

Analysis of bibliographic networks

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NetGloW workshop

St Petersburg, July 4, 2018

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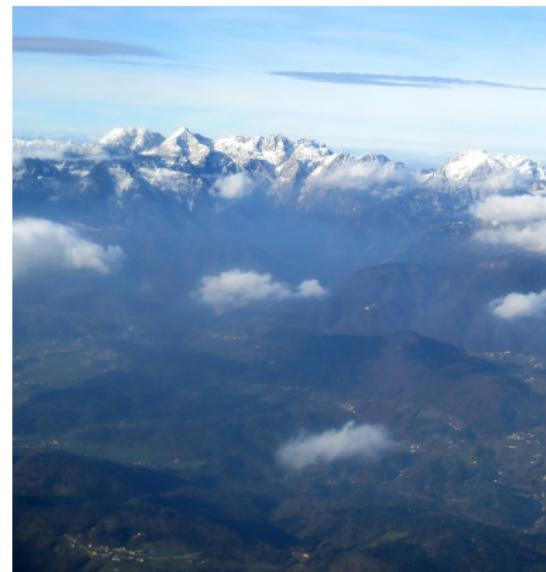
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Current version of slides (November 20, 2016 at 01 : 06): [slides PDF](http://vlado.fmf.uni-lj.si/pub/slides/bibnet16.pdf)
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A *network* is based on two sets – a set of *nodes* (vertices), that represent the selected *units*, and a set of *links* (lines), that represent *ties* between units. They determine a *graph*. A link can be *directed* – an *arc*, or *undirected* – an *edge*.

Additional data about nodes or links may be known – their *properties* (attributes). For example: name/label, type, age, value, ...

Network = Graph + Data

A *network* $\mathcal{N} = (\mathcal{V}, \mathcal{L}, \mathcal{P}, \mathcal{W})$ consists of:

- a *graph* $\mathcal{G} = (\mathcal{V}, \mathcal{L})$, where \mathcal{V} is the set of nodes, \mathcal{A} is the set of arcs, \mathcal{E} is the set of edges, and $\mathcal{L} = \mathcal{E} \cup \mathcal{A}$ is the set of links.
 $n = |\mathcal{V}|$, $m = |\mathcal{L}|$
- \mathcal{P} *vertex value functions* / properties: $p: \mathcal{V} \rightarrow A$
- \mathcal{W} *link value functions* / weights: $w: \mathcal{L} \rightarrow B$

Types of networks

In a *two-mode* network $\mathcal{N} = ((\mathcal{V}_1, \mathcal{V}_2), \mathcal{L}, \mathcal{P}, \mathcal{W})$ its set of nodes is split to two subsets. Each link has its end-nodes in both sets.

In a *multi-relational* network $\mathcal{N} = (\mathcal{V}, (\mathcal{L}_i, i \in I), \mathcal{P}, \mathcal{W})$ the set of its links is partitioned into several mutually disjoint subsets – relations. (Subject Verb Object).

In a *temporal* network $\mathcal{N} = (\mathcal{V}, \mathcal{L}, \mathcal{T}, \mathcal{P}, \mathcal{W})$ the time \mathcal{T} is added. To each node and to each link its *activity* set is assigned. Also properties and weights can change through time – temporal quantities.

A *collection* of networks consists of some networks with common subsets of nodes.

Types of networks can be combined – for example: a temporal two-mode multi-relational network.

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The saved records from a data base can still contain some inconsistencies. Some of them are detected as results of the analyses. The simplest way to deal with them is to correct them in the saved data base file and rerun the creation of Pajek's files and analyses.

To improve the quality of the data some tools for detecting (possible) inconsistencies could be developed.

Check (in Pajek) the obtained networks for multiple lines and remove them, if they exist. Remove also the loops from the citation network.

Citation networks

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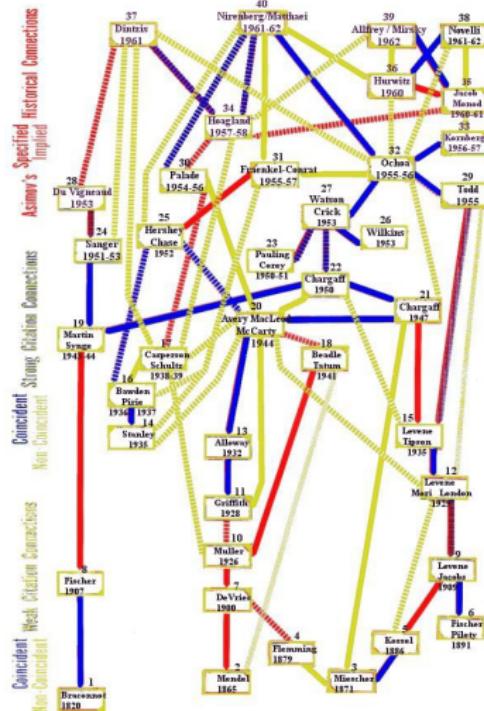
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The citation network analysis started in 1964 with the paper of **Garfield et al.** In 1989 **Hummon and Dorrian** proposed three indices – weights of arcs that provide us with automatic way to identify the (most) important part of the citation network. We developed an algorithm to efficiently compute SPC weights, provided the citation network is acyclic.

... Citation networks

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In a given set of works/nodes W (articles, books, works, etc.) we introduce a *citing relation*/set of arcs $\mathbf{Ci} \subseteq W \times W$

$$u \mathbf{Ci} v \equiv u \text{ cites } v$$

which determines a *citation network* $\mathcal{N} = (W, \mathbf{Ci})$.

A citing relation is usually *irreflexive* (no loops) and (almost) *acyclic*. We shall assume that it has these two properties. Since in real-life citation networks the strong components are small (usually 2 or 3 nodes) we can transform such network into an acyclic network by shrinking strong components and deleting loops.

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Using on a file *PRcite.net* the commands

Info/Network/General

Net/Transform/Remove/Loops

Net/Transform/Remove lines/Single line

we get the information about the number of loops and multiple links.
Remove loops, and replace multiple links with single links. The obtained network we save (Options – Save coordinates [OFF]) to file *PRciteR.net*. For further analysis the citation network has to be acyclic – has no nontrivial strong component. To identify nontrivial strong components and extract them use the commands:

Net/Components/Strong [2]

Operations/Extract from Network/Partition [1-*]

Operations/Transform/Remove Lines/Between Clusters

Save the obtained network to a file *PRstrong.net*.

... Preparing the citation network

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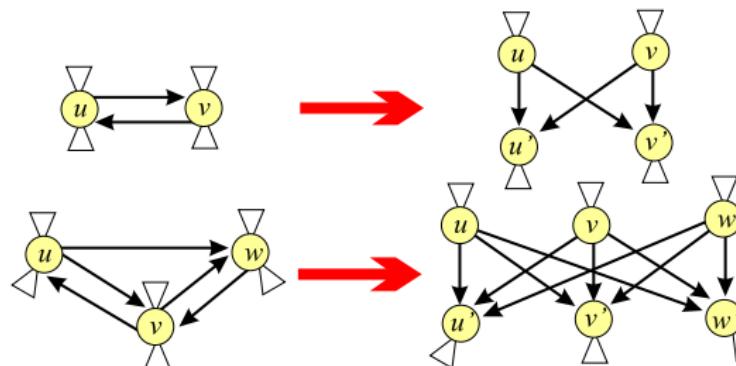
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To transform the network *PRciteR.net* into an acyclic network using the preprint transformation use the Pajek's command

Network/Acyclic Network/Transform/Preprint Transformation

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Networks obtained from a WoS file using the program WoS2Pajek are in the 'raw' form. We still have to resolve in some way the *network boundary problem*. The first option is to limit the network to the works with complete descriptions – records from the WoS file, $DC = 1$. Since for cited-only works only the first author (no keywords, ...) is known this option is used for most analyses.

We can get a richer network if we decide to include also some cited-only works that are cited often – at least k times; we delete nodes for which it holds $(0 < \text{indeg}(v) < k) \wedge (\text{outdeg}(v) = 0)$.

```
Net/Partition/Degree/Input
Partition/Binarize [1-(k-1)]
Net/Partition/Degree/Output
Partition/Binarize [0]
[select partition 1]
[select partition 2]
Partitions/Min(V1,V2)
Operations/Extract from Network/Partition [0]
```

For some (most frequent) of these additional works we can augment the WoS file with their descriptions (without CR data).

PEERE network

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To the *Web of Science* (WoS) we put the query "peer review*". In May and June 2015 we got (from Web of Science Core Collection) 17053 hits, and additional 2867 hits for the query refereeing.

In March 2016 we updated the data by adding hits for the years 2015 and 2016 and manually prepared short descriptions for the most cited works (fields: AU, PU, TI, PY, PG, KW; but without CR data).

The analysis in 2015 revealed many papers without WoS descriptions having large indegrees in the citation network. We manually searched in WoS for each of them (with indegree larger or equal to 20) and, if found, we added them into the data set. Important earlier papers often did not use the now established terminology and were therefore overlooked by our queries.

The final run of the program WoS2Pajek produced networks with sets of the following sizes: works $|W| = 721547$, authors $|A| = 295849$, journals $|J| = 39988$, and keywords $|K| = 36279$. In both phases 22981 records were collected. There were 887 duplicates (considered only once).

We removed multiple links and loops (resulting from homonyms) from the networks. The cleaned citation network **CiteAll** has $n = 721547$ nodes and $m = 869821$ arcs.

PEERE – most cited works

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	n	freq	first author	title
Bibliographic networks	1	173	Cohen, J	Statistical Power Analysis for the Behavioral Sciences. Routledge, 1988
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Networks	3	151	Egger, M	Bias in meta-analysis detected by a simple, graphical test. Brit Med J, 1997
Statistics	4	150	Stroup, DF	Meta-analysis of observational studies in epidemiology - A proposal for reporting
Citation	5	135	Dersimonian, R	Metaanalysis in clinical-trials. Control Clin Trials, 1986
Two-mode Ns	6	130	Zuckerman, H	Patterns of evaluation in science - institutionalisation, structure and function
Multiplication	7	130	Higgins, JPT	Cochrane Handbook for Systematic Reviews of Interventions. Cochrane, 2011
Derived Ns	8	126	Moher, D	Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA
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References	10	121	Cicchetti, DV	The reliability of peer-review for manuscript and grant submissions - ... Behav
Appendix	11	119	Hirsch, JE	An index to quantify an individual's scientific research output. P Natl Acad Sci
	12	114	Mahoney, M	Publication prejudices: An experimental study of confirmatory bias ... Cognit
	13	114	van Rooyen, S	Effect of open peer review on quality of reviews and on reviewers' recommend
	14	114	Easterbrook, PJ	Publication bias in clinical research. Lancet, 1991
	15	110	Landis, JR	Measurement Of Observer Agreement For Categorical Data. Biometrics, 1977
	16	109	Godlee, F	Effect on the quality of peer review of blinding reviewers and asking them to
	17	108	Horrobin, DF	The philosophical basis of peer-review and the suppression of innovation. J Am
	18	107	Moher, D	Preferred Reporting Items for Systematic Reviews and Meta-Analyses: PRISMA
	19	107	Jadad, AR	Assessing the quality of reports of randomized clinical trials: Is blinding necessary?
	20	105	Mcnutt, RA	The effects of blinding on the quality of peer-review - a randomized trial. J Am
	21	104	Cole, S	Chance and consensus in peer-review. Science, 1981
	22	103	Moher, D	Improving the quality of reports of meta-analyses of randomised controlled tri
	23	98	Justice, AC	Does masking author identity improve peer review quality? - A randomized c
	24	97	Lock, S	A Difficult Balance: Editorial Peer Review in Medicine. Nuffield Trust, 1985
	25	95	van Rooyen, S	Effect of blinding and unmasking on the quality of peer review - A randomiz
	26	92	Black, N	What makes a good reviewer and a good review for a general medical journal
	27	91	Scherer, RW	Full publication of results initially presented in abstracts - a metaanalysis. J Am
	28	90	Higgins, JPT	Quantifying heterogeneity in a meta-analysis. Stat Med, 2002
	29	90	Smith, R	Peer review: a flawed process at the heart of science and journals. J Roy Soc
	30	87	Goodman, SN	Manuscript quality before and after peer-review and editing at Annals of Inter

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We read in Pajek the citation network `cite.net` for 'centrality' literature. First we remove loops and multiple lines. Then we determine the indegrees and outdegrees. We dispose the normalized degree vectors, transform both partitions into vectors and call R from Pajek submitting all vectors.

```
#####
# R called from Pajek
# The following vectors read:
v3 : From partition 1 (548600)
v4 : From partition 2 (548600)
-----
> inTab <- table(v3)
> indeg <- as.integer(names(inTab))
> inDeg <- indeg[indeg>0]
> inFreq <- as.vector(inTab[indeg>0])
> plot(inDeg,inFreq,log='xy',main="in-degree distribution")
> ouTab <- table(v4)
> outdeg <- as.integer(names(ouTab))
> outDeg <- outdeg[outdeg>0]
> outFreq <- as.vector(ouTab[outdeg>0])
> plot(outDeg,outFreq,log='xy',main="out-degree distribution")
```

