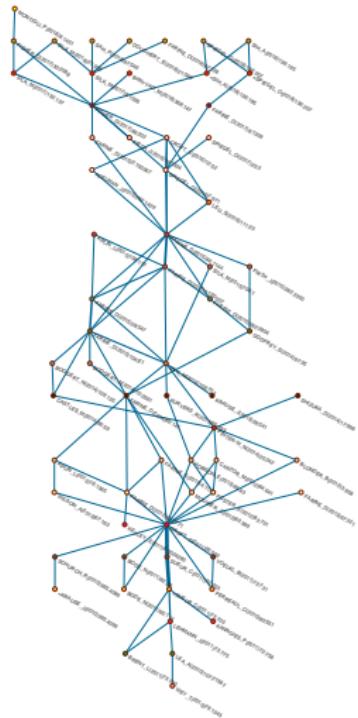
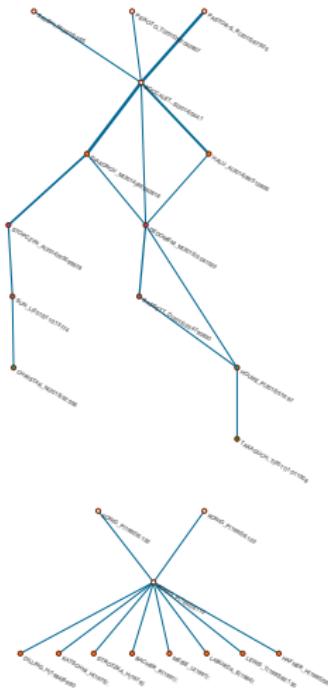
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1 - Education, 2 - Physics, 3 - Neuropsychiatry, 5 - Animal SNA



Most important works from Probabilistic Flow network

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The values were maximized by 1,000,000.

Rank	Value	Id	Rank	Value	Id
1	4691	WASSERMAN_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	CLAUSSET_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	MCPHERSON_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):

Cite net

Overlapping of components

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i	name	title	jour	comp
1	Granovet M	Strength of weak ties	amer j sociol	1, 2, 4, 5, 6
2	Newman M	The structure and function of complex networks	siam rev	1, 2, 4, 5, 6
3	Albert R	Statistical mechanics of complex networks	rev mod phys	1, 2, 4, 5, 6
4	Boccaletti S	Complex networks: structure and dynamics	phys rept	1, 2, 4, 5, 6
5	White H	Soc. str. from mult. nets. Blockmodels	amer j sociol	1, 2, 4, 5, 6
6	Newman M	Clustering and pref.l. attach. in growing nets	phys rev e	1, 2, 4, 5, 6
7	Newman M	Finding and evaluating comm. struct. in nets	phys rev e	1, 2, 4, 5, 6
8	Newman M	Mixing patterns in networks	phys rev e	1, 2, 4, 5, 6
9	Strogatz S	Exploring complex networks	nature	1, 2, 4, 5, 6
10	Newman M	Detecting community structure in nets	eur phys j b	1, 2, 4, 5, 6
11	Newman M	Spread of epidemic disease on nets	phys rev e	1, 2, 4, 5, 6
12	Newman M	Finding community str. in nets using eigenvectors	phys rev e	1, 2, 4, 5, 6
13	Cartwright D	Structural balance - a generaliz. of heider theory	psychol rev	1, 2, 4, 5, 6
14	Clauset A	Finding community struct. in very large nets	phys rev e	1, 2, 4, 5, 6
15	Newman M	Models of the small world	j statist phys	1, 2, 4, 5, 6
16	Newman M	Scaling and percolation in small-world net model	phys rev e	1, 2, 4, 5, 6
17	Valente T	Social net thresholds in the diff. of innov.	soc networks	1, 2, 4, 5
18	Burt R	Cohesion versus structural equivalences as a basis for net subgroups	soc meth res	1, 2, 4, 5
19	Stephenson K	Rethinking centrality - methods and examples	soc networks	1, 2, 4, 5
20	Breiger R	Algorithm for clustering relational data	j math psychl	1, 2, 4, 5
21	Freeman L	Centrality in valued graphs - a measure of betweenness based on net flow	soc networks	1, 2, 4, 5
22	Burt R	Models of network structure	annu rev soc	1, 2, 4, 5
23	Holland P	Method for detecting structure in sociom. data	amer j sociol	1, 2, 4, 5
24	Alba R	Intersection of social circles	socl meth res	1, 2, 4, 5
25	Moore C	Exact solution of site and bond percolation on small-world net	phys rev e	1, 2, 4, 5
26	Mcpherson J	Hypernetwork sampling - duality and differentiation among voluntary organizations	soc networks	1, 2, 4, 5
27	Mariolis P	Centrality in corporate interlock networks	adm sci quart	1, 2, 4, 5
28	Burt R	Positions in multiple network systems	soc forces	1, 2, 4, 5
29	Burt R	1. General conception of stratification and prestige	soc forces	1, 2, 4, 5
		2. Positions in multiple network systems		
		2. Stratification and prestige among elite		
		Interlock groups, cliques, or interest-groups		
30	Mizruchi M		soc networks	1, 2, 4, 5

1- Key Routes, 2- Main Path (CPM), 3- Island5, 4 - Island 4, Node Island, 5 - Prob Flow Island



Authors Collaboration

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$$\mathbf{Co} = \mathbf{WAr}^T * \mathbf{WAr}$$

The weight of the edges between the nodes i and j is equal to total number of works author i and j wrote together.

The loops in \mathbf{Co} are equal to the total number of works that each author have (which is also equal to the indegree values of the \mathbf{WA} network).

The proposed approach has some *limitations*, such as the overrating of the contribution of works with many authors.

Authors Collaboration
from Co net (20 and more works written together)

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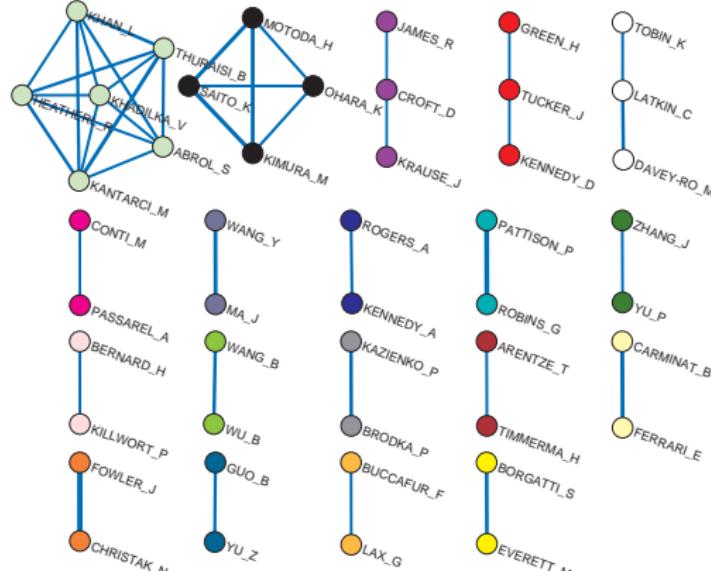
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The contribution of authors to their own works and works written with co-authors is considered. The normalization creates network $n(WA)$ where the weight of each arc is divided by the sum of weights of all arcs having the same initial node as this arc (outdegree of a node).

$$n(\mathbf{WAr})[w, a] = \frac{\mathbf{WAr}[w, a]}{\max(1, \text{Oudeg}[w])}$$

then

$$\mathbf{Cn} = \mathbf{WAr}^T * n(\mathbf{WAr})$$

The weight of the edges between the nodes (authors) is equal to the contribution of author i to works, that he or she wrote together with author j (can be not symmetric).

The total contribution for an author is equal to the number of works that he or she co-authored (indegree of WA).

The diagonal (loops) of the matrix is equal to the total contribution of author to his or her own works.

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Batagelj and Cerinšek (2013):

- **self-sufficiency index** as a proportion of author's contribution to all his/her works and her/his total number of works (which is equal to the value of Indegree of WA network),
- **collaborativity index**, which is complementary to it (is equal to 1 minus self-sufficiency).

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Collaborativeness index from Cn net

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#	Author	Tot Contr	Tot #works	Collab	#	Author	Tot Contr	Tot #works	Collab
1	BURT_R	55,73	71	0,22	31	PATTISON_P	18,94	58	0,67
2	NEWMAN_M	50,02	*81	0,38	32	THELWALL_M	18,41	37	0,50
3	DOREIAN_P	46,19	72	0,36	33	KRACKHARD	18,24	38	0,52
4	PARK_H	41,94	*113	0,63	34	FALOUTSO_C	17,86	60	0,70
5	DUNBAR_R	40,02	*91	0,56	35	JACKSON_M	17,78	38	0,53
6	WELLMAN_B	36,43	63	0,42	36	GONZALEZ_M	17,76	52	0,66
7	VALENTE_T	34,96	*97	0,64	37	MOODY_J	17,7	40	0,56
8	PARK_S	34,59	*109	0,68	38	SCOTT_J	17,54	28	0,37
9	BONACICH_P	34	46	0,26	39	MORRIS_M	17,22	43	0,60
10	LEYDESDO_L	33,28	51	0,35	40	RODRIGUE_J	15,9	52	0,69
11	LATKIN_C	32,99	*130	0,75	41	WASSERMA_S	15,64	35	0,55
12	LITWIN_H	32,42	50	0,35	42	KLEINBER_J	15,05	34	0,56
13	MARSDEN_P	30,17	39	0,23	43	BATAGELJ_V	14,64	33	0,56
14	BORGATTI_S	29,72	71	0,58	44	WILLIAMS_A	14,5	31	0,53
15	SNIJders_T	29,63	67	0,56	45	SINGH_A	14,5	36	0,60
16	FRIEDKIN_N	28,17	36	0,22	46	BRANDES_U	14,39	35	0,59
17	CARLEY_K	28,11	72	0,61	47	BERKMAN_L	14,3	39	0,63
18	BARABASI_A	27,61	67	0,59	48	MASUDA_N	14,26	28	0,49
19	WHITE_H	27,28	42	0,35	49	SMITH_A	14,2	40	0,65
20	CHRISTAK_N	22,89	74	0,69	50	LAZEGA_E	14,17	26	0,46
21	EVERETT_M	22,58	44	0,49	51	CONTRACT_N	14,15	43	0,67
22	KAZIENKO_P	21,97	64	0,66	52	GONZALEZ_A	14,13	35	0,60
23	MARTINEZ_M	21,9	53	0,59	53	PENTLAND_A	14,12	41	0,66
24	JOHNSON_J	21,19	54	0,61	54	FARINE_D	14,04	34	0,59
25	FOWLER_J	20,14	65	0,69	55	SCHNEIDE_J	13,89	52	0,73
26	SKVORETZ_J	20,07	42	0,52	56	WATTS_D	13,67	27	0,49
27	FREEMAN_L	20,03	27	0,26	57	FAUST_K	13,5	25	0,46
28	BREIGER_R	19,73	31	0,36	58	SMITH_M	13,29	39	0,66
29	ROBINS_G	19,67	64	0,69	59	RODRIGUE_M	13,21	46	0,71
30	RAHMAN_M	19,18	59	0,67	60	RICE_E	13,09	48	0,73

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Network Ct'

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Newman's normalization: "strict collaboration" – the weight is a proportion of time spent for the collaboration with each co-author. The weight of each arc is divided by the sum of weights of all arcs having the same initial node as this arc (outdegree of a node) subtracting the initial author.

$$n'(\mathbf{WAr})[w, a] = \frac{\mathbf{WAr}[w, a]}{\max(1, \text{Outdeg}(w) - 1)}$$

then

$$\mathbf{Ct}' = n(\mathbf{WAr})^T * n'(\mathbf{WAr})$$

The final Ct' is undirected without loops. The contribution of a complete subgraph corresponding to each work is 1.

The weights of the edges between the nodes (authors) are equal to the total contribution of "strict collaboration" of authors i and j to works they wrote together.

The total contribution for an author is counted by line weights – it is equal to the sum of the weights of all the works he or she co-authored.