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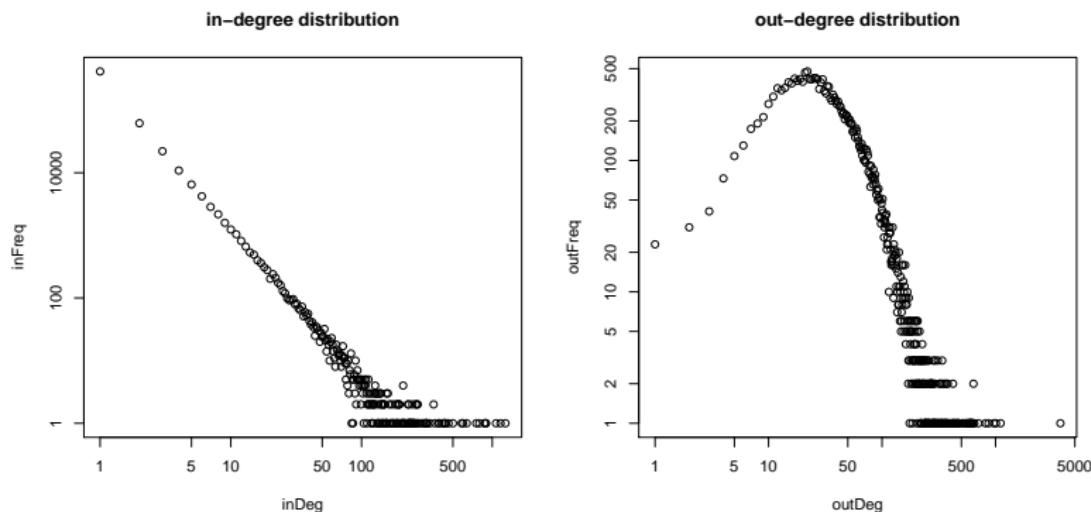
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The in-degree distribution is "scale-free"-like. The parameters can be determined using the package of [Clauset, Shalizi and Newman](#). See also [Stumpf, et al.: Critical Truths About Power Laws](#).

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From the file Year.clu we can get the distribution of *citations by years*.
For the centrality network we get:

```
> setwd("C:/Users/Batagelj/work/Python/WoS/Central")
> years <- read.table(file="Year.clu",header=FALSE,skip=2)$V1
> t <- table(years)
> year <- as.integer(names(t))
> freq <- as.vector(t[1950<=year & year<=2009])
> y <- 1950:2009
> plot(y,freq)
> model <- nls(freq~c*dlnorm(2010-y,a,b),start=list(c=350000,a=2,b=0.7))
> model
Nonlinear regression model
  model: freq ~ c * dlnorm(2010 - y, a, b)
  data: parent.frame()
      c      a      b 
5.427e+05 2.491e+00 6.624e-01 
  residual sum-of-squares: 20474181

Number of iterations to convergence: 7
Achieved convergence tolerance: 3.978e-06
> lines(y,predict(model,list(x=2010-y)),col='red')
```

It can be well approximated by the *lognormal distribution*, but also by the *generalized reciprocal power exponential curve* $c * (x+d)^{\frac{a}{b+x}}$.

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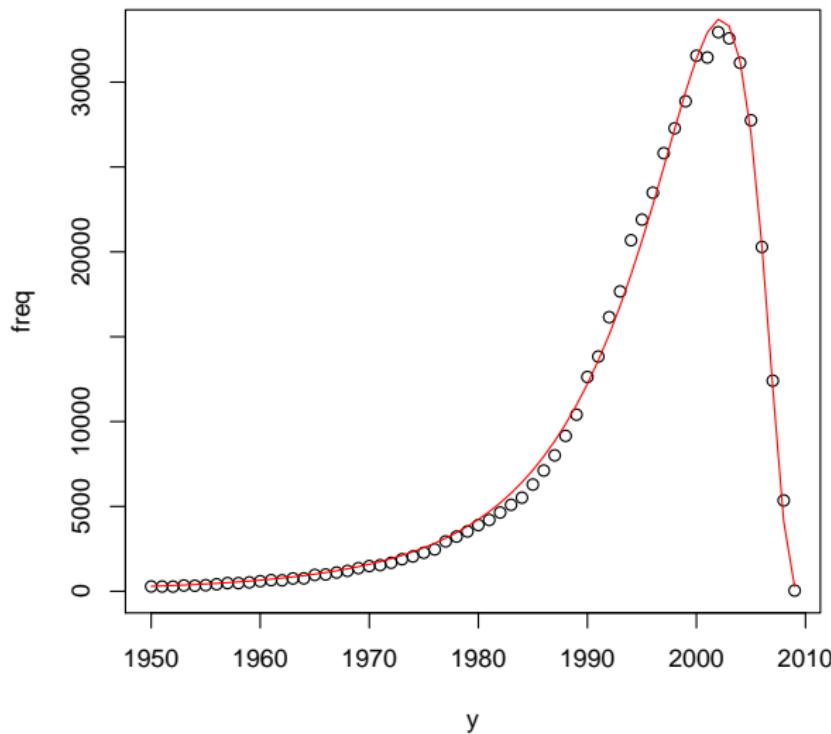
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Data from the ZB data base for years 1990–2010.

Network	WA	WJ	WK	WM
Size of the first set	1339201	1339201	1339201	1339201
Size of the second set	557104	3158	143513	12390
Number of arcs	2550437	1331036	15062377	3370820

See the [paper](#).

Distributions – number of keywords

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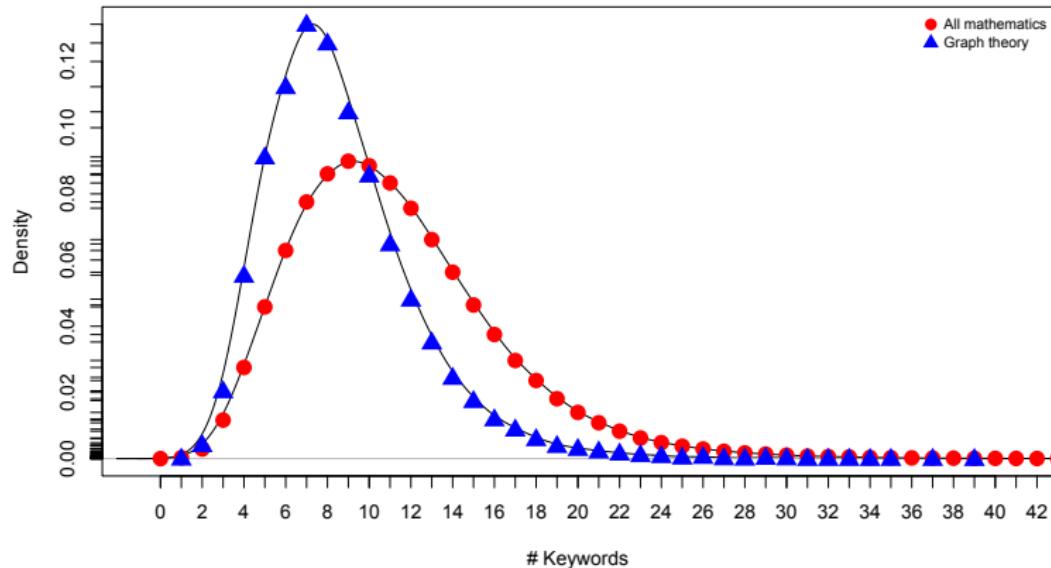
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Distributions – keywords by the number of works using a keyword in their description

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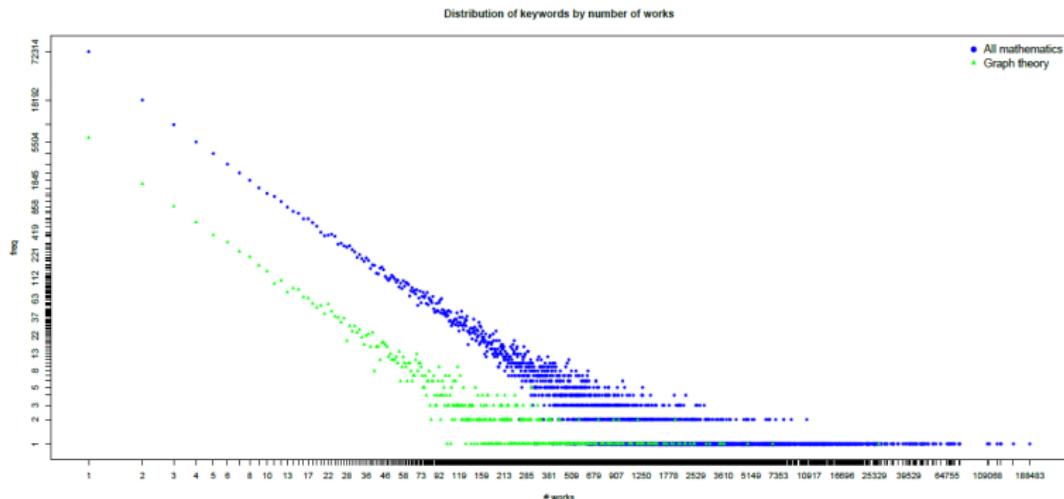
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Standardized citation network

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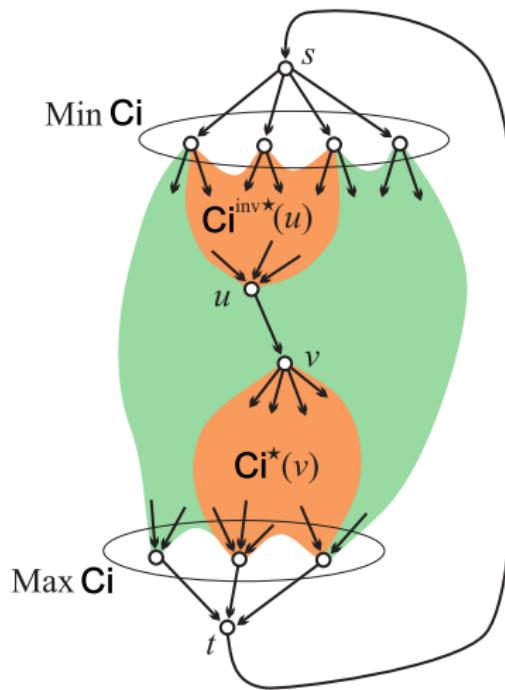
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We assume that the citation relation \mathbf{Ci} is acyclic. It is useful to transform a citation network to its *standardized* form by adding a common *source* node $s \notin W$ and a common *sink* node $t \notin W$. The source s is linked by an arc to all minimal elements of \mathbf{Ci} ; and all maximal elements of \mathbf{Ci} are linked to the sink t . We add also the ‘feedback’ arc (t, s) .

Search path count method

Hummon and Doreian

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The *search path count* (SPC) method is based on counters $n(u, v)$ that count the number of different paths from s to t through the arc (u, v) . To compute $n(u, v)$ we introduce two auxiliary quantities: $n^-(v)$ counts the number of different paths from s to v , and $n^+(v)$ counts the number of different paths from v to t . Then

$$n(u, v) = n^-(u) \cdot n^+(v)$$

There exists a very efficient algorithm to compute counters $n^-(v)$ and $n^+(v)$.

The quantities used to compute the arc weights n can be used also to define the corresponding *node weight* t_c

$$t_c(u) = n^-(u) \cdot n^+(u)$$

It is counting the number of paths through the node u .

Properties of SPC weights

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The values of counters $n(u, v)$ form a flow in the citation network – the *Kirchoff's vertex law* holds: For every node u in a standardized citation network $\text{incoming flow} = \text{outgoing flow}$:

$$\sum_{v: v \text{ Ci } u} n(v, u) = \sum_{v: u \text{ Ci } v} n(u, v) = n^-(u) \cdot n^+(u) = t_c(u)$$

The weight $n(t, s)$ equals to the total flow through network and provides a natural normalization of weights

$$w(u, v) = \frac{n(u, v)}{n(t, s)} \quad \Rightarrow \quad 0 \leq w(u, v) \leq 1$$

and if C is a minimal arc-cut-set $\sum_{(u,v) \in C} w(u, v) = 1$.

In large networks the values of weights can grow very large. This should be considered in the implementation of the algorithms.

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The standard approach to find interesting groups inside a network was based on properties/weights – they can be *measured* or *computed* from network structure (for example Kleinberg's **hubs and authorities**).

The *node-cut* of a network $\mathcal{N} = (\mathcal{V}, \mathcal{L}, p)$, $p : \mathcal{V} \rightarrow \mathbb{R}$, at selected level t is a subnetwork $\mathcal{N}(t) = (\mathcal{V}', \mathcal{L}(\mathcal{V}'), p)$, determined by the set

$$\mathcal{V}' = \{v \in \mathcal{V} : p(v) \geq t\}$$

and $\mathcal{L}(\mathcal{V}')$ is the set of links from \mathcal{L} that have both endnodes in \mathcal{V}' .