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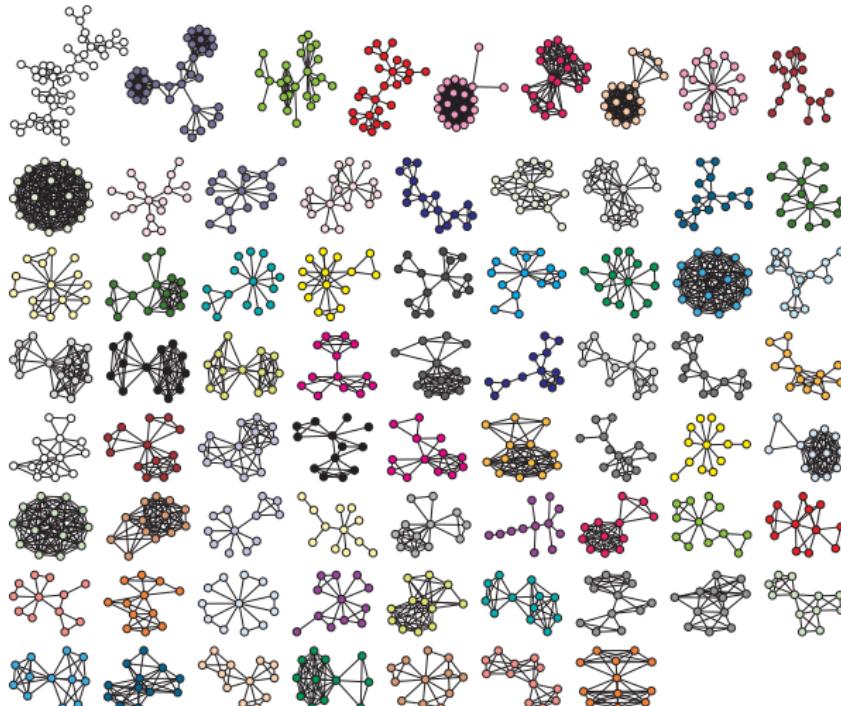
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Keywords

co-occurrence

Temporal

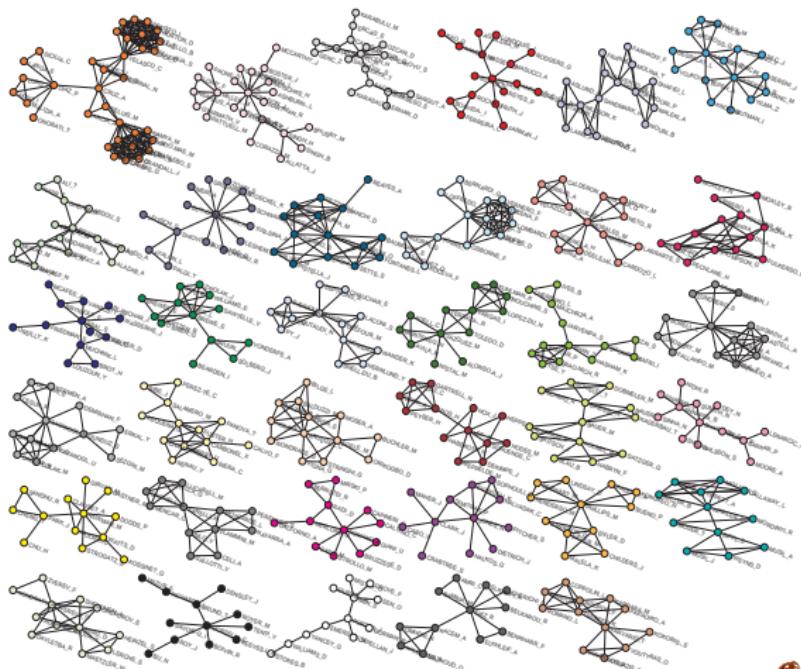
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Authors with largest line weights from Ct' net

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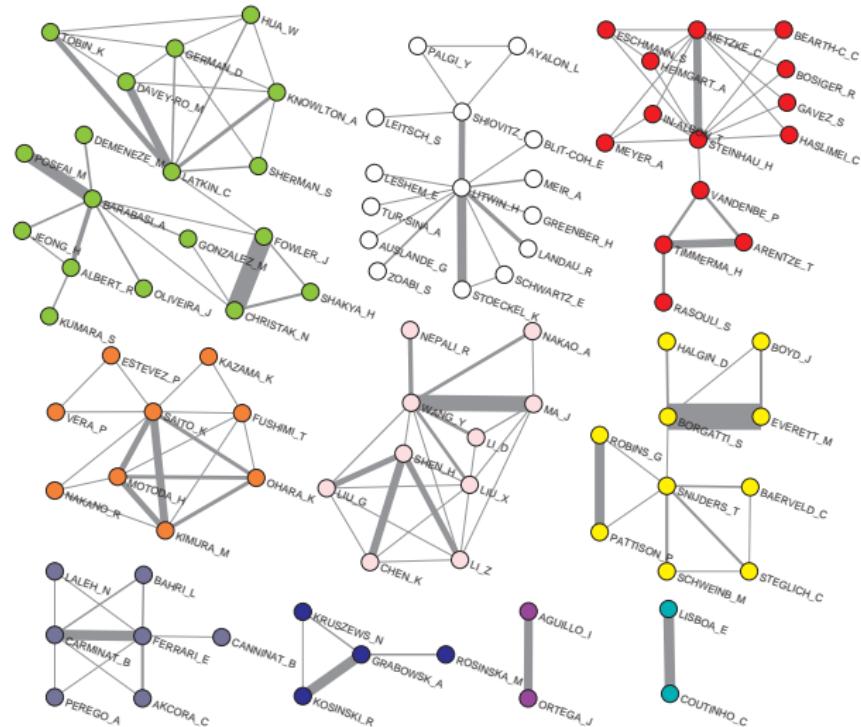
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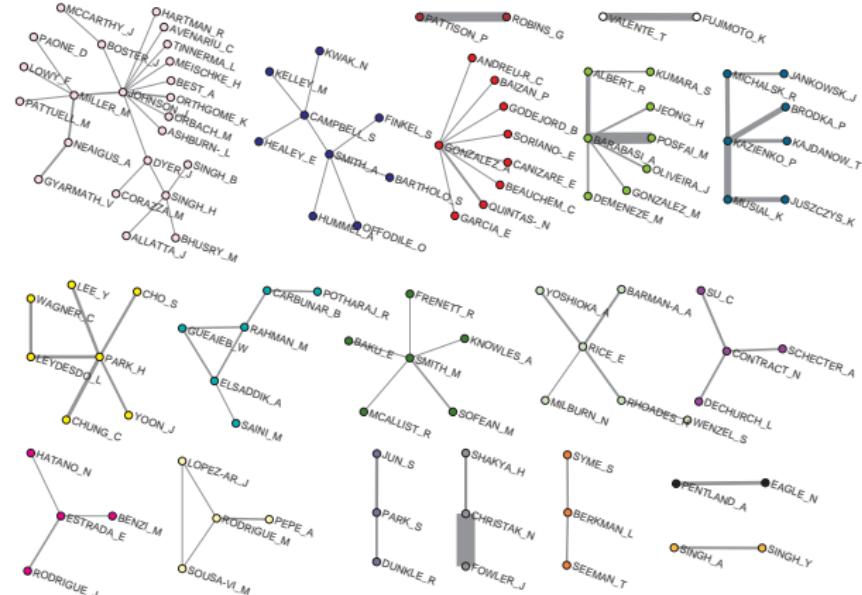
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Key words in coauthorship islands

AK net

SNA.

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AnalysisD. Maltseva,
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$$\mathbf{AK} = n(\mathbf{WAr})^T * n(\mathbf{WKr})$$

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The weight of the edges between the nodes a and k is equal to the fractional contribution for a given keyword k to the works of author a or a group of authors C .

$$\mathbf{AK}[C, k] = \sum_{a \in C} \mathbf{AK}[a, k]$$

Key words in coauthorship islands

AK net

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	BORGATTI_S		BARABASI_A		CHRISTAKIS_K	
Rank	Value	Id	Value	Id	Value	Id
1	4.9303	network	7.0709	network	3.1788	network
2	2.5918	social	2.0782	social	2.9358	social
3	2.0858	graph	1.7068	dynamics	1.0204	spread
4	1.4210	centrality	1.6670	complex	1.0192	behavior
5	1.4202	analysis	1.6362	scale	0.7261	health
6	1.3399	role	1.5946	web	0.5512	large
7	1.2780	regular	1.5516	community	0.5169	model
8	1.2424	equivalence	1.4709	world	0.4778	smoking
9	1.0530	semigroup	1.3622	internet	0.4522	human
10	1.0000	correction	1.1906	model	0.4479	cooperation
11	0.9891	structure	1.1858	free	0.4313	obesity
12	0.7755	clique	1.0210	evolve	0.4125	influence
13	0.7576	homomorphism	1.0087	science	0.3973	life
14	0.7241	relation	0.9808	random	0.3728	dynamics
15	0.6346	power	0.9476	wide	0.3715	evolution
16	0.6301	betweenness	0.8178	human	0.3463	analysis
17	0.6287	exchange	0.8076	theory	0.3286	cosponsorship
18	0.6232	algorithm	0.7561	small	0.3044	norm
19	0.6167	similarity	0.7536	graph	0.3036	trial
20	0.5595	ebloc	0.6603	phenomenon	0.2985	study
Sum:	63.0810		76.6373		46.8865	

Key words in coauthorship islands

from AK net (nAWr x nWKr)

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	PATTISON_P		SNIJDERS_T		VALENTE_T	
Rank	Value	Id	Value	Id	Value	Id
1	2.2196	network	2.6375	network	2.5536	network
2	2.0729	social	2.0902	social	1.9553	social
3	1.7567	model	1.6702	model	1.0000	untitled
4	1.3084	graph	1.0692	graph	0.9419	health
5	0.8939	random	0.8857	dynamics	0.8737	diffusion
6	0.8583	markov	0.7390	markov	0.7802	behavior
7	0.8531	logit	0.6903	random	0.7402	innovation
8	0.8220	logistic	0.6734	friendship	0.6974	model
9	0.8220	regression	0.6228	datum	0.6521	use
10	0.8012	exponential	0.5932	statistical	0.6349	peer
11	0.7055	analysis	0.5780	behavior	0.6216	adolescent
12	0.6752	p	0.5547	analysis	0.5717	influence
13	0.5530	statistical	0.5423	peer	0.5610	smoking
14	0.5038	structure	0.5383	inference	0.5371	analysis
15	0.3561	semigroup	0.5346	influence	0.5247	prevention
16	0.3522	asterisk	0.4623	stochastic	0.4987	cigarette
17	0.3368	process	0.4612	actor	0.4979	opinion
18	0.3333	multirelational	0.4480	selection	0.4860	leader
19	0.3249	family	0.4372	longitudinal	0.4545	risk
20	0.3031	dynamics	0.3785	orient	0.4491	intervention
Sum:		38.6110		46.6732		44.8812

Citation among authors

CiteA and CiteAn nets

$$\text{CiteA} = (\text{WAr})^T * \text{CiteR} * \text{WAr}$$

The value of weight of the element $[u,v]$ is equal to the **absolute number of citations** from works coauthored by u to works coauthored by v .

$$\text{CiteAn} = (\text{WAr})^T * n(\text{CiteR}) * \text{WAr}$$

where

$$n(\text{CiteR})[u, v] = \frac{\text{CiteR}[u, v]}{\max(1, \text{outdeg}(u))}$$

The value of element $\text{CiteAn}[u,v]$ is equal to the number of **fractional contribution** of citations from works coauthored by u to works coauthored by v .

Citation among authors

self-citation from CiteA.net

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Rank	Value	Id	Rank	Value	Id
1	589	DUNBAR_R	11	201	BARABASI_A
2	387	LATKIN_C	12	191	FARINE_D
3	292	CHRISTAK_N	13	188	SNIJDERS_T
4	280	VALENTE_T	14	153	WELLMAN_B
5	268	BURT_R	15	148	DOREIAN_P
6	248	NEWMAN_M	16	146	BORGATTI_S
7	232	ROBINS_G	17	146	ZENOU_Y
8	224	PATTISON_P	18	143	RICE_E
9	221	FOWLER_J	19	142	JAMES_R
10	204	CROFT_D	20	141	KRAUSE_J

Citation among authors

Authors with largest line weights from CiteA net

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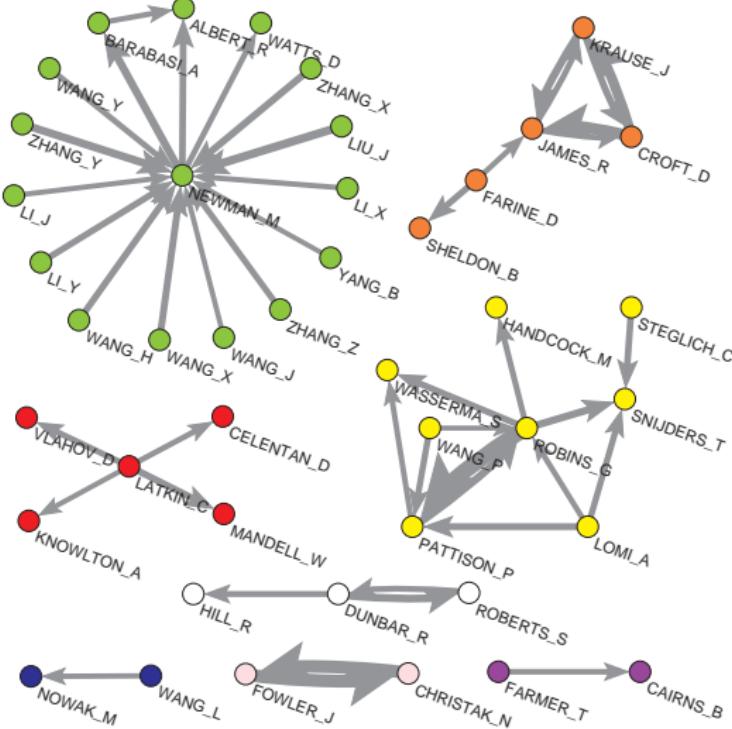
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#	Author	Value	%	#	Author	Value	%
1	TANG_J	9.786	0.025	26	FALOUTSO_C	8.169	0.014
2	FARINE_D	9.778	0.074	27	HANSON_B	8.091	0.041
3	PENTLAND_A	9.746	0.016	28	SUEUR_C	8.025	0.092
4	MARATHE_M	9.528	0.034	29	FRANK_K	7.995	0.062
5	ZENOU_Y	9.466	0.077	30	LIX	7.966	0.020
6	EVERETT_M	9.342	0.012	31	MORENO_M	7.724	0.034
7	KRAUSE_J	9.035	0.022	32	THELWALL_M	7.698	0.033
8	CHEN_H	8.975	0.032	33	SHEN_X	7.679	0.039
9	BERKMAN_L	8.949	0.007	34	KENNEDY_A	7.619	0.070
10	POTTERAT_J	8.899	0.027	35	GARLAND_S	7.606	0.087
11	MORRIS_M	8.861	0.025	36	ZHANG_D	7.586	0.041
12	KAZIENKO_P	8.802	0.067	37	NOWAK_M	7.554	0.021
13	SHEN_H	8.799	0.049	38	MAGLIANO_L	7.542	0.051
14	LIU_J	8.763	0.034	39	BONACICH_P	7.540	0.020
15	XU_Q	8.667	0.085	40	LU_R	7.458	0.045
16	TUCKER_J	8.496	0.061	41	WANG_J	7.414	0.023
17	SKVORETZ_J	8.481	0.056	42	WANG_L	7.345	0.038
18	THAI_M	8.453	0.068	43	SAITO_K	7.335	0.055
19	BATAGELJ_V	8.421	0.032	44	CHEN_W	7.245	0.012
20	MUTH_S	8.382	0.026	45	FERRARI_E	7.209	0.038
21	MARTINEZ_M	8.313	0.141	46	COHEN_S	7.202	0.010
22	LITWIN_H	8.297	0.052	47	RYAN_L	7.193	0.080
23	STANTON_N	8.250	0.216	48	MEYBODI_M	7.175	0.314
24	TUREL_O	8.227	0.161	49	KIMURA_M	7.139	0.053
25	ABDELZAH_T	8.176	0.085	50	KIM_H	7.121	0.037

Citation among authors

Main island from CiteAn.net

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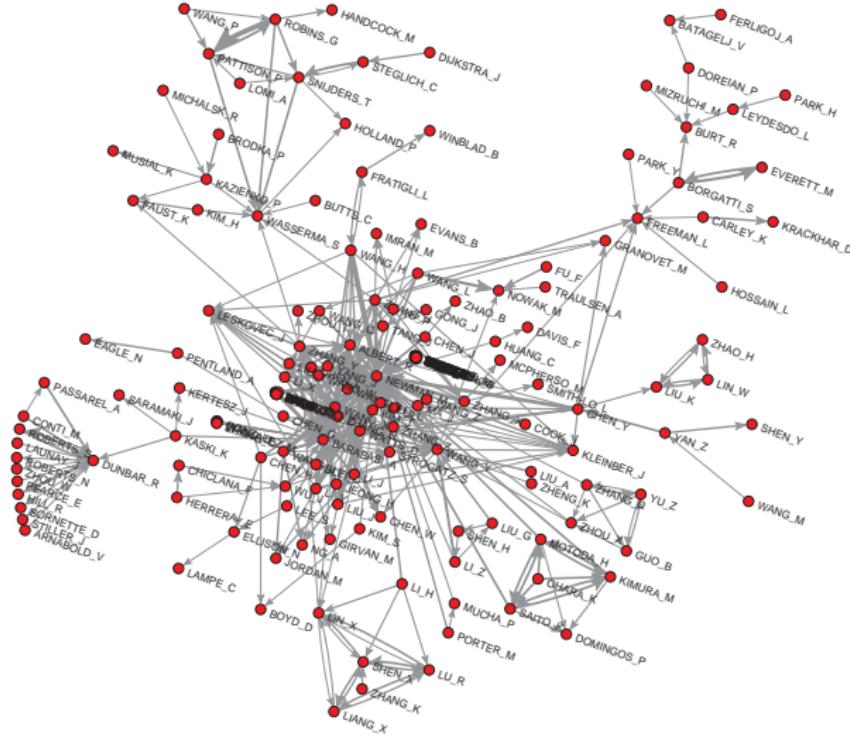
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CiteJ and CiteJn nets

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Networks takes into account citations from papers published in journal i to papers published in journal j , which appeared in the works included into the **WJr** network. In the obtained network, the value of weight of the element $[u,v]$ is equal to the **absolute number of citations** from journal i to journal j .

$$\text{CiteJ} = (\text{WJr})^T * \text{CiteR} * \text{WJr}$$

Line weights take into account *fractional* contribution of citations from papers published in journal i to papers published in journal j .

$$\text{CiteJn} = (\text{WJr})^T * n(\text{CiteR}) * \text{WJr}$$

Citation among journals

self-citation from CiteJ net

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Rank	Value	Id
1	4443	SOC NETWORKS
2	2058	COMPUT HUM BEHAV
3	569	PHYSICA A
4	429	PHYS REV E
5	382	LECT NOTES COMPUT SC
6	339	CYBERPSYCHOL BEHAV
7	328	SOC SCI MED
8	315	AM J SOCIOl
9	303	PLOS ONE
10	258	ANIM BEHAV
11	246	SCIENTOMETRICS
12	232	J MED INTERNET RES
13	226	P NATL ACAD SCI USA
14	209	ORGAN SCI
15	194	BEHAV ECOL SOCIOBIOL

Citation among journals

authors with largest line weights from CiteJ net

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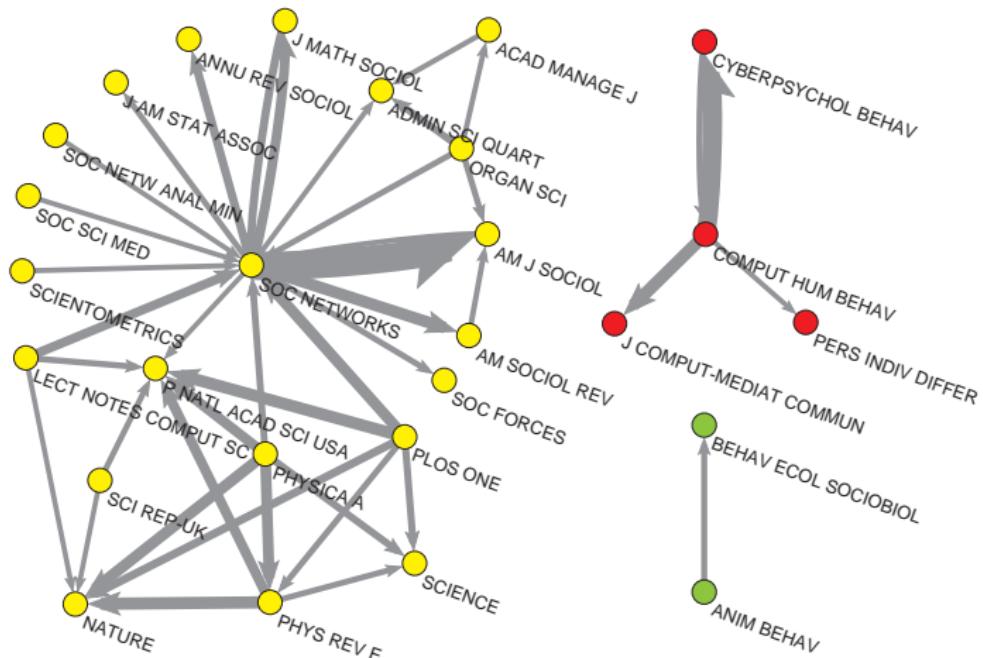
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#	Value	%	Journal	#	Value	%	Journal
1	355.65	0.34	SOC NETWORKS	16	18.35	0.17	ANIM BEHAV
2	168.39	0.22	COMPUT HUM BEHAV	17	17.03	0.12	AIDS BEHAV
3	122.57	0.09	LECT NOTES COMPUT SC	18	16.03	0.19	AM J COMMUN PSYCHO
4	57.75	0.13	PHYSICA A	19	14.87	0.10	INFORM SCI
5	43.00	0.14	SOC SCI MED	20	14.14	0.14	KNOWL-BASED SYST
6	42.18	0.24	J MED INTERNET RES	21	12.64	0.19	PROF INFORM
7	41.49	0.21	CYBERPSYCHOL BEHAV	22	12.35	0.23	COMUNICAR
8	33.16	0.05	PLOS ONE	23	12.00	0.18	BEHAV ECOL SOCIOBI
9	32.93	0.11	PHYS REV E	24	11.87	0.25	AM J EPIDEMIOL
10	30.22	0.13	SCIENTOMETRICS	25	11.01	0.11	DECIS SUPPORT SYST
11	24.16	0.14	P NATL ACAD SCI USA	26	10.58	0.14	J ETHN MIGR STUD
12	23.15	0.26	AM J SOCIOL	27	10.43	0.13	COMPUT EDUC
13	20.04	0.05	LECT NOTES ARTIF INT	28	10.31	0.18	SEX TRANSM DIS
14	19.31	0.12	EXPERT SYST APPL	29	10.19	0.28	NATURE
15	18.77	0.14	NEW MEDIA SOC	30	9.85	0.09	ORGAN SCI

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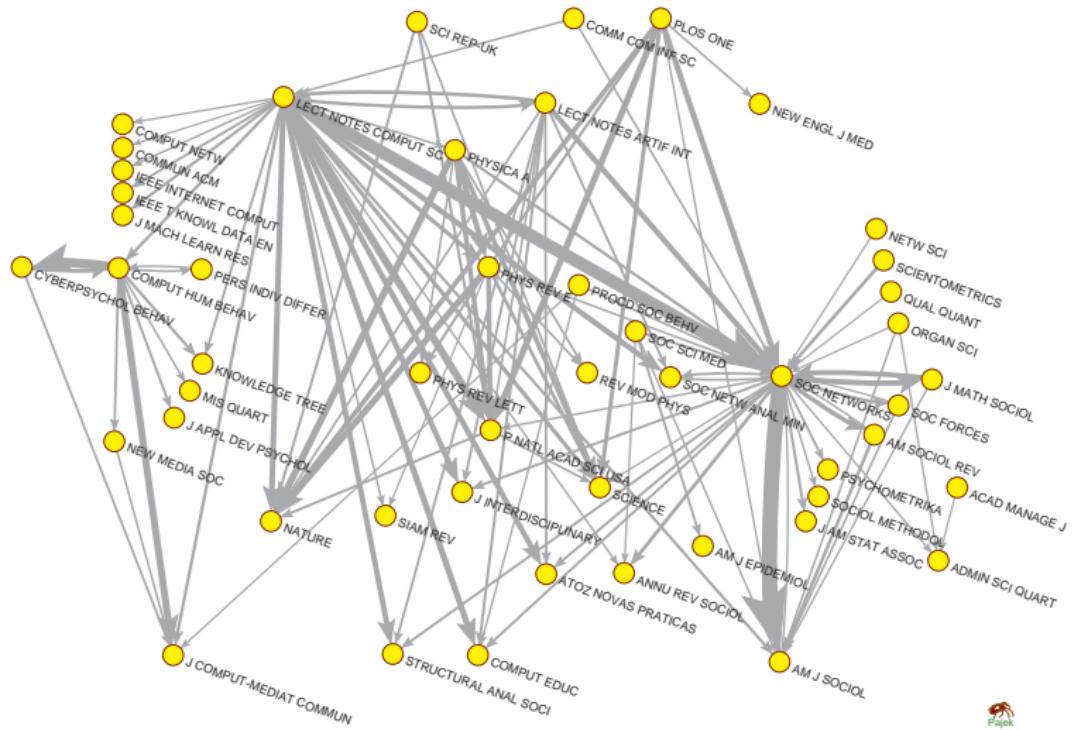
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Pairs of journals with largest line weights from CiteJn net

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#	value	from journal	to journal
1	8,1	IEEE GLOB COMM CONF	IEEE INFOCOM SER
2	6,26	HIST COMUN SOC	COMUNICAR
3	4,63	J YOUTH ADOLESCENCE	J RES ADOLESCENCE
4	4,44	INT J GERIATR PSYCH	J PSYCHIAT RES
5	4,38	INT MIGR	INT MIGR REV
6	4,31	J BUS ETHICS	ACAD MANAGE REV
7	3,99	DEMOGR RES	DEMOGRAPHY
8	3	J INTELL FUZZY SYST	J APPL MATHE COMPUT
9	3	J INT DEV	TROP MED INT HEALTH
10	3	PERVASIVE MOB COMPUT	INT CONF PERVAS COMP
11	2,78	J CONSTR ENG M	J CONSTR ENG M ASCE
12	2,68	PHYS EDUC RES CONF	PHYS REV SPEC TOP-PH
13	2,59	ENERGY RES SOC SCI	ENERG POLICY
14	2,5	INT P ECON DEV RES	TECHNOVATION
15	2,37	COMPUT ASSIST LANG L	LANG LEARN TECHNOL
16	2,33	INFORM SOC-ESTUD	PERSPECT CIENC INF
17	2,33	WORLD DEV	ECON J
18	2,31	J PEACE RES	J CONFLICT RESOLUT
19	2,22	HEALTH RES POLICY SY	HEALTH POLICY PLANN
20	2,1	SEX HEALTH	INT J STD AIDS
21	2	REV LAT COMUN SOC	PALABRA CLAVE
22	2	J RETAIL CONSUM SERV	AUSTRALAS MARK J
23	2	ETHN DIS	HEART LUNG
24	2	IEEE INT SYMP INFO	IEEE T INFORM THEORY
25	2	REV BRAS ENFERM	REV LAT-AM ENFERM

Bibliographic coupling

Jaccard biCo, JCoj and ACoj nets

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$$\mathbf{biCo} = \mathbf{CiteR} * (\mathbf{CiteR})^T$$

Normalization creates networks $n(\mathbf{WJr})$ and $n(\mathbf{WAr})$ where the weight of each arc is divided by the sum of weights of all arcs having the same initial node (journal or author) as this arc (outdegree of a node).