The *link-cut* of a network $\mathcal{N} = (\mathcal{V}, \mathcal{L}, w)$, $w : \mathcal{L} \rightarrow \mathbb{R}$, at selected level t is a subnetwork $\mathcal{N}(t) = (\mathcal{V}(\mathcal{L}'), \mathcal{L}', w)$, determined by the set

$$\mathcal{L}' = \{e \in \mathcal{L} : w(e) \geq t\}$$

and $\mathcal{V}(\mathcal{L}')$ is the set of all endnodes of the links from \mathcal{L}' .

```
File/Network/read eatRS.net
Info/Network/Line values ... >= 70
Net/Transform/Remove/Lines with Value/lower than    70
Net/Partitions/Degree/All
Operations/Extract from Network/Partition    1-*
Net/Components/Weak
Draw/Draw-Partition
```

Citation weights

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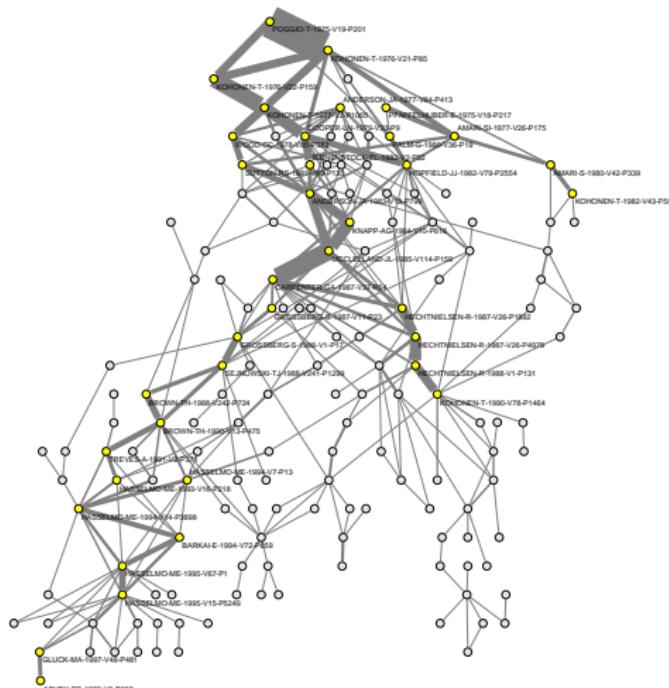
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Main subnetwork (arc cut at level 0.007) of the SOM (selforganizing maps) citation network (4470 nodes, 12731 arcs). See [paper](#).

Cores and generalized cores

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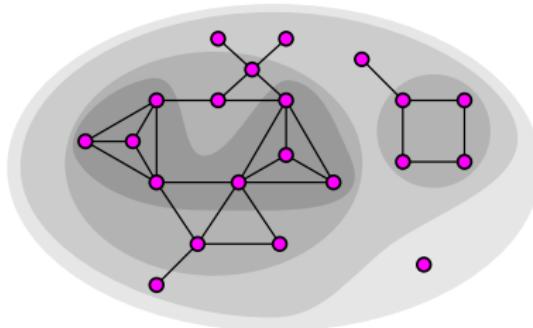
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The notion of core was introduced by Seidman in 1983. Let $\mathcal{G} = (\mathcal{V}, \mathcal{E})$ be a graph. A subgraph $\mathcal{H} = (\mathcal{C}, \mathcal{E}|_{\mathcal{C}})$ induced by the set \mathcal{C} is a ***k*-core** or a ***core of order k*** iff $\forall v \in \mathcal{C} : \deg_{\mathcal{H}}(v) \geq k$, and \mathcal{H} is a maximal subgraph with this property. The core of maximum order is also called the ***main*** core.

The ***core number*** of a node v is the highest order of a core that contains this node. The degree $\deg(v)$ can be: in-degree, out-degree, in-degree + out-degree, etc., determining different types of cores.

Properties of cores

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From the figure, representing 0, 1, 2 and 3 core, we can see the following properties of cores:

- The cores are nested: $i < j \implies \mathcal{H}_j \subseteq \mathcal{H}_i$
- Cores are not necessarily connected subgraphs.

An efficient algorithm for determining the cores hierarchy is based on the following property:

If from a given graph $\mathcal{G} = (\mathcal{V}, \mathcal{E})$ we recursively delete all nodes, and edges incident with them, of degree less than k , the remaining graph is the k -core.

... Properties of cores

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The cores, because they can be determined very efficiently, are one among few concepts that provide us with meaningful decompositions of large networks. We expect that different approaches to the analysis of large networks can be built on this basis. For example: we get the following bound on the chromatic number of a given graph \mathcal{G}

$$\chi(\mathcal{G}) \leq 1 + \text{core}(\mathcal{G})$$

Cores can also be used to localize the search for interesting subnetworks in large networks since: if it exists, a k -component is contained in a k -core; and a k -clique is contained in a k -core.
For details see the [paper](#).

Generalized cores

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The notion of core can be generalized to networks. Let $\mathcal{N} = (\mathcal{V}, \mathcal{E}, w)$ be a network, where $\mathcal{G} = (\mathcal{V}, \mathcal{E})$ is a graph and $w : \mathcal{E} \rightarrow \mathbb{R}$ is a function assigning values to edges. A *node property function* on \mathbf{N} , or a *p-function* for short, is a function $p(v, U)$, $v \in \mathcal{V}$, $U \subseteq \mathcal{V}$ with real values. Let $N_U(v) = N(v) \cap U$. Besides degrees and (corrected) clustering coefficient, here are some examples of *p-functions*:

$$p_S(v, U) = \sum_{u \in N_U(v)} w(v, u), \text{ where } w : \mathcal{E} \rightarrow \mathbb{R}_0^+$$

$$p_M(v, U) = \max_{u \in N_U(v)} w(v, u), \text{ where } w : \mathcal{E} \rightarrow \mathbb{R}$$

$$p_k(v, U) = \text{number of cycles of length } k \text{ through the node } v \text{ in } (U,$$

The subgraph $\mathcal{H} = (C, \mathcal{E}|_C)$ induced by the set $C \subseteq \mathcal{V}$ is a *p-core at level* $t \in \mathbb{R}$ iff $\forall v \in C : t \leq p(v, C)$ and C is a maximal such set.

Additional p -functions

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relative density

$$p_\gamma(v, \mathcal{C}) = \frac{\deg(v, \mathcal{C})}{\max_{u \in N(v)} \deg(u)}, \text{ if } \deg(v) > 0; 0, \text{ otherwise}$$

diversity

$$p_\delta(v, \mathcal{C}) = \max_{u \in N^+(v, \mathcal{C})} \deg(u) - \min_{u \in N^+(v, \mathcal{C})} \deg(u)$$

average weight

$$p_a(v, \mathcal{C}) = \frac{1}{|N(v, \mathcal{C})|} \sum_{u \in N(v, \mathcal{C})} w(v, u), \text{ if } N(v, \mathcal{C}) \neq \emptyset; 0, \text{ otherwise}$$

Generalized cores algorithm

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The function p is *monotone* iff it has the property

$$C_1 \subset C_2 \Rightarrow \forall v \in \mathcal{V} : (p(v, C_1) \leq p(v, C_2))$$

The degrees and the functions p_S , p_M and p_k are monotone. For a monotone function the p -core at level t can be determined, as in the ordinary case, by successively deleting nodes with value of p lower than t ; and the cores on different levels are nested

$$t_1 < t_2 \Rightarrow \mathcal{H}_{t_2} \subseteq \mathcal{H}_{t_1}$$

The p -function is *local* iff $p(v, U) = p(v, N_U(v))$.

The degrees, p_S and p_M are local; but p_k is **not** local for $k \geq 4$. For a local p -function an $O(m \max(\Delta, \log n))$ algorithm for determining the p -core levels exists, assuming that $p(v, N_C(v))$ can be computed in $O(\deg_C(v))$.

For details see the [paper](#).