Line weights in the obtained networks take into account *fractional* similarity of journals i and j , or authors u and v .

$$\mathbf{JCoj} = n(\mathbf{WJr})^T * \mathbf{biCoj} * n(\mathbf{WJr})$$

$$\mathbf{ACoj} = n(\mathbf{WAr})^T * \mathbf{biCoj} * n(\mathbf{WAr})$$

The values of links from biCoj are redistributed in JCoj and ACoj.

$$\sum_{e \in E(\mathbf{JCoj})} \mathbf{JCoj}[e] = \sum_{e \in E(\mathbf{biCoj})} \mathbf{biCoj}[e]$$

The total sum of link weights is preserved.

Bibliographic coupling

Jaccard biCo, JCoj and ACoj nets

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The produced Jaccard network **biCo** contained a large number of links – 62.079.457, – and the computation of networks **JCoj** and **ACoj** would be quite time consuming.

The decision was made to make a line cut in the Jaccard **biCo** at the level 0.085, and then use the obtained network for the multiplication with WJs and WAsr networks, respectively.

Obtained **biCo** network contained 70.792 works and 13.208.451 links. After multiplication, we got **JCoj** network with 8.943 nodes and 4.966.617 arcs, and **ACoj** network with 93.011 nodes and 127.220.243 arcs. In both obtained networks, the loops were deleted, the bidirected arcs were converted to edges (with summation of values) before the further analysis.

Bibliographic coupling

Co-citation among journals JCoj

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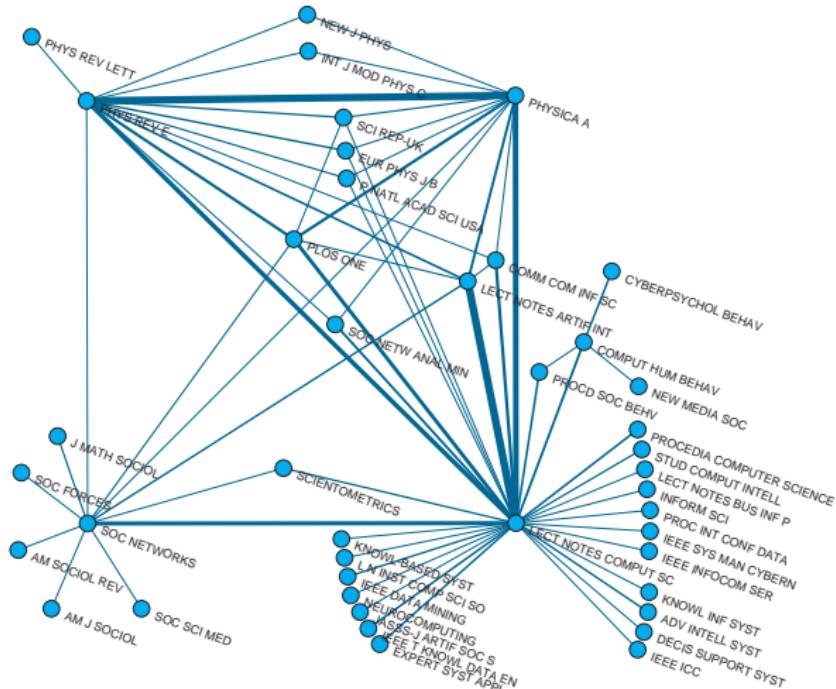
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Co-citation among authors ACoj

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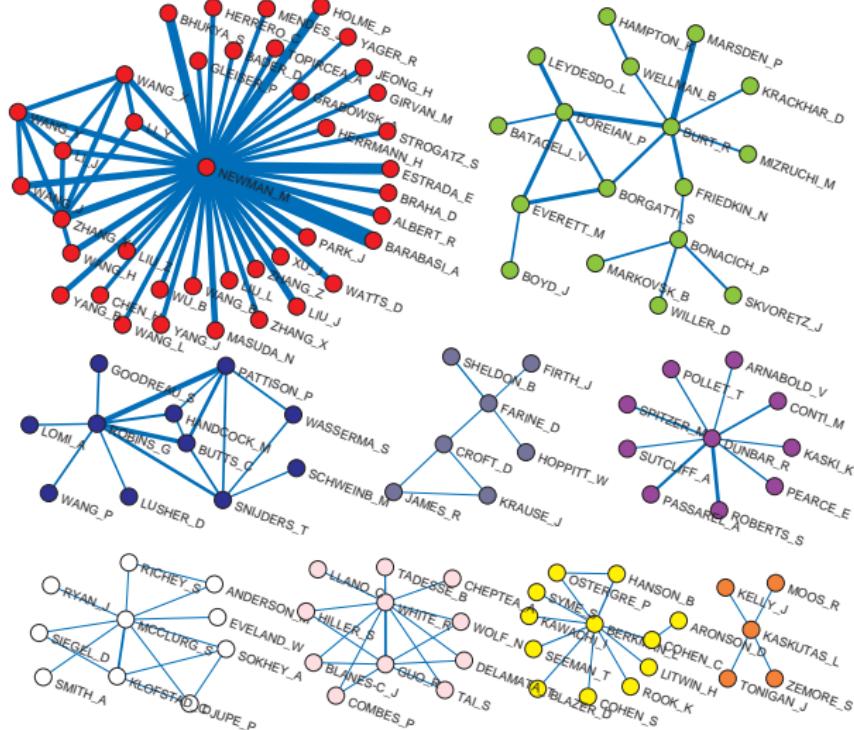
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Keywords co-occurrence

KK net

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$$\mathbf{KKn} = n(\mathbf{WK})^T * n(\mathbf{WK})$$

where

$$n(\mathbf{WK})[w, k] = \frac{\mathbf{WK}[w, k]}{\max(1, \text{outdeg}(w))}$$

Fractional approach:

The fractional contribution of each complete subgraph in \mathbf{KKn} is 1 – all works are contributing equally (the works with large number of keywords are not overrepresented).

The weight of the edges between the nodes (keywords) is equal to the *fractional* co-occurrence of keywords i and j in the same works.

Keywords co-occurrence

KK net Main island

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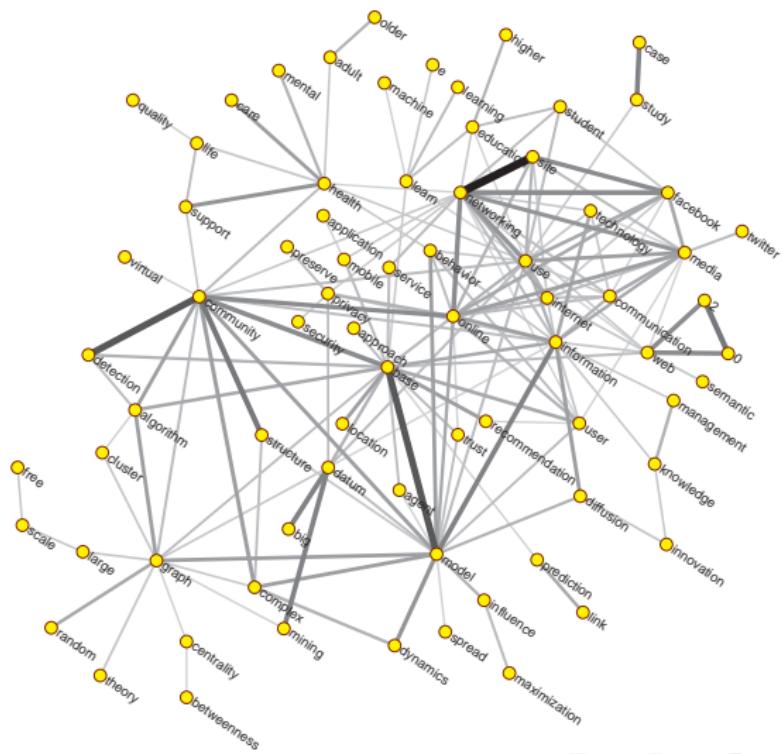
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Using the **Temporal quantities approach** [Batagelj and Praprotnik, 2016] and Python packages **Nets.py** and **TQ.py**, out of the reduced networks **WAr**, **WJr**, **WKr**, and **CiteR** we constructed the set of temporal networks of two types – *instantaneous* (with values given per each year) and *cumulative* (with cumulative values over the years) in .json format. These are the networks **WAins**, **WAcum**, **WJins**, **WJcum**, **WKrins**, **WKcum**, and **CiteIns**, **CiteCum**.

These temporal networks were used for construction of other **obtained** temporal networks.

Temporal networks

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Example of node with temporal quantities - *instantaneous*:

```
['NEWMAN_M', [(1894, 1999, 0), (1999, 2000, 2), (2000, 2001, 4),  
(2001, 2002, 9), (2002, 2003, 10), (2003, 2004, 9), (2004, 2005, 15),  
(2005, 2006, 7), (2006, 2007, 13), (2007, 2008, 4), (2008, 2009, 1),  
(2009, 2010, 2), (2010, 2011, 3), (2011, 2016, 0), (2016, 2017, 2),  
(2017, 2019, 0)]]
```

Example of node with temporal quantities - *cumulative*:

```
['NEWMAN_M', [(1894, 1999, 0), (1999, 2000, 2), (2000, 2001, 6),  
(2001, 2002, 15), (2002, 2003, 25), (2003, 2004, 34), (2004, 2005, 49),  
(2005, 2006, 56), (2006, 2007, 69), (2007, 2008, 73), (2008, 2009, 74),  
(2009, 2010, 76), (2010, 2011, 79), (2011, 2016, 79),  
(2016, 2017, 81), (2017, 2019, 81)]]
```

Number of publications for certain authors

Indegree of WAins network

SNA.
Bibliographic
Network
Analysis

D. Maltseva,
V. Batagelj

Introduction

Data

Networks

Static

Statistics

Works citations

Collaboration

Citation

Co-citation

Keywords

co-occurrence

Temporal

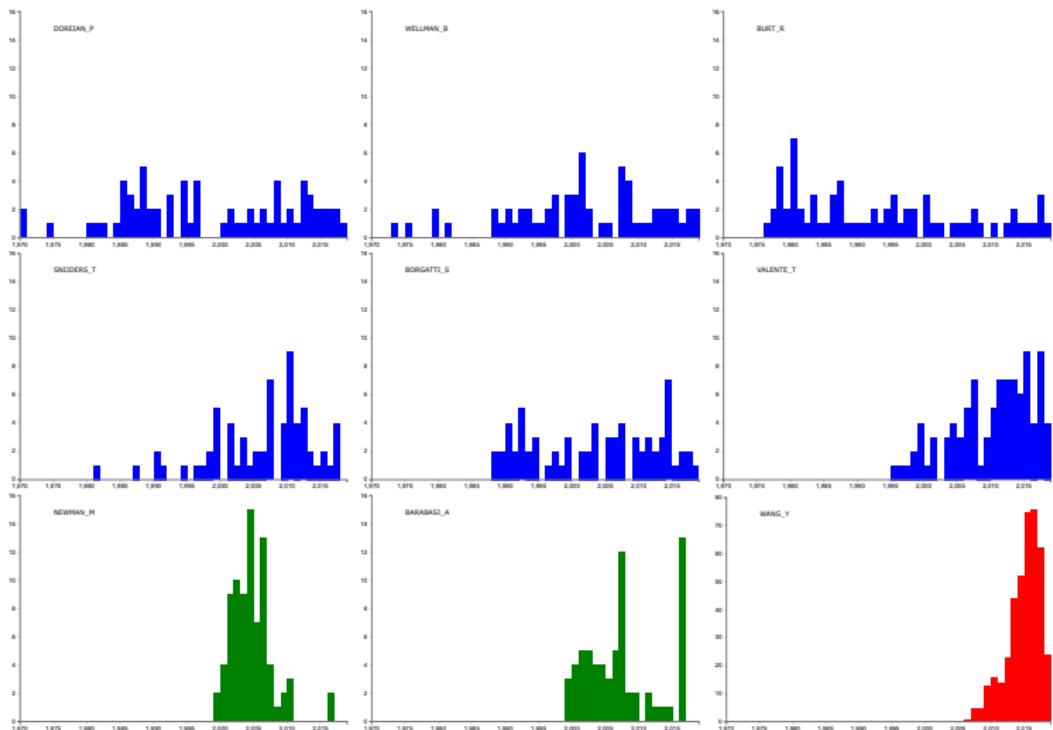
Networks

Authors

Journals

Keywords

Bibliography



Number of publications for certain authors

Indegree from WAcum network

SNA.

Bibliographic
Network
AnalysisD. Maltseva,
V. Batagelj

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Data

Networks

Static

Statistics

Works citations

Collaboration

Citation

Co-citation

Keywords

co-occurrence

Temporal

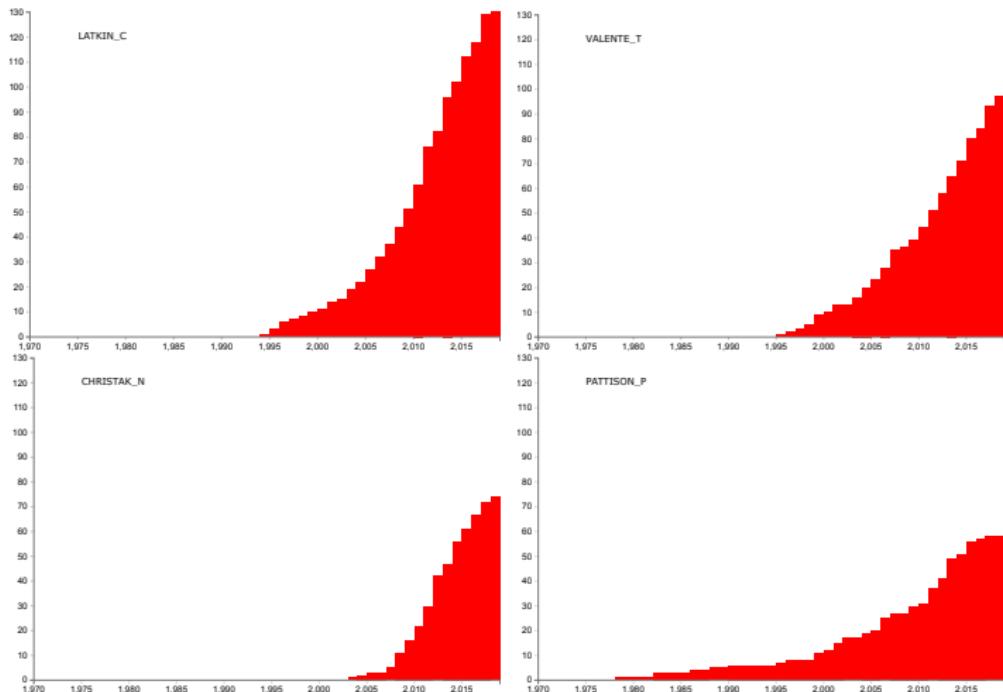
Networks

Authors

Journals

Keywords

Bibliography



Collaboration networks CCn and CCtt

Constructed from WAins and WAcum networks

SNA.

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Network
Analysis

D. Maltseva,
V. Batagelj

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Keywords

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Journals

Keywords

Bibliography

$$n(\mathbf{WAcum})[w, a] = \frac{\mathbf{WAcum}[w, a]}{\max(1, \text{outdeg}(w))}$$

then

$$\mathbf{CCn} = (\mathbf{WAcum})^T * n(\mathbf{WAcum}),$$

The weight of the edges between the nodes (authors) is equal to the contribution of author i to works, that he or she wrote together with author j .

$$n'(\mathbf{WAins})[w, a] = \frac{\mathbf{WAins}[w, a]}{\max(1, \text{outdeg}(w) - 1)}$$

then

$$\mathbf{CCtt} = n(\mathbf{WAins})^T * n'(\mathbf{WAins}),$$

The weights of the edges between the nodes (authors) are equal to the total contribution of “strict collaboration” of authors i and j to works they wrote together.

Collaborativeness indexes for certain authors from Collaboration network CCn

SNA.

Bibliographic
Network
Analysis

D. Maltseva,
V. Batagelj

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Static

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Works citations

Collaboration

Citation

Co-citation

Keywords

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Temporal

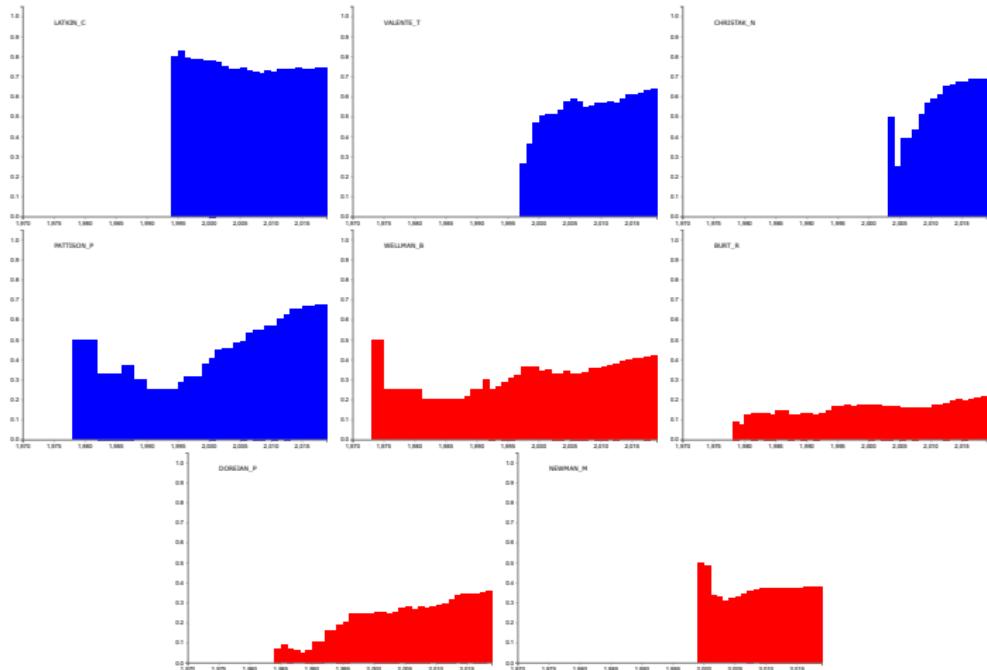
Networks

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Journals

Keywords

Bibliography



Input to collaboration for certain authors from Collaboration network CCtt

SNA.
Bibliographic
Network
Analysis

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V. Batagelj

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Temporal

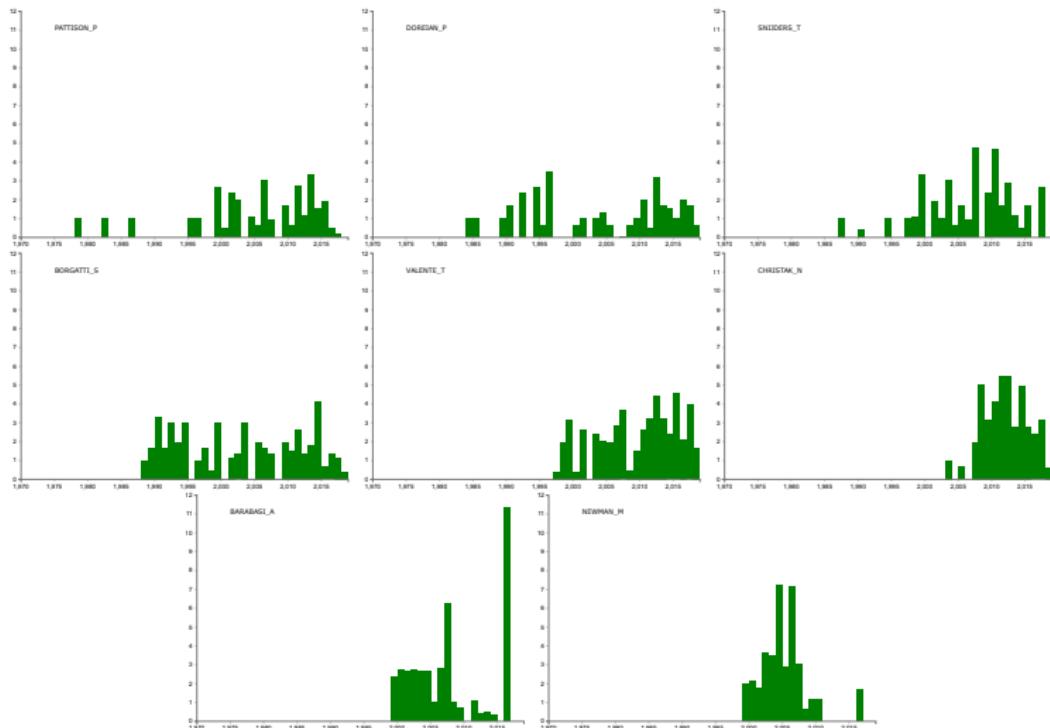
Networks

Authors

Journals

Keywords

Bibliography



Citations among authors

ACA and ACAn nets from WAins, WAcum and CiteIns nets

$$\mathbf{ACA} = (\mathbf{WAins})^T * \mathbf{CiteIns} * \mathbf{WAcum}$$

The value of weight of the element $ACA[u, v]$ is equal to the **absolute number of citations** per year from works coauthored by u to works coauthored by v .

$$\mathbf{ACAn} = (\mathbf{WAins})^T * n(\mathbf{CiteIns}) * \mathbf{WAcum}$$

where

$$n(\mathbf{CiteIns})[u, v] = \frac{\mathbf{CiteIns}[u, v]}{\max(1, \text{outdeg}(u))}$$

The value of element $ACAn[u, v]$ is equal to the number of **fractional contribution** of citations per year from works coauthored by u to works coauthored by v .

Self-citations among certain authors

Loops from ACA network

SNA.

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V. Batagelj

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Temporal

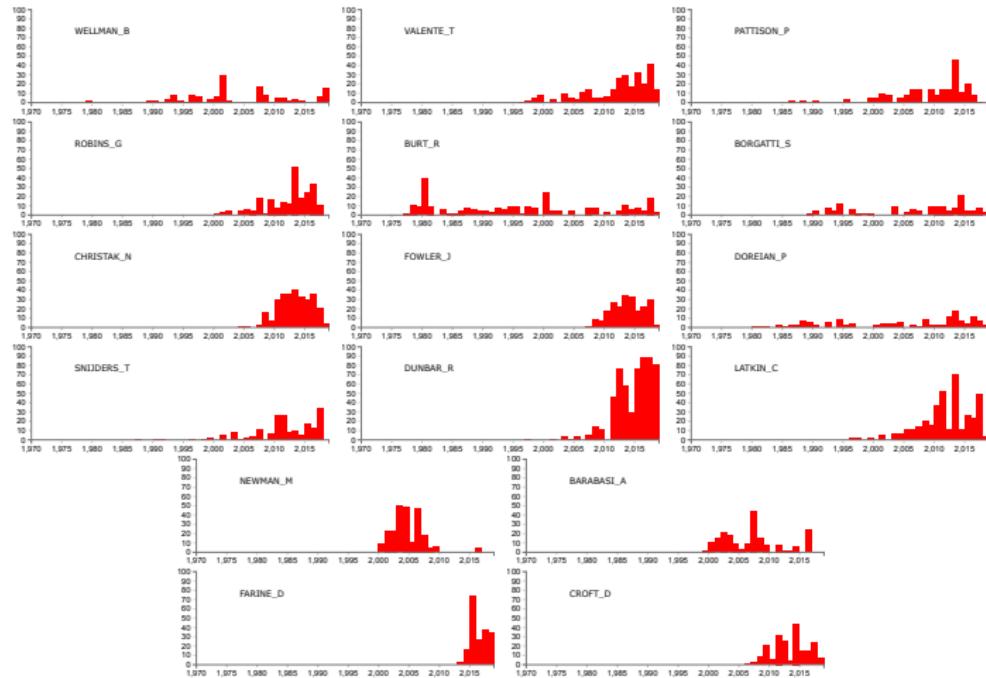
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Citations among authors with largest line weights from ACA network with extracted loops

SNA.

Bibliographic
Network
AnalysisD. Maltseva,
V. Batagelj

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Citation

Co-citation

Keywords

co-occurrence

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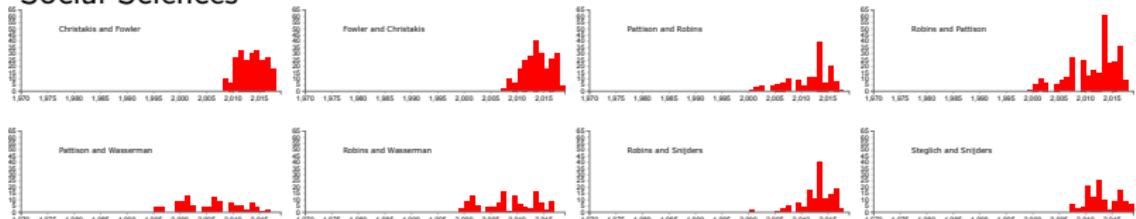
Authors

Journals

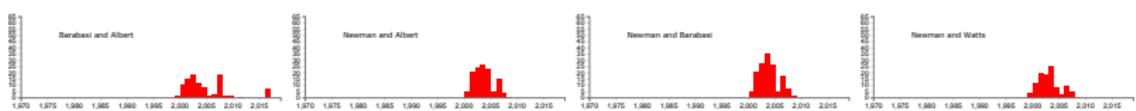
Keywords

Bibliography

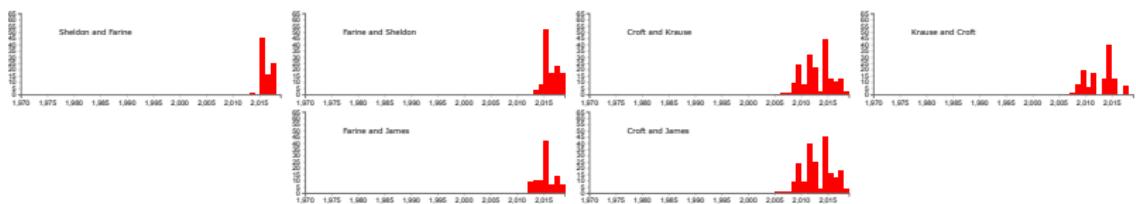
Social Sciences



Physics



Animal social networks



Outcoming citations for certain authors from ACAn network

SNA.