Cores and generalized cores / Pajek commands

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```
File/Network/Read [Geom.net]
Net/Partitions/Core/All
Info/Partition
Operations/Extract from Network/Partition [13-*]
Draw/Draw-Partition
Layout/Energy/Kamada-Kawai
Options/Values of lines/Similarities
Layout/Energy/Kamada-Kawai
Operations/Extract from Network/Partition [21]
Draw
Layout/Energy/Kamada-Kawai
Options/Values of lines/Forget
Layout/Energy/Kamada-Kawai
[select Geom.net]
Net/Vector/PCore/Sum/All
Info/Vector
Vector/Make Partition/by Intervals/Selected Thresholds [45]
Info/Partition
Operations/Extract from Network/Partition [2]
Draw
Options/Values of lines/Similarities
Layout/Energy/Fruchterman-Reingold
```

Cores of orders 10–21 in Computational Geometry

Bibliographic networks

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Two-mode Ns

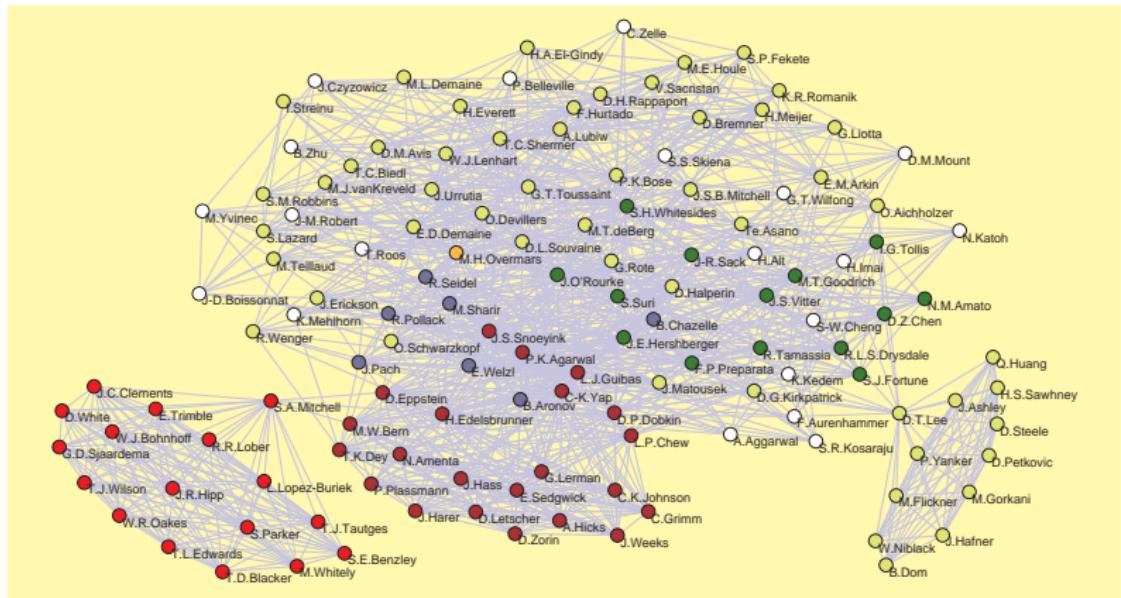
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p_S -core at level 46 in Computational Geometry network

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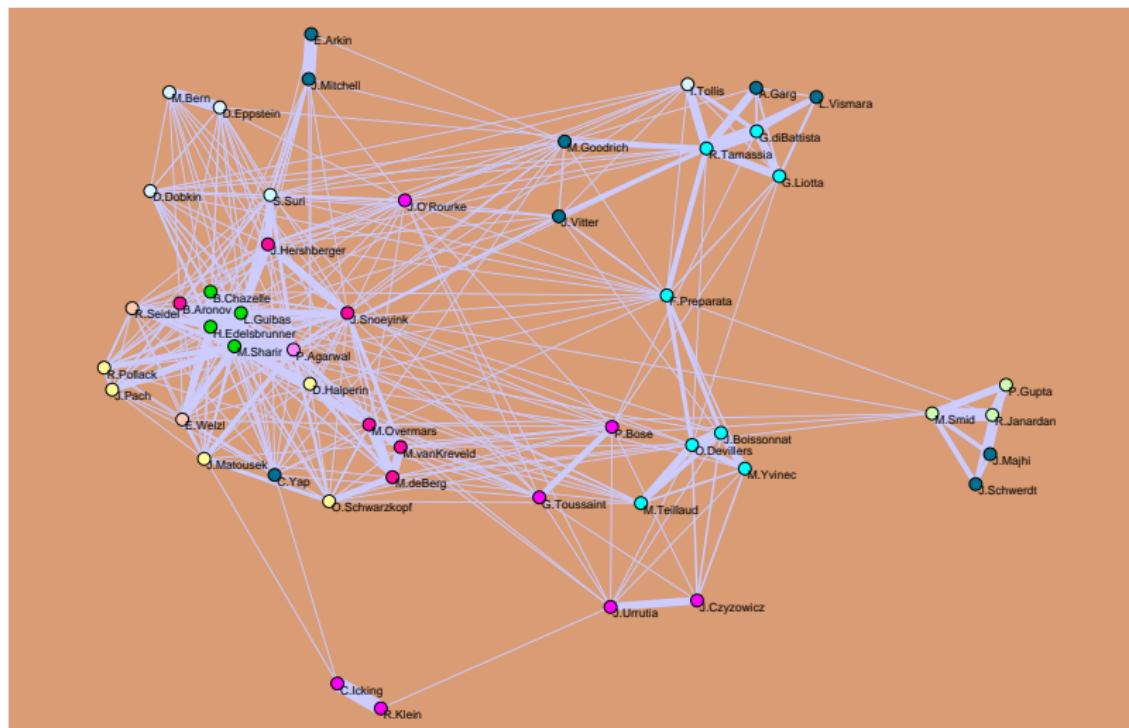
Multiplication

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Islands

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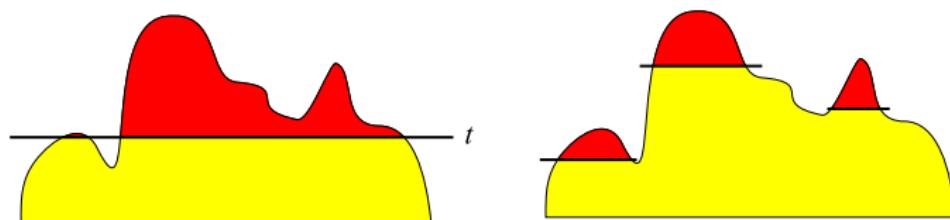
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If we represent a given or computed value of nodes / links as a height of nodes / links and we immerse the network into a water up to selected level we get *islands*. Varying the level we get different islands.



We developed very efficient algorithms to determine the islands hierarchy and to list all the islands of selected sizes.
See [details](#).

... Islands

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Islands are very general and efficient approach to determine the 'important' subnetworks in a given network.

We have to express the goals of our analysis with a related property of the nodes or weight of the links. Using this property we determine the islands of an appropriate size (in the interval k to K).

In large networks we can get many islands which we have to inspect individually and interpret their content.

An important property of the islands is that they identify locally important subnetworks on different levels. Therefore they detect also emerging groups.

The set of nodes $\mathcal{C} \subseteq \mathcal{V}$ is a *local node peak*, if it is a regular node island and all of its nodes have the same value. Node island with a single local node peak is called a *simple node island*. In similar way we define simple link island.

... Islands

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A set of nodes $C \subseteq \mathcal{V}$ is a *regular node island* in a network $\mathcal{N} = (\mathcal{V}, \mathcal{L}, p)$, $p : \mathcal{V} \rightarrow \mathbb{R}$ iff it induces a connected subgraph and the nodes from the island are 'higher' than the neighboring nodes

$$\max_{u \in N(C)} p(u) < \min_{v \in C} p(v)$$

A set of nodes $C \subseteq \mathcal{V}$ is a *regular link island* in a network $\mathcal{N} = (\mathcal{V}, \mathcal{L}, w)$, $w : \mathcal{L} \rightarrow \mathbb{R}$ iff it induces a connected subgraph and the links inside the island are 'stronger related' among them than with the neighboring nodes – in \mathcal{N} there exists a spanning tree \mathcal{T} over C such that

$$\max_{(u,v) \in \mathcal{L}, u \notin C, v \in C} w(u,v) < \min_{(u,v) \in \mathcal{T}} w(u,v)$$

Network/Create Partition/Islands/Line Weights
Operations/Network+Vector/Islands/Vertex Property

Some properties of islands

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- The sets of nodes of connected components of node/link-cut at selected level t are regular node/link islands.
- The set $\mathcal{H}_p(\mathcal{N})$ of all regular node islands of a network \mathcal{N} is a complete hierarchy:
 - two islands are disjoint or one of them is a subset of the other
 - each node belongs to at least one island
- The set $\mathcal{H}_w(\mathcal{N})$ of all nondegenerated regular link islands of a network \mathcal{N} is a hierarchy (not necessarily complete):
 - two islands are disjoint or one of them is a subset of the other
 - Node/link islands are invariant for the strictly increasing transformations of the property p / weight w .
 - Two linked nodes cannot/may belong to two disjoint regular node/link islands.

A *simple island* is an island with only one peak.



US patents

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US patents network ([Nber, US Patents](#)) has 3774768 nodes and 16522438 arcs (1 loop). Without the loop it is acyclic. The weight of an arc is the proportion of paths through the arc from some initial node to some terminal node. We determined all (2,90)-link islands. The corresponding subnetwork has 470137 nodes, 307472 arcs and different k : $C_2 = 187610$, $C_5 = 8859$, $C_{30} = 101$, $C_{50} = 30$, ... islands. [Rolex](#)

[1]	0	139793	29670	9288	3966	1827	997	578	362	250
[11]	190	125	104	71	47	37	36	33	21	23
[21]	17	16	8	7	13	10	10	5	5	5
[31]	12	3	7	3	3	3	2	6	6	2
[41]	1	3	4	1	5	2	1	1	1	1
[51]	2	3	3	2	0	0	0	0	0	1
[61]	0	0	0	0	1	0	0	2	0	0
[71]	0	0	1	1	0	0	0	1	0	0
[81]	2	0	0	0	0	1	2	0	0	7

The [Main path](#) starts in a link with the largest SPC weight and expands in both directions following the adjacent link with the largest SPC weight.

The [CPM path](#) is determined using the Critical Path Method from Operations Research (the sum of SPC weights along a path is maximal).



Distribution of island size

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Two-mode Ns

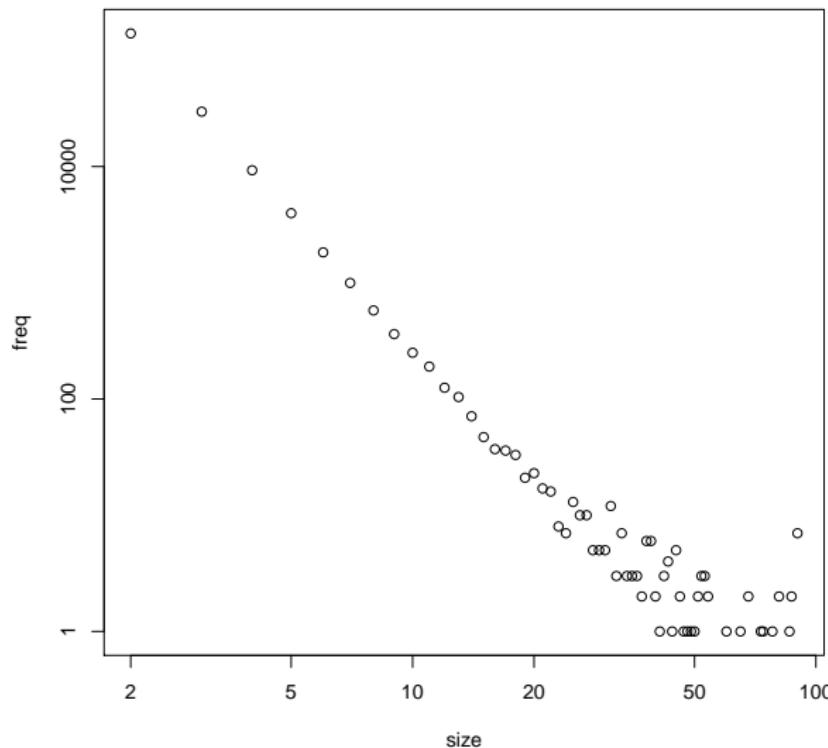
Multiplication

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Main path and main island in US Patents

Nber, US Patents; $n = 3774768$, $m = 16522438$

Bibliographic networks

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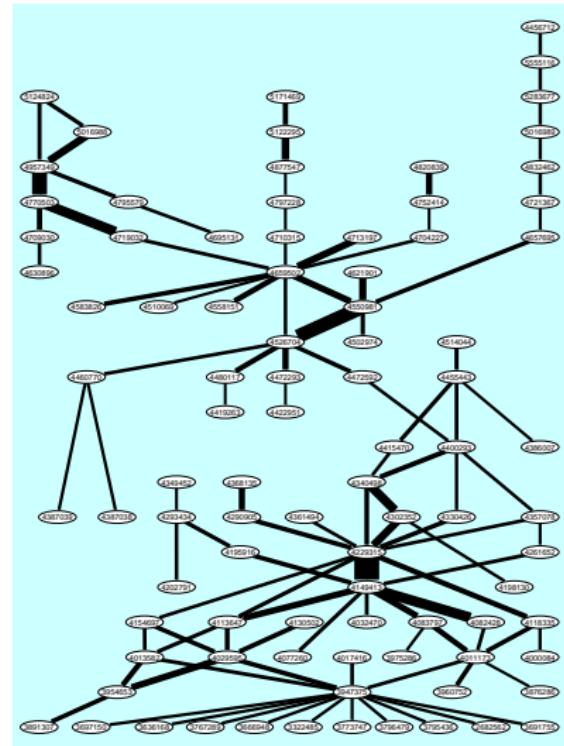
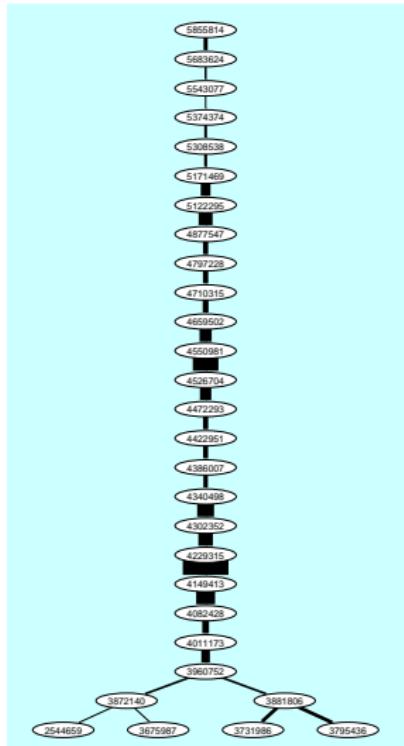
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Main island – Liquid crystal display

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Table 1: Patents on the liquid-crystal display

patent	date author(s) and title
2544069	Mar 13, 1964 Dreyer, Delecke light polarizing sheet and the like and the method of making same
2682762	Jun 29, 1964 Wunder, et al. Reduction of aromatic carbamate
3322485	May 30, 1967 Willisau, Electro-optical elements utilizing an organic
3636168	Jan 18, 1972 Josephson, Preparation of polymeric aromatic compounds
3660048	May 30, 1972 Hirai, Liquid crystal compositions and devices having an undisturbed layer on a distorted background
3675087	Jul 11, 1972 Hirai, Liquid crystal compositions and devices
3693150	Oct 10, 1972 Wysotski, Electro-optic systems in which an electrophoretic or dipolar material is dispersed throughout a liquid medium and the like
3731986	May 8, 1973 Ferguson, Display device utilizing liquid crystal light
3767280	Oct 23, 1973 Aizawa, et al. Class of stable trans-stilbene compounds, some displaying nematic mesophases at or near room temperature and useful as liquid crystal materials
3772737	Nov 20, 1973 Sotomatsu, Substituted azoxy benzene compounds
3795436	Mar 5, 1974 Boller, et al. Nonaromatic material which exhibits the Kerr effect
3796749	Mar 12, 1974 Boller, et al. Electro-optical liquid-mechanism which exhibits the Kerr effect at isotropic temperatures
3872140	Mar 18, 1975 Klauderian, et al. Liquid crystalline compositions and methods of preparing same
3876286	Apr 8, 1975 Dontcher, et al. Use of nematic liquid crystal substances
3881486	May 6, 1975 Suzuki, Electro-optical display device
3901307	Jun 24, 1975 Takemoto, et al. Use of the voltage applied to opposite electrodes for a cholesteric to nematic phase transition
3947375	Mar 30, 1976 Goto, et al. Liquid crystal materials and devices
3954653	May 4, 1976 Yamamoto, Liquid crystal composition having high dielectric constant
3960752	Jun 1, 1976 Klauderian, et al. Liquid crystal compositions
3975286	Aug 17, 1976 Oil, Low viscosity liquid crystal compositions
4000094	Dec 28, 1976 Hoek, et al. Novel liquid crystal compositions and method of preparing same
4011173	Mar 8, 1977 Sotomatsu, Modified nematic substance with positive dielectric anisotropy
4013582	Mar 22, 1977 Klauderian, et al. Liquid crystal compounds and electro-optic devices incorporating them
4074316	Apr 12, 1977 Takemoto, et al. Polyesters of 4-alkyl-4'-phenylbenzoic acids, method for preparing same and liquid crystal compositions using same
4029595	Jun 14, 1977 Bilous, et al. Novel liquid crystal compounds and electro-optic devices incorporating them
4032170	Jun 26, 1977 Bilous, et al. Electro-optic device
4077260	Mar 7, 1978 Hsu, Liquid crystal compositions containing cyano-biphenyl compounds and liquid crystal materials containing them
4082428	Apr 4, 1978 Hsu, Liquid crystal composition and method

Table 2: Patents on the liquid-crystal display

patent	date author(s) and title
4083876	Aug 11, 1978 Ob, Nematic liquid crystal compositions
4118232	Oct 3, 1978 Krause, et al. Liquid crystalline materials of reduced viscosity
4138320	Dec 19, 1978 Eldenbaek, et al. Liquid crystalline cyclohexane derivatives
4139412	Apr 17, 1979 Eldenbaek, et al. Liquid crystalline cyclohexane derivatives and liquid crystal devices containing them
4154007	May 15, 1979 Eldenbaek, et al. Liquid crystalline hexadecyldiphenyl derivatives
4159516	Aug 1, 1979 Coates, et al. Liquid crystal compounds
4162150	Aug 15, 1979 Sato, et al. Nematic liquid crystal materials
4202779	May 13, 1980 Sato, et al. Nematic liquid crystalline cyclodiene derivatives
4263452	Oct 14, 1980 Gray, et al. Liquid crystalline compounds and materials and devices containing them
4290005	Sep 22, 1980 Eldenbaek, et al. Liquid crystal compounds
4293434	Oct 6, 1980 Eldenbaek, et al. Fluorophenoxyphenylcyclohexane, the preparation of liquid crystal dyes and liquid crystal devices
4302356	Oct 24, 1980 Eldenbaek, et al. Cyclohexylbiphenyl, their preparation and use in dielectric and electrooptical display elements
4304248	May 18, 1981 Eldenbaek, et al. Liquid crystal compositions containing an alkylene ring and exhibiting a low dielectric anisotropy and liquid crystal materials and devices incorporating such compounds
4308135	Nov 20, 1981 Klauderian, et al. Liquid crystal compositions containing an amine. Anisotropic compounds with negative or positive DC-anisotropy and low optical anisotropy
4340067	Jul 20, 1982 Oman, et al. Cyclohexylbiphenyl derivatives
4349452	Sep 5, 1982 Oman, et al. Cyclohexylbiphenyl derivatives
4357070	Nov 2, 1982 Eldenbaek, et al. Liquid crystal compositions containing an alkylene ring and exhibiting a low dielectric anisotropy and liquid crystal materials and devices incorporating such compounds
4361454	Nov 30, 1982 Klauderian, et al. Liquid crystal compositions containing an amine. Anisotropic compounds with negative or positive DC-anisotropy and low optical anisotropy
4368135	Jan 11, 1983 Krause, et al. Liquid crystal compositions containing an amine
4369007	Mar 21, 1983 Oman, Anisotropic compounds with negative or positive DC-anisotropy and low optical anisotropy
4376703	Jun 7, 1983 Fukut, et al. 4-(Trans-4'-alkylbiphenyl) benzoic acid
4387039	Jun 7, 1983 Suzuki, et al. Trans-4-(trans-4'-alkylbiphenyl)-cyclohexane carboxylic acid 4'-cyanoaliquenyl ester
4406252	Aug 23, 1983 Eldenbaek, et al. Liquid crystalline fluorine-containing cyclohexylbiphenyl and dextroscopic and electro-optical display elements
4415470	Nov 15, 1983 Eldenbaek, et al. Liquid crystalline fluorine-containing cyclohexylbiphenyl and dextroscopic and electro-optical display elements
4422953	Feb 14, 1984 Przeofnicki, et al. Liquid crystalline cyclohexylcarboxylic acid
4422954	Feb 14, 1984 Przeofnicki, et al. Liquid crystalline cyclohexylcarboxylic acid
4422955	Feb 14, 1984 Suzuki, et al. Liquid crystal benzene derivatives
4455443	Jun 19, 1984 Takemoto, et al. Nematic liquid Compon
4457227	Jul 17, 1984 Petzrikka, et al. Liquid crystal
4460870	Jul 17, 1984 Petzrikka, et al. High temperature liquid crystal substances of the same
4472295	Sep 18, 1984 Takemoto, et al. Nematic liquid crystal compositions
4472502	Sep 18, 1984 Takemoto, et al. Nematic liquid crystal compositions
4492954	Mar 5, 1985 Hsu, High temperature liquid-crystalline ester compounds
4502974	Mar 5, 1985 Hsu, Liquid crystal composition and method
4510003	Aug 9, 1985 Eldenbaek, et al. Cyclohexane derivatives

Table 3: Patents on the liquid-crystal display

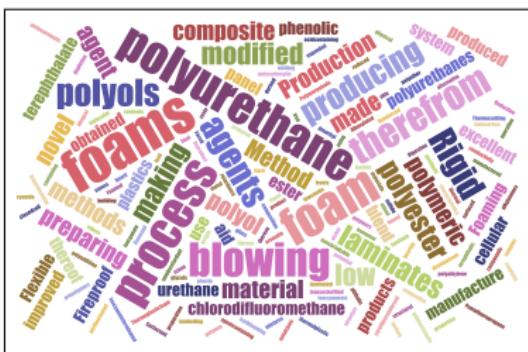
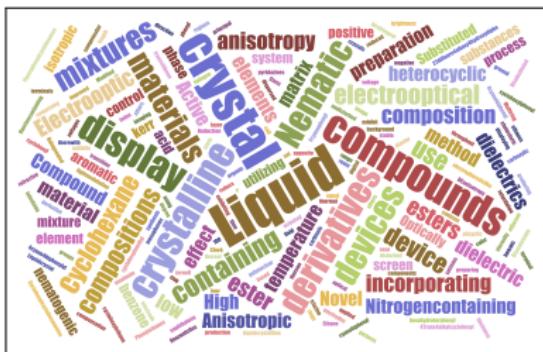
patent	date author(s) and title
4534644	Apr 20, 1985 Grajeda, et al. 1-(trans-4-alkylcyclohexyl)-2-(trans-4-(p-ethylphenyl)cyclohexyl)benzene and its use in liquid crystal mixtures
4535704	Jul 2, 1985 Petzrikka, et al. Multilayer liquid crystal esters
4550861	Nov 5, 1985 Petzrikka, et al. Liquid crystalline esters and mixtures
4553636	Apr 22, 1986 Petzrikka, et al. Plastic ketones
4553637	Apr 22, 1986 Petzrikka, et al. Plastic ketone compounds
4583001	Nov 11, 1986 Saito, et al. Novel liquid crystal mixtures
4583002	Dec 16, 1986 Saito, et al. Novel liquid crystal mixtures
4587395	Apr 14, 1987 Saito, et al. Substituted pyridazines
4592150	May 11, 1987 Balkwill, et al. Diheteriated ethanes and their use in liquid crystal mixtures and devices
4605131	Sep 22, 1987 Balkwill, et al. Diheteriated ethanes and their use in liquid crystal mixtures and devices
4704227	Nov 3, 1987 Schaff, et al. Liquid crystal compounds
4709030	Nov 24, 1987 Petzrikka, et al. Novel liquid crystal mixture
4710115	Dec 1, 1987 Schaff, et al. Aromatic compounds and liquid crystal
4713197	Dec 15, 1987 Eldenbaek, et al. Nitrogen-containing heterocyclic compounds
4717261	Jan 21, 1988 Yoshimura, et al. Liquid crystal device
4723414	Jan 21, 1988 Eldenbaek, et al. Nitrogen-containing heterocyclic compounds
4725180	Jan 21, 1988 Vaschke, et al. Liquid crystal devices
4735279	Jan 3, 1989 Vaschke, et al. 2,2-dithiobis-4-alkyl-1-hydroxybiphenyl and their derivatives and processes for producing and using in liquid crystal display devices
4737228	Jan 10, 1989 Goto, et al. Cyclohexane derivative and liquid crystal
4740339	Apr 11, 1989 Krause, et al. Nitrogen-containing heterocyclic esters