Bibliographic
Network
AnalysisD. Maltseva,
V. Batagelj

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Co-citation

Keywords

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Networks

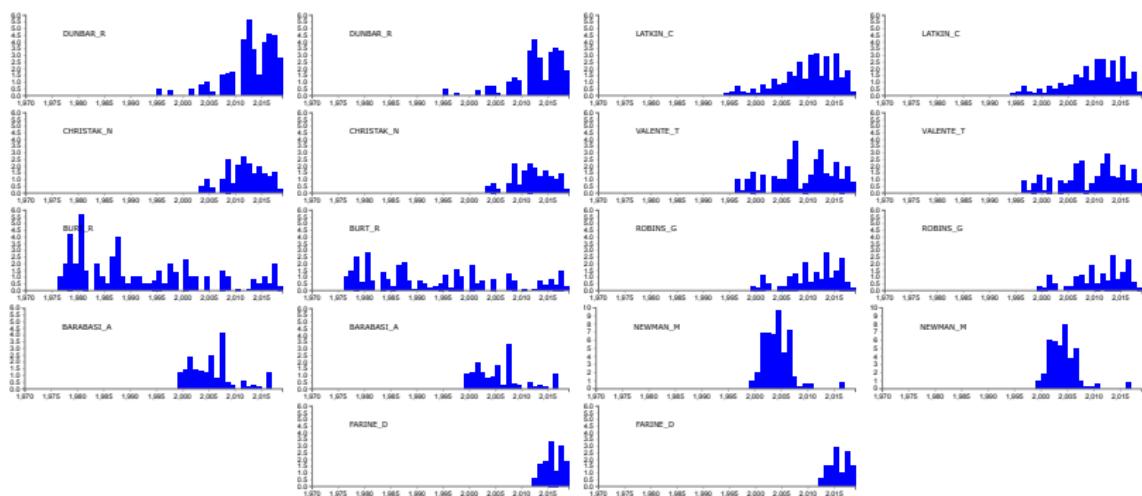
Authors

Journals

Keywords

Bibliography

Outdegree of ACAn: how many authors are cited by a certain author



Incoming citations for certain authors from ACAn network

SNA.
Bibliographic
Network
Analysis

D. Maltseva,
V. Batagelj

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Networks

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Works citations

Collaboration

Citation

Co-citation

Keywords

co-occurrence

Temporal

Networks

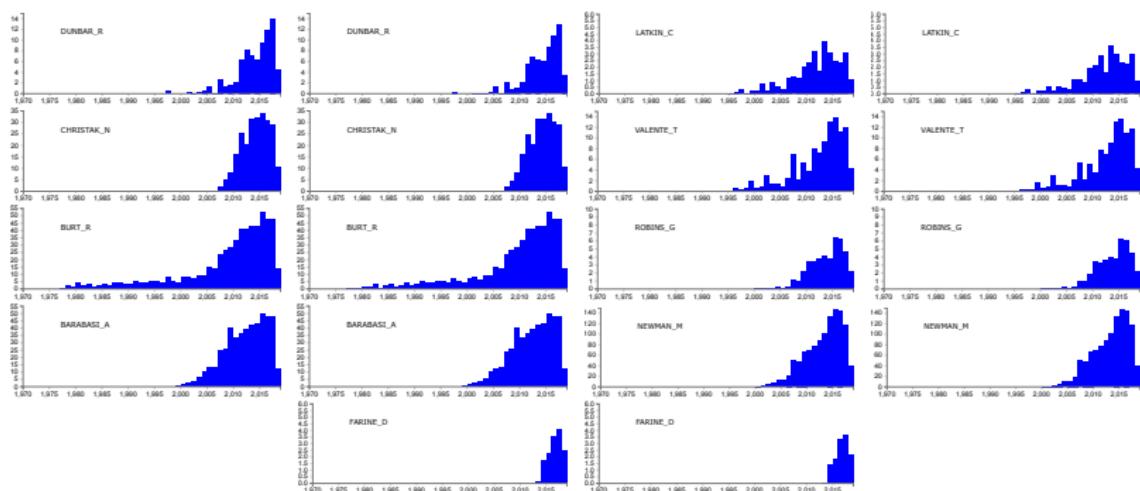
Authors

Journals

Keywords

Bibliography

Indegree of ACAn: how many authors cite certain authors (note different scales)



Number of journals and papers from WJins network

SNA.
Bibliographic
Network
Analysis

D. Maltseva,
V. Batagelj

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Co-citation

Keywords

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Temporal

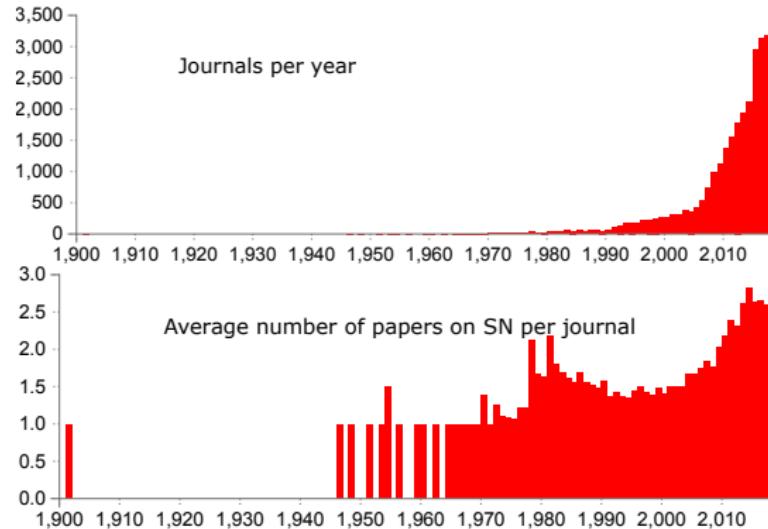
Networks

Authors

Journals

Keywords

Bibliography



We counted a proportion of the *Number of works* published in each journal in each year and the *Maximum number of papers* published per year (in any journal). This proportions aims to normalize the input of the certain journal in each year in range from 0 to 100% and shows their importance through time.

Input of SNA journals from WJins norm network

SNA.

Bibliographic
Network
AnalysisD. Maltseva,
V. Batagelj

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Works citations

Collaboration

Citation

Co-citation

Keywords

co-occurrence

Temporal

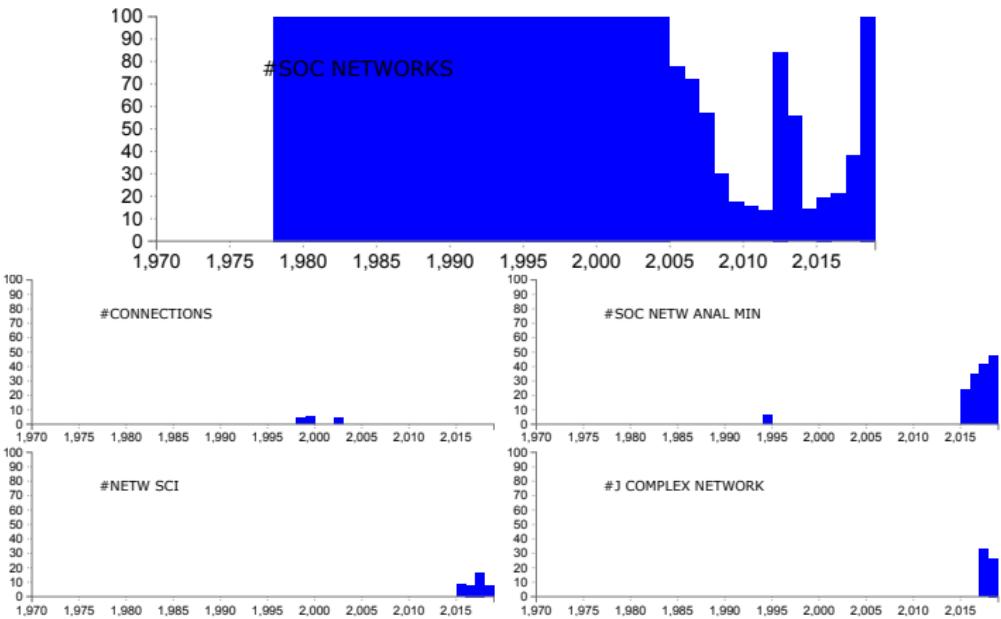
Networks

Authors

Journals

Keywords

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Inputs of journals in Social Sciences from WJins norm network

SNA.
Bibliographic
Network
Analysis

D. Maltseva,
V. Batagelj

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Works citations

Collaboration

Citation

Co-citation

Keywords

co-occurrence

Temporal

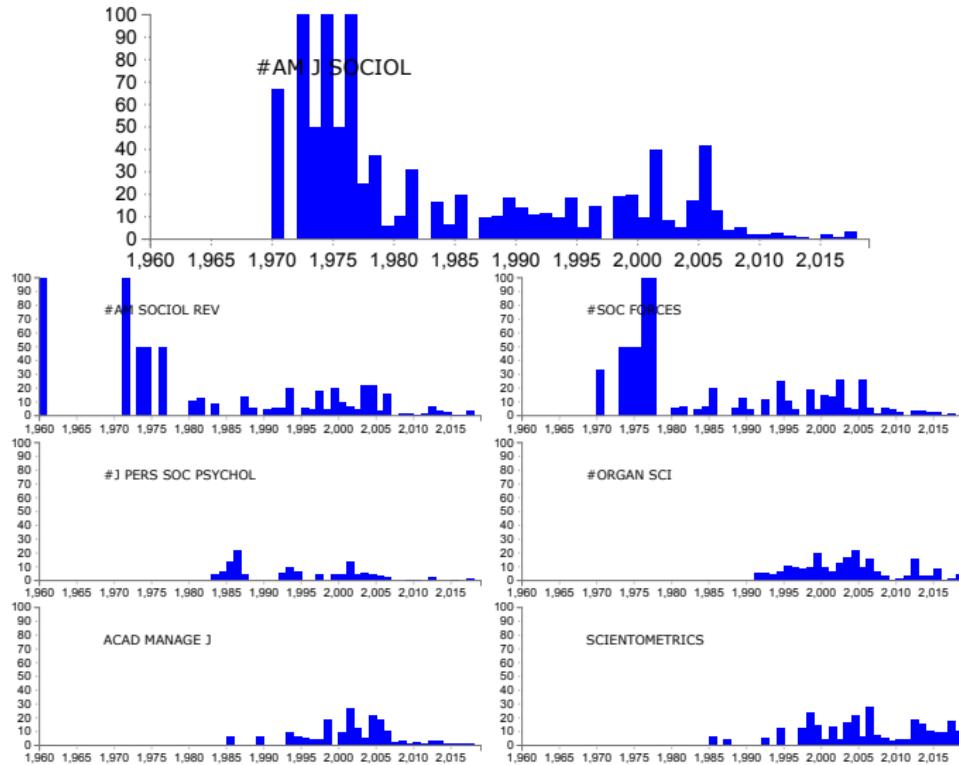
Networks

Authors

Journals

Keywords

Bibliography



Input of other journals from WJins norm network

SNA.

Bibliographic
Network
AnalysisD. Maltseva,
V. Batagelj

Introduction

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Works citations

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Citation

Co-citation

Keywords

co-occurrence

Temporal

Networks

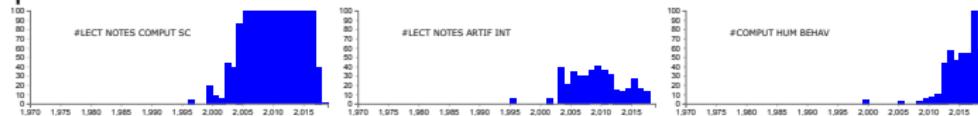
Authors

Journals

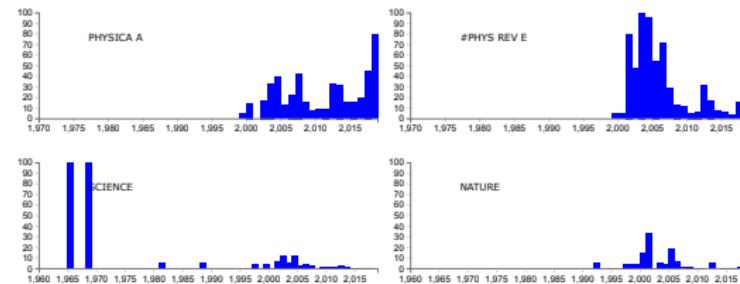
Keywords

Bibliography

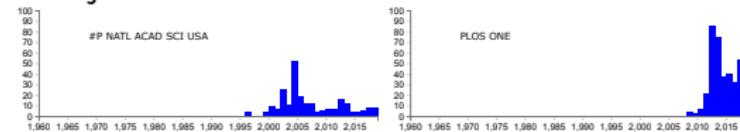
Computer Science



Physics



General scientific journals



Input of other journals from WJins norm network

SNA.

Bibliographic
Network
AnalysisD. Maltseva,
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Works citations

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Citation

Co-citation

Keywords

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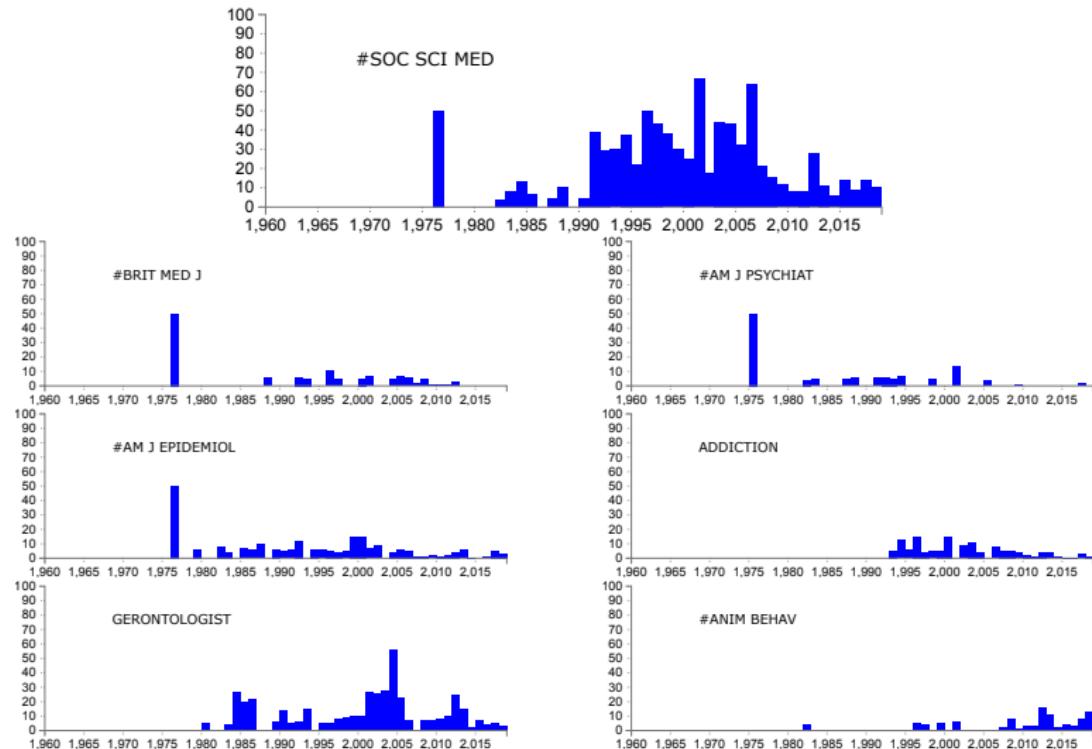
Networks

Authors

Journals

Keywords

Bibliography



Citations among journals

JCJ and JCJn from WJins, WJcum, CiteIns nets

SNA.

Bibliographic
Network
Analysis

D. Maltseva,
V. Batagelj

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Temporal

Networks

Authors

Journals

Keywords

Bibliography

$$\mathbf{JCJ} = (\mathbf{WJins})^T * \mathbf{CiteIns} * \mathbf{WJcum}$$

The value of weight of the element $JCJ[i, j]$ is equal to the **absolute number of citations** per year from journal i to journal j .

$$\mathbf{JCJn} = (\mathbf{WJins})^T * n(\mathbf{CiteIns}) * \mathbf{WJcum}$$

where

$$n(\mathbf{CiteIns})[u, v] = \frac{\mathbf{CiteIns}[u, v]}{\max(1, \text{outdeg}(u))}$$

The value of element $JCJn[i, j]$ is equal to the number of **fractional contribution** of citations per year from journal i to journal j .

Self-citations among journals

SNA.

Bibliographic Network Analysis

D. Maltseva,
V. Batagelj

Introduction

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Networks

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Works citation

Collaboration

Citation

Co-citation

Keywords

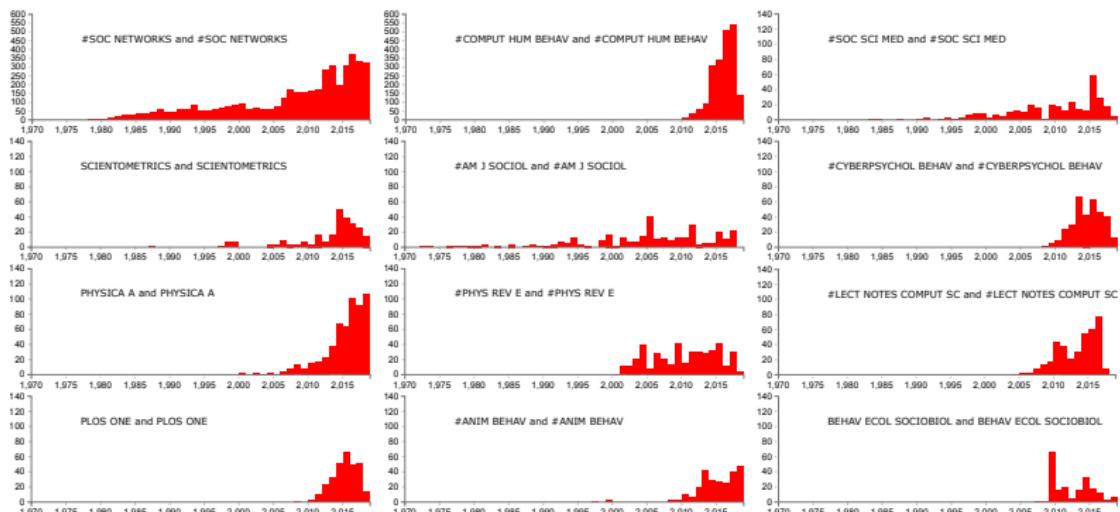
Temporal

Networks

Authors

Journals

Keywords



Citations of Social Networks journal

Indegree and Outdegree of JCJ network without loops

SNA.

Bibliographic
Network
Analysis

D. Maltseva,
V. Batagelj

Introduction

Data

Networks

Static

Statistics

Works citations

Collaboration

Citation

Co-citation

Keywords

co-occurrence

Temporal

Networks

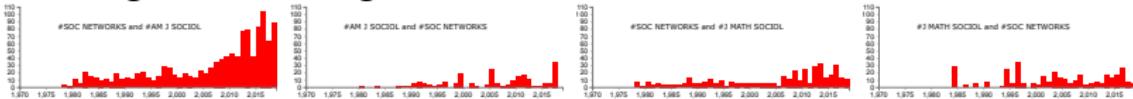
Authors

Journals

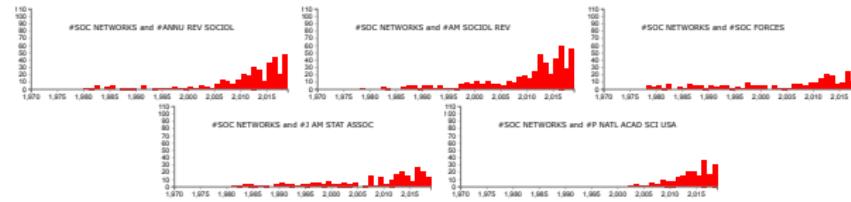
Keywords

Bibliography

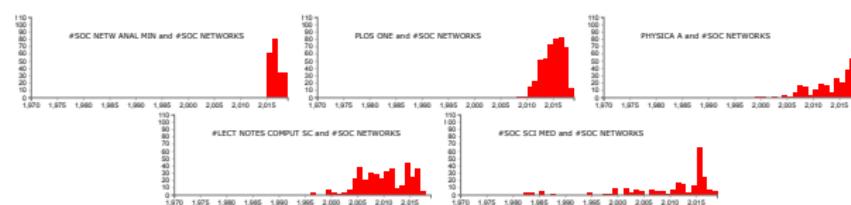
Outdegree and Indegree:



Outdegree:



Indegree:



Genreal Scientific journals: from JCJ network without loops

SNA.

Bibliographic
Network
AnalysisD. Maltseva,
V. Batagelj

Introduction

Data

Networks

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Works citations

Collaboration

Citation

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Keywords

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Temporal

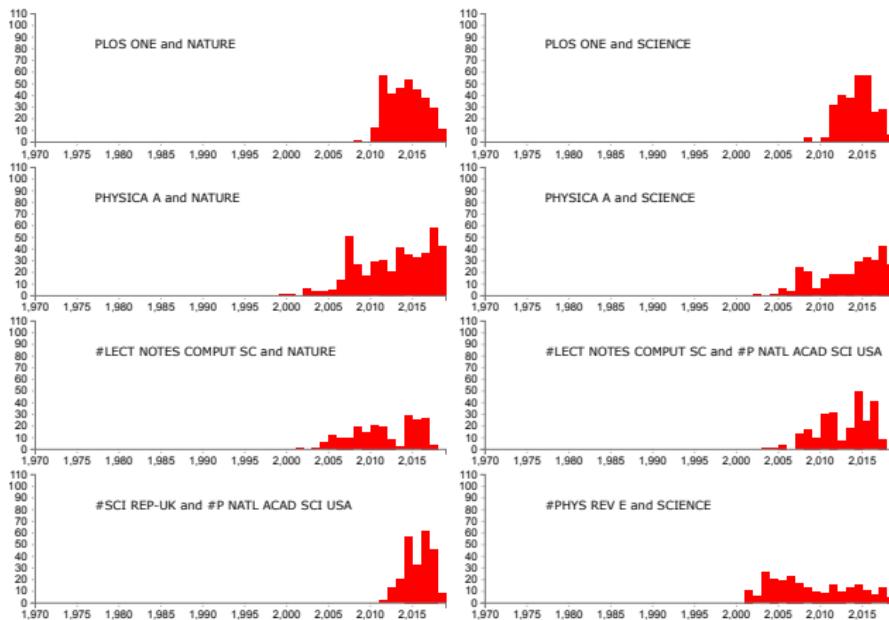
Networks

Authors

Journals

Keywords

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Other journals from JCJ network without loops

SNA.

Bibliographic
Network
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Works citations

Collaboration

Citation

Co-citation

Keywords
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Networks

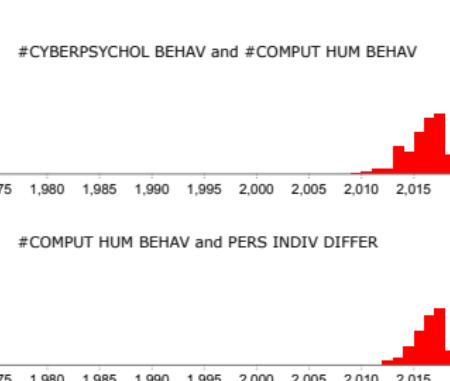
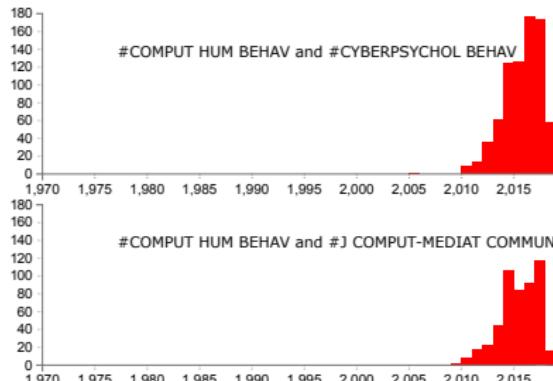
Authors

Journals

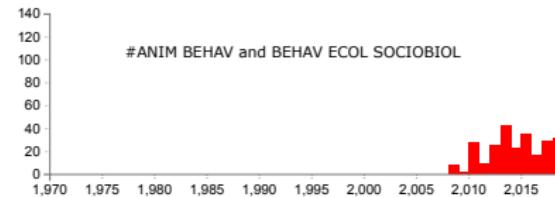
Keywords

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Computer Science:



Animal social networks:



Outcoming citations with/without loops from JCJn network

SNA.