4742190	Apr 25, 1989 Clark, et al. Liquid crystal devices
4757147	Oct 12, 1989 Chen, et al. Active matrix screen for the color display of television pictures, control system and process for producing said screen
4757349	Sep 18, 1989 Imura, Liquid crystal display device with a brightener
5010988	May 21, 1991 Komaki, et al. Matrix liquid crystal display
5010989	May 21, 1991 Okada, Liquid crystal element with improved contrast and brightness
5122295	Jun 16, 1992 Hirata, et al. Matrix liquid crystal display
5124924	Jan 12, 1992 Komaki, et al. Liquid crystal display device comprising a liquid crystal polymer having a maximum transmission wavelength in the thickness direction
5171469	Dec 15, 1992 Hirata, et al. Liquid crystal matrix display
5203837	Feb 1, 1994 Hirata, et al. Liquid crystal matrix display
5205980	Feb 1, 1994 Hirata, et al. Liquid crystal matrix display
5237074	May 3, 1994 Wolter, et al. Superlattice liquid-crystal display
5240760	May 10, 1994 Binger, et al. Liquid crystal display
5353077	Aug 6, 1996 Binger, et al. Nematic liquid-crystal composition
5353116	Sep 10, 1996 Binger, et al. Nematic liquid-crystal composition having adjacent electrode terminals set equal in length
5600324	Sep 4, 1997 Seiguraku, et al. Liquid crystal composition
5600324	Sep 4, 1997 Seiguraku, et al. Liquid crystal composition and liquid crystal display elements

Word clouds for LCD island and foam island

Bibliographic networks

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- Networks
- Statistics
- Citation**
- Two-mode Ns
- Multiplication
- Derived Ns
- Temporal Ns
- References
- Appendix



Main SPC island in SN5

Bibliographic networks

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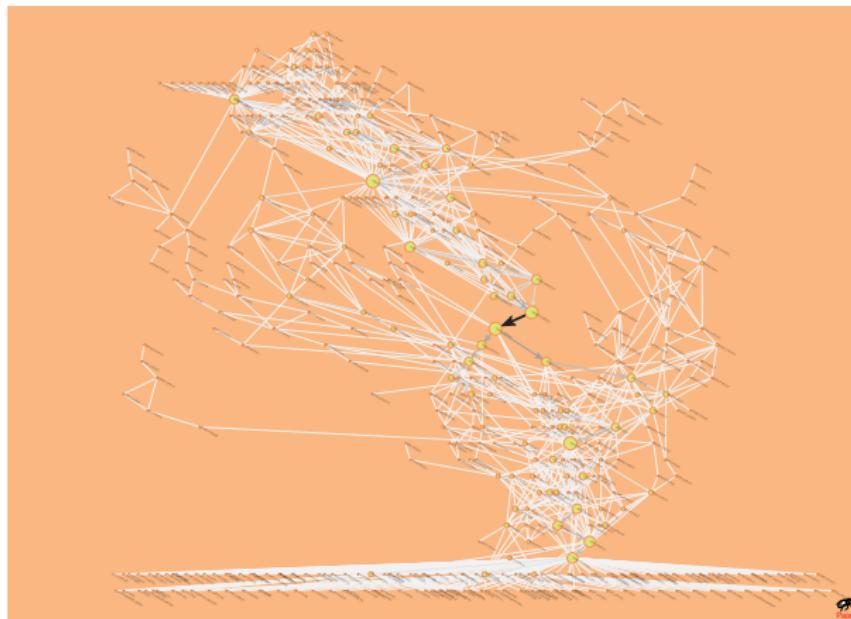
Derived Ns

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Appendix

Network SN5 (2008): for "social network*" + most frequent references + around 100 social networkers;
 $|W| = 193376, |C| = 7950, |A| = 75930, |J| = 14651, |K| = 29267$. Citation networks are acyclic.
Acyclic networks can be displayed by levels – run macro Layers1.mcr from the map Geneo.



PEERE – Main path

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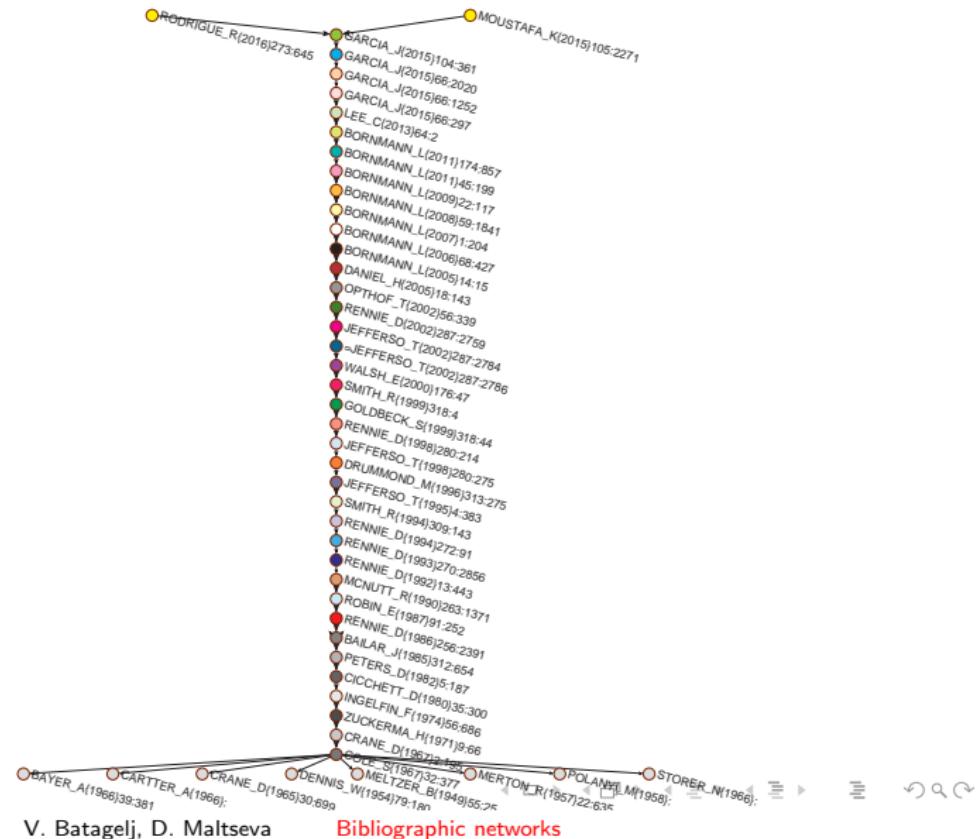
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List of publications on main path

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	year	first author	title	journal
	1949	Meltzer BN	The productivity of social scientists	AmJSociol
	1954	Dennis W	Bibliographies of eminent scientists	ScientificM
	1957	Merton RK	Priorities in scientific discovery - a chapter in the sociology of sci...	AmSocSciRev
	1958	Polanyi M	Personal Knowledge: Towards a Post-Critical Philosophy	UPChicago
Networks	1965	Crane D	Scientists at major and minor universities	AmSocSciRev
Statistics	1966	Bayer AE	Some correlates of citation measure of productivity in science	SociolEduc
Citation	1966	Storer NW	The Social System of Science	HRW
	1966	Cartter A	An Assessment of Quality in Graduate Education	ACE
	1967	Crane D	Gatekeepers of science - some factors affecting selection...	AmSociol
	1967	Cole S	Scientific output and recognition - study in operation of reward...	AmSocSciRev
Two-mode Ns	1971	Zuckerman H	Patterns of evaluation in science - institutionalisation, struct...	Minerva
Multiplication	1974	Ingelfinger FJ	Peer review in biomedical publication	AmJMed
Derived Ns	1980	Cicchetti DV	Reliability of reviews for the american-psychologist	AmPsychol
Temporal Ns	1982	Peters DP	Peer-review practices of psychological journals - the fate...	BehavBrainS
References	1985	Bailar JC	Journal peer-review - the need for a research agenda	NewEnglJMe
	1986	Rennie D	Guarding the guardians - a conference on editorial peer-review	Jama
	1987	Robin ED	Peer-review in medical journals	Chest
	1990	Mcnutt RA	The effects of blinding on the quality of peer-review	Jama
	1992	Rennie D	Suspended judgment - editorial peer-review - let us put it on trial	ControlClinT
Appendix	1993	Rennie D	More peering into editorial peer-review	Jama
	1994	Rennie D	The 2nd international-congress on peer-review in biomedical...	Jama
	1994	Smith R	Promoting research into peer-review	BritMedJ
	1995	Jefferson T	Are guidelines for peer-reviewing economic evaluations necessary	HealthEcon
	1996	Drummond M	Guidelines for authors and peer reviewers of economic submis...	BritMedJ
	1998	Jefferson T	Evaluating the BMJ guidelines for economic submissions	Jama
	1998	Rennie D	Peer review in Prague	Jama

List of works on main path cont.

Bibliographic networks

V. Batagelj,
D. Maltseva

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Appendix

	year	first author	title	journal
	1999	Smith R	Opening up BMJ peer review - A beginning that should lead to...	BritMedJ
	1999	Goldbeck-W. S	Evidence on peer review - scientific quality control or smokescreen?	BritMedJ
	2000	Walsh E	Open peer review: a randomised controlled trial	BritJPsych
	2002	Jefferson T	Effects of editorial peer review - A systematic review	Jama
	2002	Rennie D	Fourth International Congress on Peer Review in Biomedical Pub...	Jama
	2002	Ophof T	The significance of the peer review process against . . . bias	Cardiovasc
	2002	Jefferson T	Measuring the quality of editorial peer review	Jama
	2005	Bornmann L	Committee peer review at an international research foundation	ResEvaluat
	2005	Daniel HD	Publications as a measure of scientific advancement and of...	LearnPubl
	2006	Bornmann L	Selecting scientific excellence through committee peer review	Scientometr
	2007	Bornmann L	Convergent validation of peer review decisions using the h index	JInformetr
	2008	Bornmann L	Selecting manuscripts for a high-impact journal through peer review	JAmSocInfr
	2009	Bornmann L	The luck of the referee draw: the effect of exchanging reviews	LearnPubl
	2011	Bornmann L	Scientific Peer Review	AnnuRevIn
	2011	Bornmann L	A multilevel modelling approach to investigating the predictive...	JRStatSoc
	2013	Lee CJ	Bias in peer review	JAmSocInfr
	2015	Garcia JA	The Principal-Agent Problem in Peer Review	JAssocInfr
	2015	Garcia JA	Adverse selection of reviewers	JAssocInfr
	2015	Garcia JA	Bias and effort in peer review	JAssocInfr
	2015	Garcia JA	The author-editor game	Scientometr
	2015	Moustafa K	Don't infer anything from unavailable data	Scientometr
	2016	Rodriguez-S. R	Evolutionary games between authors and their editors	ApplMathO

The main path publications

Phases

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Appendix

- before 1982: social science journals;
- from 1982 to 2002: biomedical journals;
- after 2002: specialized journals on science studies.

The main path publications till 1982

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Appendix

Journals: social science journals (sociological, psychological, educational,...) and three books.

The most **influential authors:** Meltzer (1949), Dennis (1954), Merton (1957), Polany (1958), Crane (1965, 1967), Bayer and Folger (1966), Storer (1966), Cartter (1966), Cole and Cole (1967), Zuckerman and Merton (1971), Ingelfinger (1974), Cicchetti (1980) and Peters and Ceci (1982).