Bibliographic
Network
Analysis

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Works citations

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Keywords

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Temporal

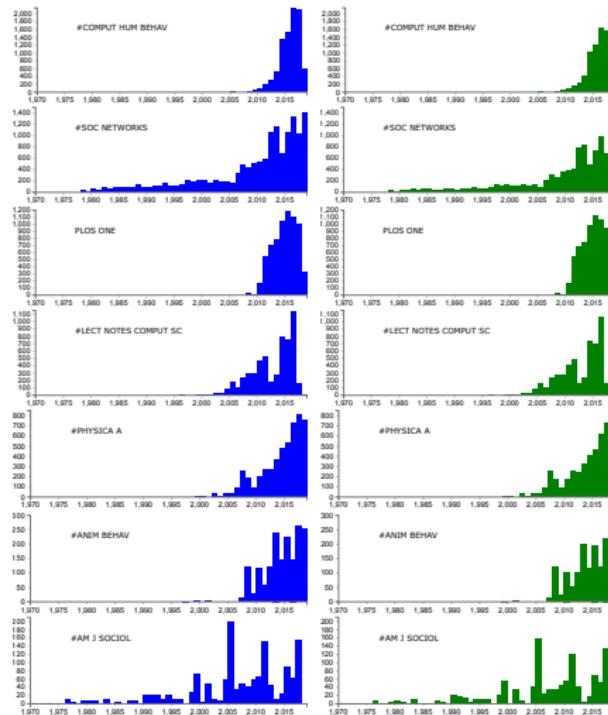
Networks

Authors

Journals

Keywords

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Incoming citations citations with/without loops from JCJn network

SNA.

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Network
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Temporal

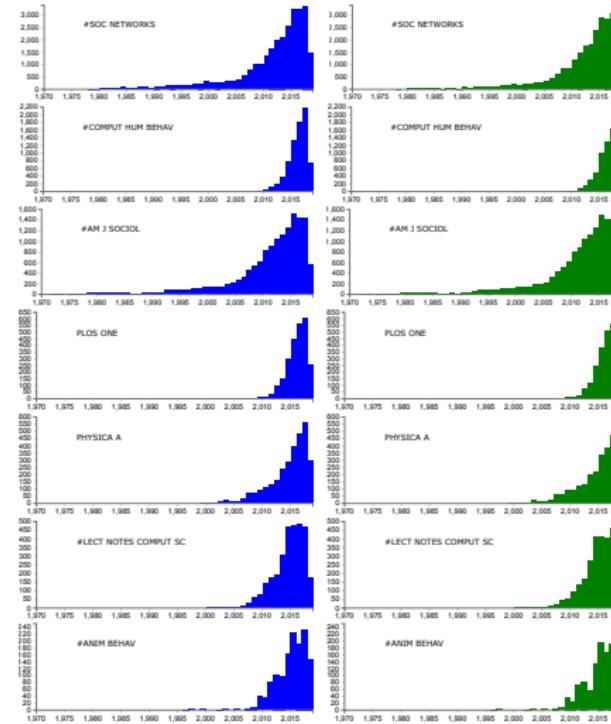
Networks

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Number of keywords from WKins network

SNA.
Bibliographic
Network
Analysis

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Co-citation

Keywords

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Temporal

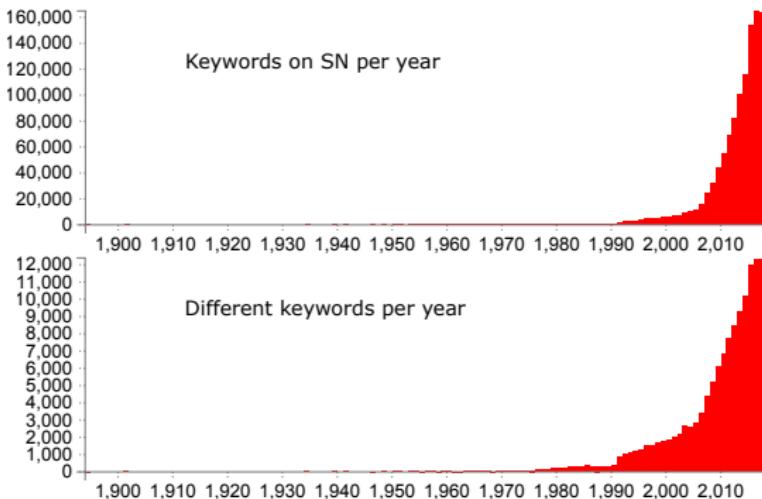
Networks

Authors

Journals

Keywords

Bibliography



Basing on **WKins** network, we counted a proportion of the *Number of each keyword per year* and the *Maximum number of keywords* for each year. This proportions aims to normalize the importance of certain keywords through time in range from 0 to 100%.

Input of certain keywords from WKins network [100 scale]

SNA.

Bibliographic
Network
Analysis

D. Maltseva,
V. Batagelj

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Temporal

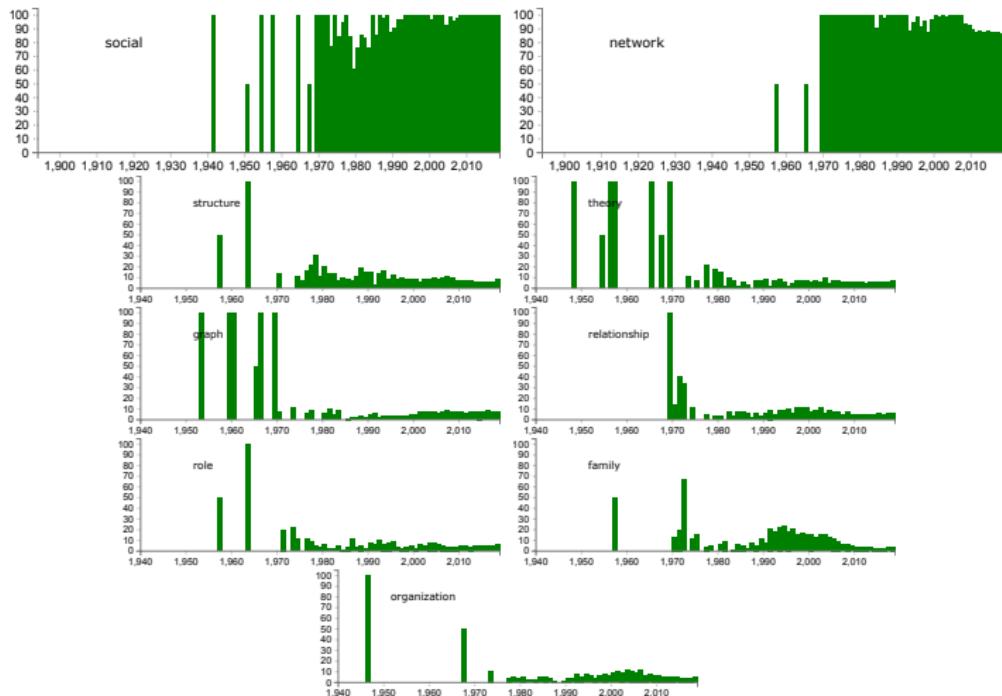
Networks

Authors

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Keywords

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Input of certain keywords from WKins network [50 scale]

SNA.

Bibliographic
Network
AnalysisD. Maltseva,
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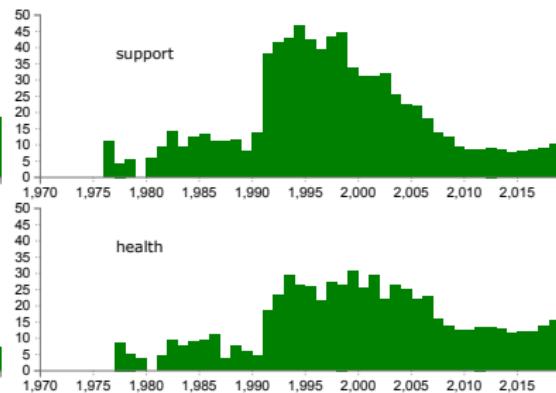
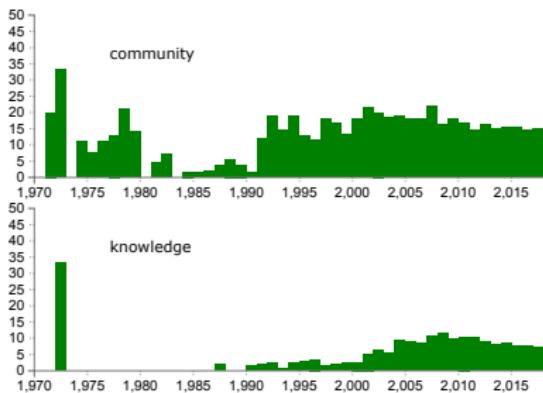
Networks

Authors

Journals

Keywords

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Input of certain keywords from WKins network [30 scale]

SNA.

Bibliographic
Network
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Keywords
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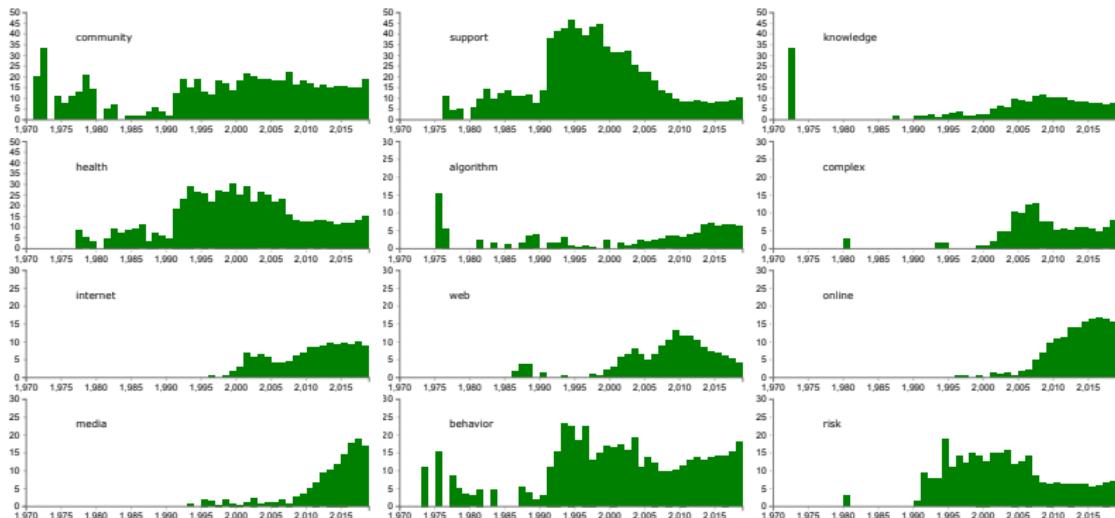
Networks

Authors

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Keywords

Bibliography



Input of certain keywords from WKins network [14 and 10 scale]

SNA.

Bibliographic
Network
AnalysisD. Maltseva,
V. Batagelj

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Keywords

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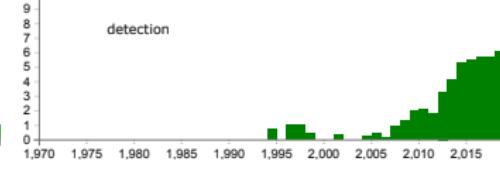
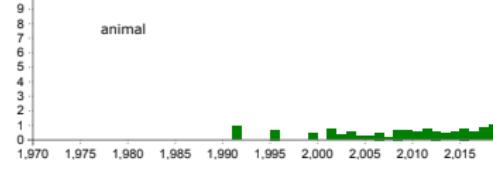
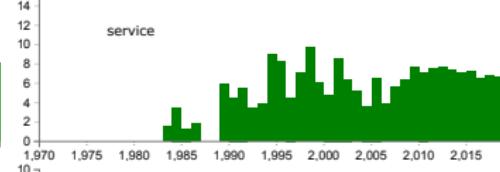
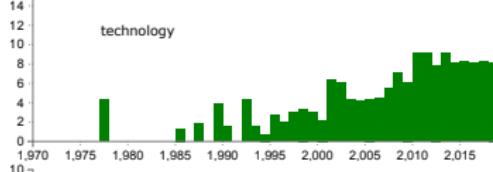
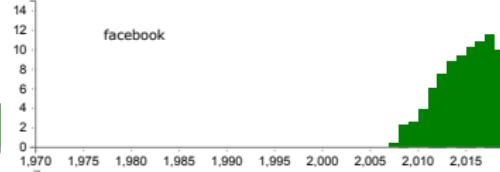
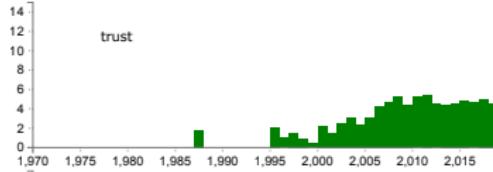
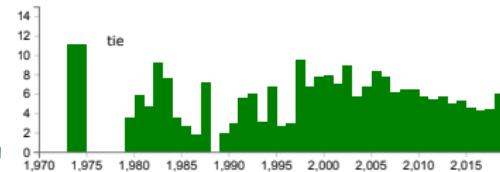
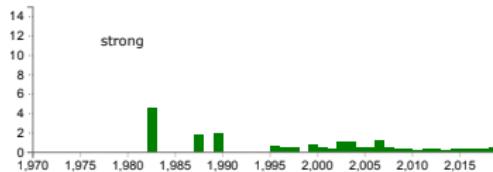
Networks

Authors

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Bibliography

- ① Batagelj, V. (2007) WoS2Pajek. Networks from Web of Science. Version 0.3. Manual. URL: <http://vlado.fmf.uni-lj.si/pub/networks/pajek/WoS2Pajek/WoS2Pajek.pdf>
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- ③ Batagelj, V., Doreian P., V., Ferligoj, A., Kejzar N. Understanding Large Temporal Networks and Spatial Networks: Exploration, Pattern Searching, Visualization and Network Evolution, 2014.
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