Topics: scientific productivity, bibliographies, knowledge, citation measures as measures of scientific accomplishment, scientific output and recognition, evaluation in science, referee system, journal evaluation, peer-evaluation system, review process, peer review practices.

The main path publications from 1983 to 2002

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Journals: biomedical journals, mainly JAMA. From 1986 the International Congress on Peer Review and Biomedical Publication is organized every four years.

The most **influential authors:** Rennie (1986, 1992, 1993, 1994, 1998, 2002), Smith (1994, 1999), Jefferson (1995, 1998, 2002), and their collaborators.

Topics: the effects of blinding on review quality, research into peer review, guidelines for peer reviewing, monitoring the peer review performance, open peer review, bias in peer review system, measuring the quality of editorial peer review. Development of meta-analysis and systematic reviews studies of peer-review.

The main path publications from 2003 on

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Journals: specialized journals on science studies: Scientometrics, Research Evaluation, Journal of Informetrics, JASIST.

The most **influential authors:** Bornmann and Daniel (2005, 2006, 2007, 2008, 2009, 2011) and Garcia, Rodriguez-Sanchez and Fdez-Valdivia (4 papers in 2015, 2016). Others are Lee et al. (2013) and Moustafa (2015).

Topics: Bornmann and Daniel studied the validity of committee peer review process for awarding long-term fellowship to post-graduate researchers, the use of h-index and pre-screening of applications at Boehringer Ingelheim Fonds. They also analysed citations of accepted and rejected papers at a prime chemistry journal, the effect of exchanging reviews, the peer review process in this journal, the validity of its editorial decisions. The other papers studied bias in peer review, selection of reviewers, and the author-editor game.

PEERE – Main paths for 100 largest weights

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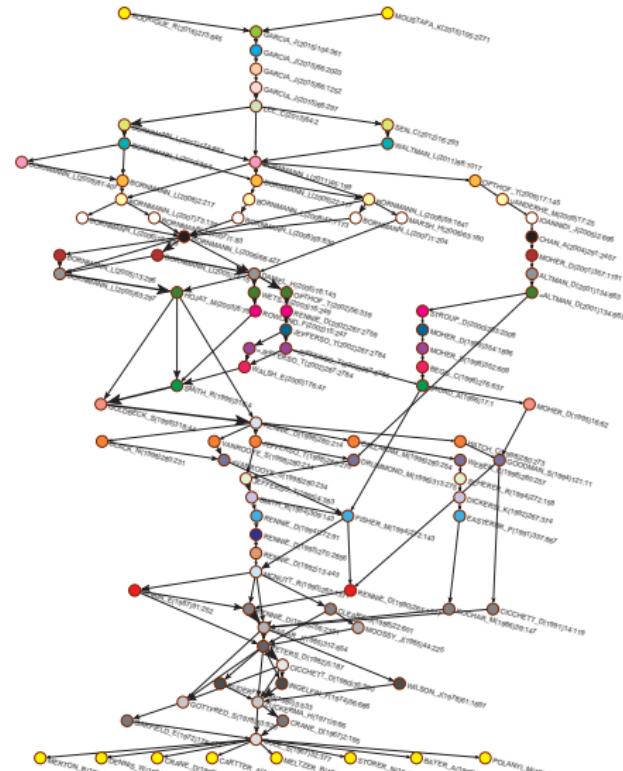
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PEERE – SPC link islands [20 200]

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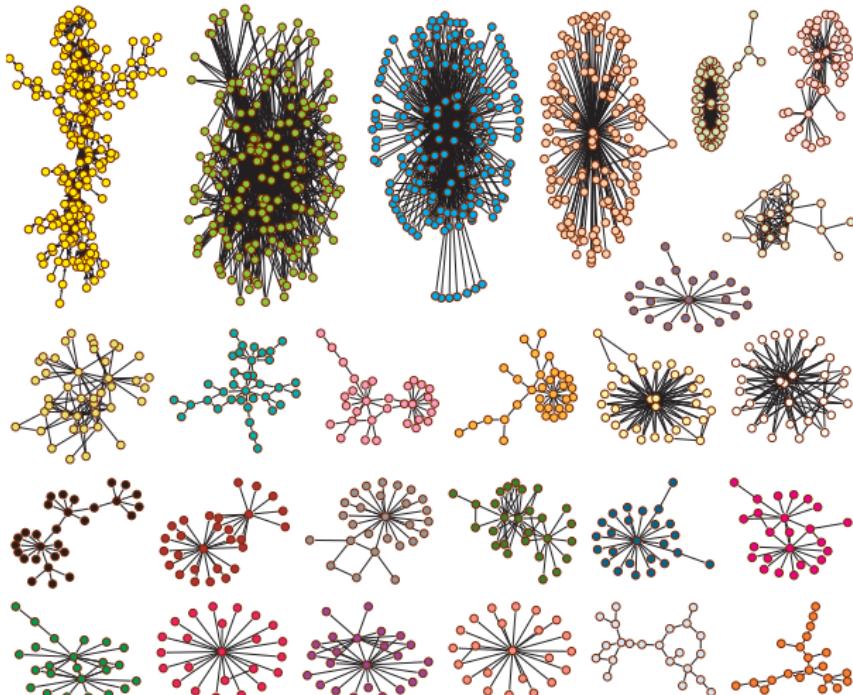
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PEERE – SPC – Link island1

$$w_{max} = 0.297$$

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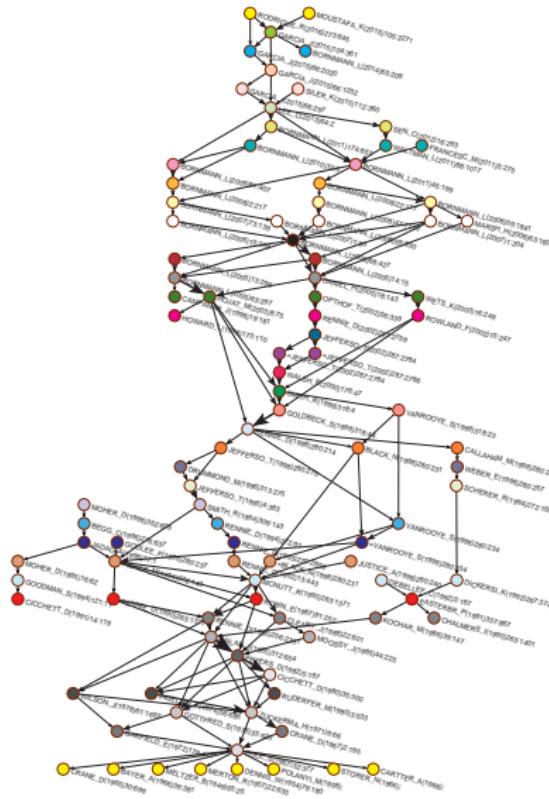
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This island is very similar to the main paths for 100 largest weights and includes main path.

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In a *two-mode* network $\mathcal{N} = ((\mathcal{U}, \mathcal{V}), \mathcal{L}, \mathcal{P}, \mathcal{W})$ the set of nodes consists of two disjoint sets of nodes \mathcal{U} and \mathcal{V} , and all the links from \mathcal{L} have one end-node in \mathcal{U} and the other in \mathcal{V} . Often also a *weight* $w : \mathcal{L} \rightarrow \mathbb{R} \in \mathcal{W}$ is given; if not, we assume $w(u, v) = 1$ for all $(u, v) \in \mathcal{L}$.

A two-mode network can also be described by a rectangular matrix $\mathbf{A} = [a_{uv}]_{\mathcal{U} \times \mathcal{V}}$.

$$a_{uv} = \begin{cases} w_{uv} & (u, v) \in \mathcal{L} \\ 0 & \text{otherwise} \end{cases}$$

Examples: (persons, societies, years of membership),
(buyers/consumers, goods, quantity),
(parliamentarians, problems, positive vote),
(persons, journals, reading),
(papers, keywords, is described by), etc.

Deep South

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Classical example of two-mode network are the Southern women (Davis 1941).

[Davis.paj](#). Freeman's overview.

NAME OF PARTICIPANTS OR GROUP I	CODE NUMBERS AND DATES OF SOCIAL EVENTS REPORTED IN <i>Old City Herald</i>													
	(1) 6/27	(2) 3/2	(3) 4/12	(4) 9/16	(5) 3/25	(6) 5/19	(7) 3/25	(8) 9/16	(9) 4/6	(10) 6/10	(11) 3/23	(12) 4/7	(13) 11/21	(14) 8/3
1. Mrs. Evelyn Jefferson.....	X	X	X	X	X	X	X	X
2. Miss Laura Mandeville.....	X	X	X	X	X	X	X	X
3. Miss Theresa Anderson.....		X	X	X	X	X	X	X	X
4. Miss Brenda Rogers.....			X	X	X	X	X	X	X
5. Miss Charlotte McDowell.....	X			X	X	X	X	X	X
6. Miss Frances Anderson.....			X	X	X	X	X	X	X
7. Miss Eleanor Nye.....				X	X	X	X	X	X
8. Miss Pearl Oglethorpe.....					X	X	X	X	X
9. Miss Ruth DeSand.....						X	X	X	X
10. Miss Verne Sanderson.....							X	X	X	X	X
11. Miss Myra Liddell.....								X	X	X	X	X
12. Miss Katherine Rogers.....									X	X	X	X	X
13. Mrs. Sylvia Avondale.....										X	X	X	X	X
14. Mrs. Norm Fayette.....										X	X	X	X	X
15. Mrs. Helen Lloyd.....										X	X	X	X	X
16. Mrs. Dorothy Murchison.....											X	X
17. Mrs. Olivia Carleton.....											X	X
18. Mrs. Flora Price.....											X	X

Approaches to two-mode network analysis

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The usual approach to analyze a two-mode network is to transform it to a one-mode network and use standard methods on it.

For direct analysis of two-mode networks we can use the *eigen-vector approach* – a two-mode variant of Kleinberg's hubs and authorities. The weight vector (\mathbf{x}, \mathbf{y}) on $\mathcal{U} \cup \mathcal{V}$ is determined by relations $\mathbf{y} = \mathbf{Ax}$ and $\mathbf{x} = \mathbf{A}^T \mathbf{y}$.

Network/2-Mode Network/Important Vertices

There are also special methods for *clustering* and *blockmodeling* in two-mode networks.

In this lecture we will present two additional direct methods: *two-mode cores* and *4-rings*.

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- 3. [Elizabethtown](#)
- 4. [Flightplan](#)
- 5. [In Her Shoes](#)
- ▶ more

Opening this Week

- [Doom](#)
- [Where the Truth Lies](#)
- [Kiss Kiss, Bang Bang](#)
- [Shopgirl](#)

The Internet Movie Database

Visited by over 30 million movie lovers each month!

Welcome to the Internet Movie Database, the biggest, best, most award-winning movie site on the planet. Want to make IMDb your home page? Drag [this link](#) onto your Home button.

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PITCH YOUR PICTURE.

You have the idea for your movie. You even have the poster. Now, [Honda Civic](#) and IMDb want you to "Pitch Your Picture." Submit your poster for your made-up movie, along with the tagline, and you may be eligible to be [entered into](#) our "Pitch Your Picture" competition (please note [game rules and restrictions](#)). We are now accepting submissions (voting will commence on the 14th). Use only your original ideas and your original images. Do not use existing screen captures, posters, or stills from other

Movie and TV News

Wed 19 October 2005:

Celebrity News

- [Kidman Photographer Wins DNA Appeal](#)
- [Sizemore Has His Probation Reinstated](#)
- [Madonna Thanks ABBA for the Music](#)

Studio Briefing

- ['Fog' Obscures Box Office](#)
- [Schwarzenegger Wants To Terminate Video Game Lawsuit](#)
- [Jackson Dumps 'King Kong' Music](#)

Born Today

Wednesday, 19 October 2005:

12th Annual Graph Drawing Contest, 2005. The IMDb network is two-mode and has $1324748 = 428440 + 896308$ nodes and 3792390 arcs.

Two-mode cores

The subset of nodes $C \subseteq \mathcal{V}$ is a **(p, q) -core** in a two-mode network $\mathcal{N} = (\mathcal{V}_1, \mathcal{V}_2; \mathcal{L})$, $\mathcal{V} = \mathcal{V}_1 \cup \mathcal{V}_2$ iff

- a. in the induced subnetwork $\mathcal{K} = (C_1, C_2; \mathcal{L}(C))$,
 $C_1 = C \cap \mathcal{V}_1$, $C_2 = C \cap \mathcal{V}_2$ it holds $\forall v \in C_1 : \deg_{\mathcal{K}}(v) \geq p$
and $\forall v \in C_2 : \deg_{\mathcal{K}}(v) \geq q$;
- b. C is the maximal subset of \mathcal{V} satisfying condition a.

Properties of two-mode cores:

- $C(0, 0) = \mathcal{V}$
- $\mathcal{K}(p, q)$ is not always connected
- $(p_1 \leq p_2) \wedge (q_1 \leq q_2) \Rightarrow C(p_1, q_1) \subseteq C(p_2, q_2)$
- $\mathcal{C} = \{C(p, q) : p, q \in \mathbb{N}\}$. If all nonempty elements of \mathcal{C} are different it is a lattice.

Algorithm for two-mode cores

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To determine a (p, q) -core the procedure similar to the ordinary core procedure can be used:

repeat

remove from the first set all nodes of degree less than p ,

and from the second set all nodes of degree less than q

until no node was deleted

It can be implemented to run in $O(m)$ time.

Interesting (p, q) -cores? Table of cores' characteristics

$n_1 = |C_1(p, q)|$, $n_2 = |C_2(p, q)|$ and k – number of components in $\mathcal{K}(p, q)$:

- $n_1 + n_2 \leq$ selected threshold
- 'border line' in the (p, q) -table.

Table ($p, q : n_1, n_2$) for Internet Movie Database

Networks

Statistics

1 1590: 1590 1 | 16 39: 2173 678 | 44 14: 29 83

Citation

2 516: 788 3 | 17 35: 2791 995 | 46 13: 29 94

Two-mode Ns

3 212: 1705 18 | 18 32: 2684 1080 | 49 12: 26 95

Multiplication

4 151: 4330 154 | 19 30: 2395 1063 | 52 11: 16 79

5 131: 4282 209 | 20 28: 2216 1087 | 56 10: 34 162

Derived Ns

6 115: 3635 223 | 21 26: 1988 1087 | 62 9: 31 177

Temporal Ns

7 101: 3224 244 | 22 24: 1854 1153 | 66 8: 29 198

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8 88: 2860 263 | 24 23: 34 39 | 72 7: 22 203

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9 77: 3467 393 | 27 22: 31 38 | 96 6: 7 114

10 69: 3150 428 | 29 20: 35 52 | 119 5: 6 137

11 63: 2442 382 | 32 19: 34 57 | 141 4: 8 258

12 56: 2479 454 | 35 18: 33 61 | 186 3: 3 186

13 50: 3330 716 | 36 17: 33 65 | 247 2: 2 247

14 46: 2460 596 | 39 16: 29 70 | 1334 1: 1 1334

15 42: 2663 739 | 42 15: 28 76 |

(247,2)-core and (27,22)-core

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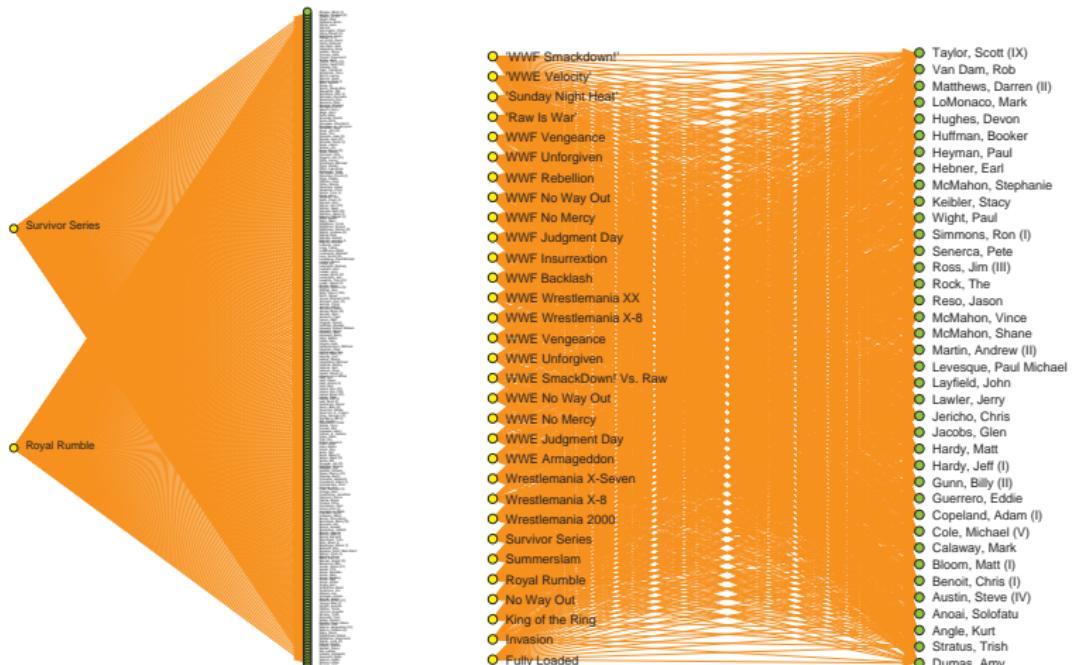
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IMDb: $n_1 = 428440$, $n_2 = 896308$, $m = 3792390$.

(2,516)-Hard core

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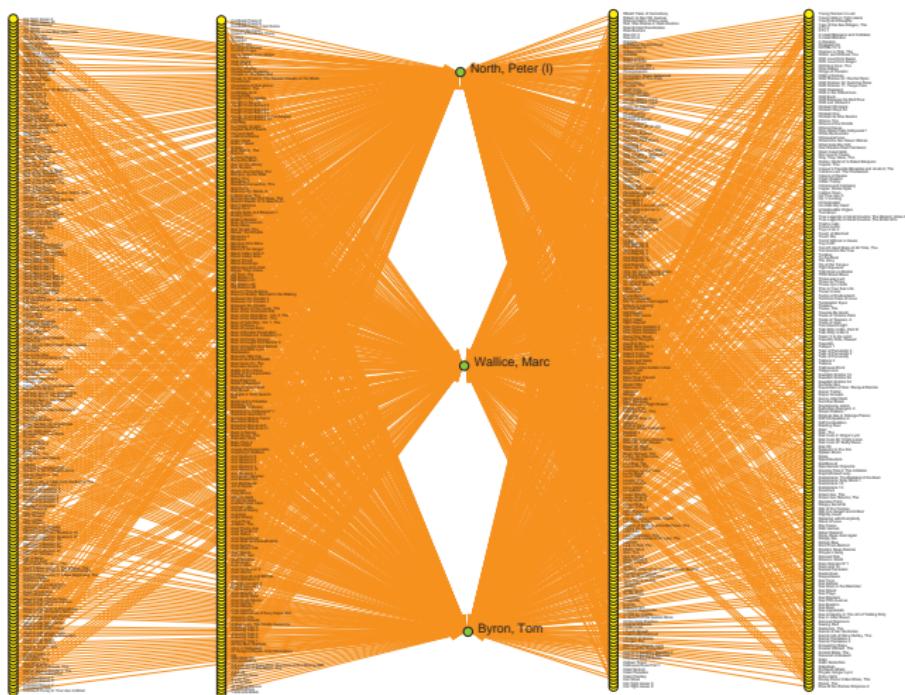
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4-rings and analysis of two-mode networks

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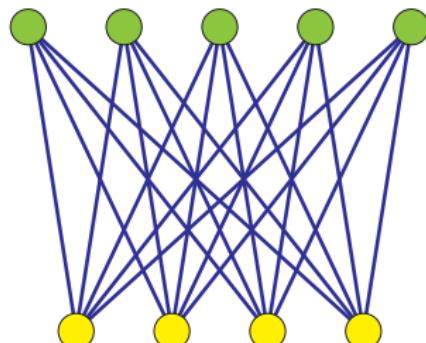
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A *k-ring* is a simple closed chain of length k . Using k -rings we can define a weight of edges as

$$w_k(e) = \# \text{ of different } k\text{-rings containing the edge } e \in \mathcal{E}$$

In two-mode network there are no 3-rings. The densest substructures are complete bipartite subgraphs $K_{p,q}$. They contain many 4-rings.



There are

$$\binom{p}{2} \binom{q}{2} = \frac{1}{4} p(p-1)q(q-1)$$

4-rings in $K_{p,q}$; and each of its edges e has weight

$$w_4(e) = (p-1)(q-1)$$

Network/Create New Network/with Ring Counts.../4-Rings/Undirected

Directed 4-rings

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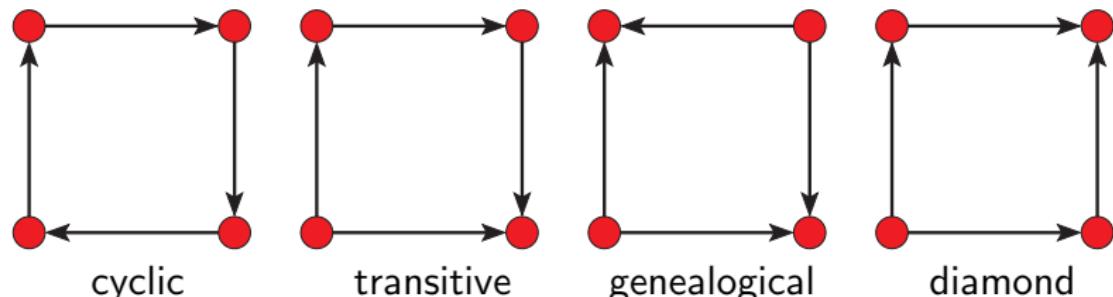
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In the case of transitive rings Pajek provides a special weight counting on how many transitive rings the arc is a *shortcut*.

Network/Create New Network/with Ring Counts/4-Rings/Directed

Simple link islands in IMDb for w_4

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We obtained 12465 simple link islands on 56086 nodes. Here is their size distribution.

	Size	Freq									
	2	5512		20	19		38	4		59	2
	3	1978		21	18		39	3		61	1
	4	1639		22	15		40	2		64	1
	5	968		23	9		42	2		67	1
	6	666		24	13		43	3		70	1
	7	394		25	12		45	3		73	1
	8	257		26	6		46	4		76	1
	9	209		27	6		47	5		82	1
	10	148		28	5		48	1		86	1
	11	118		29	6		49	2		106	1
	12	87		30	3		50	2		122	1
	13	55		31	6		51	1		135	1
	14	62		32	5		52	2		144	1
	15	46		33	3		53	1		163	1
	16	39		34	1		54	2		269	1
	17	27		35	5		55	1		301	1
	18	28		36	4		57	1		332	2
	19	29		37	7		58	1		673	1

Example: Islands for w_4

Charlie Brown and Adult

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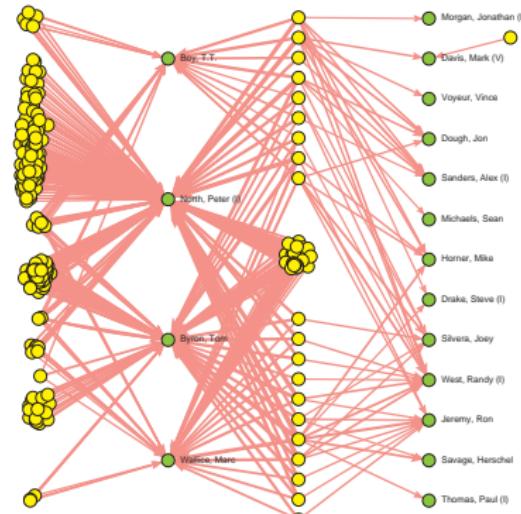
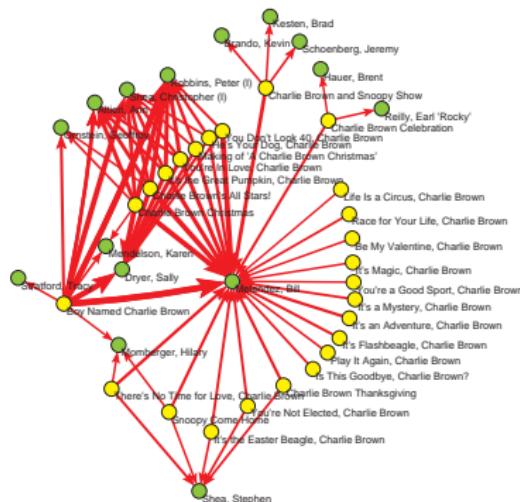
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Example: Islands for w_4 Mark Twain and Abid

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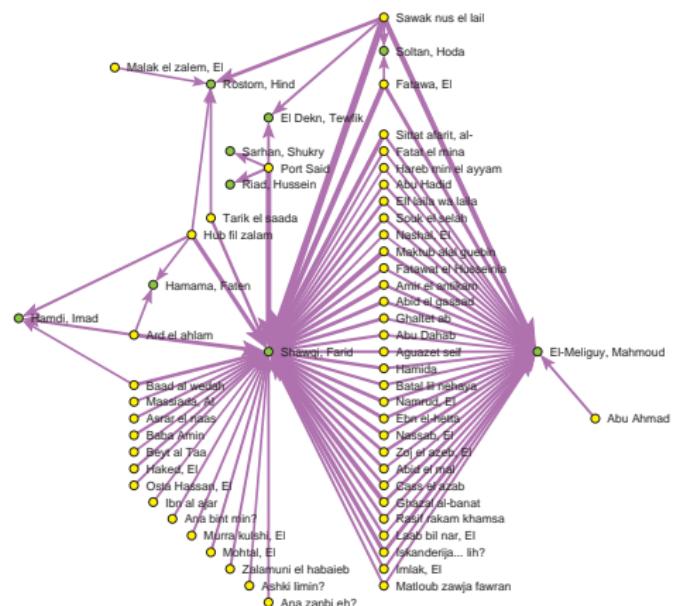
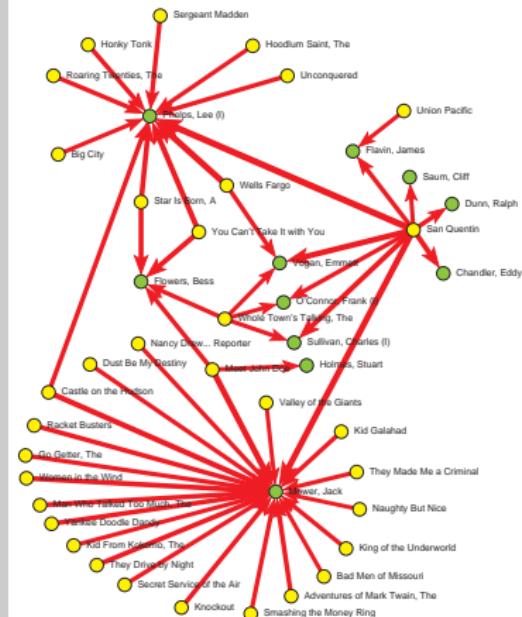
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Annals



Example: Island for w_4

Polizeiruf 110 and Starkes Team

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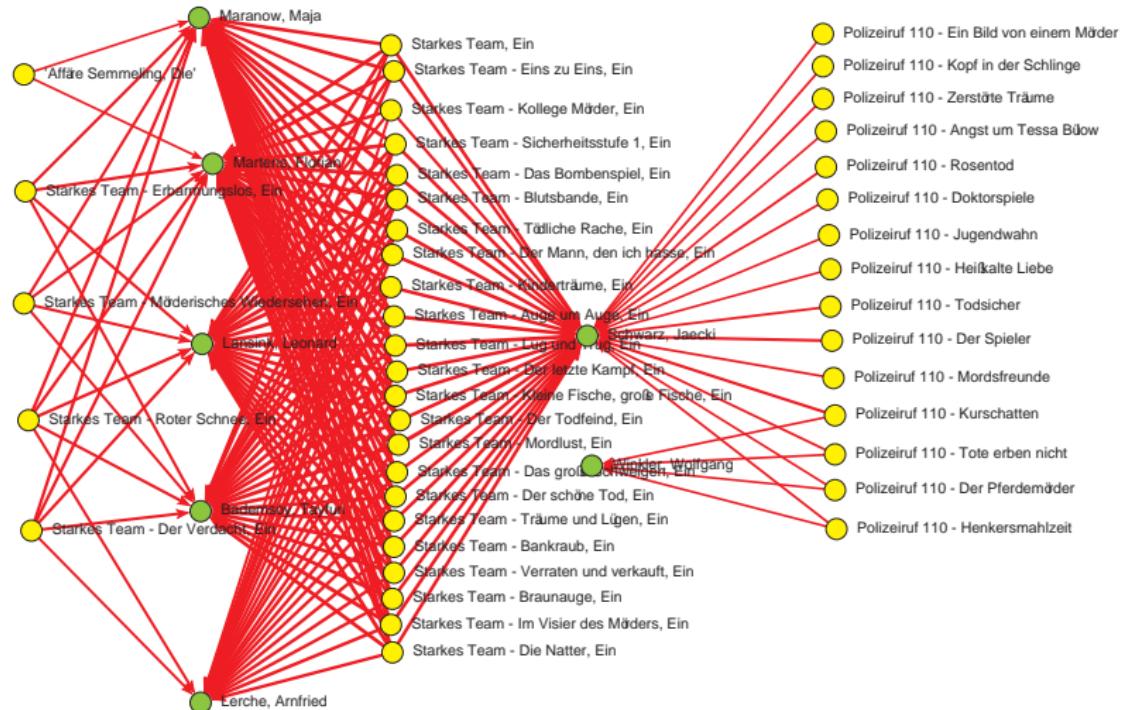
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Multiplication of networks

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To a simple (no parallel arcs) two-mode **network** $\mathcal{N} = (\mathcal{I}, \mathcal{J}, \mathcal{A}, w)$; where \mathcal{I} and \mathcal{J} are sets of **nodes**, \mathcal{A} is a set of **arcs** linking \mathcal{I} and \mathcal{J} , and $w : \mathcal{A} \rightarrow \mathbb{R}$ (or some other semiring) is a **weight**; we can assign a **network matrix** $\mathbf{W} = [w_{i,j}]$ with elements: $w_{i,j} = w(i,j)$ for $(i,j) \in \mathcal{A}$ and $w_{i,j} = 0$ otherwise.

Given a pair of compatible networks $\mathcal{N}_A = (\mathcal{I}, \mathcal{K}, \mathcal{A}_A, w_A)$ and $\mathcal{N}_B = (\mathcal{K}, \mathcal{J}, \mathcal{A}_B, w_B)$ with corresponding matrices $\mathbf{A}_{\mathcal{I} \times \mathcal{K}}$ and $\mathbf{B}_{\mathcal{K} \times \mathcal{J}}$ we call a **product of networks** \mathcal{N}_A and \mathcal{N}_B a network $\mathcal{N}_C = (\mathcal{I}, \mathcal{J}, \mathcal{A}_C, w_C)$, where $\mathcal{A}_C = \{(i,j) : i \in \mathcal{I}, j \in \mathcal{J}, c_{i,j} \neq 0\}$ and $w_C(i,j) = c_{i,j}$ for $(i,j) \in \mathcal{A}_C$. The product matrix $\mathbf{C} = [c_{i,j}]_{\mathcal{I} \times \mathcal{J}} = \mathbf{A} * \mathbf{B}$ is defined in the standard way

$$c_{i,j} = \sum_{k \in \mathcal{K}} a_{i,k} \cdot b_{k,j}$$

In the case when $\mathcal{I} = \mathcal{K} = \mathcal{J}$ we are dealing with ordinary one-mode networks (with square matrices).

Multiplication of networks

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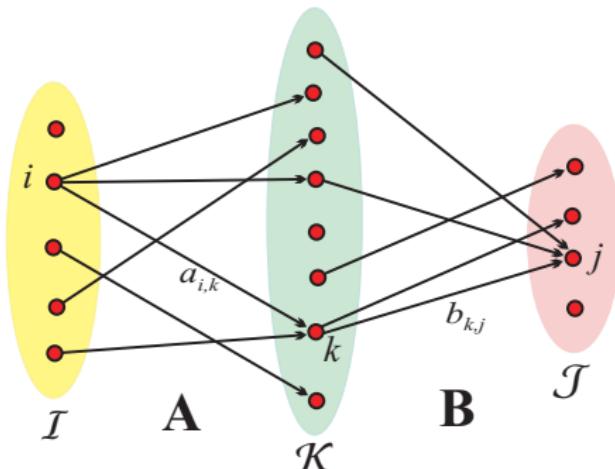
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$$c_{i,j} = \sum_{k \in N_A(i) \cap N_B^-(j)} a_{i,k} \cdot b_{k,j}$$

If all weights in networks \mathcal{N}_A and \mathcal{N}_B are equal to 1 the value of $c_{i,j}$ counts the number of ways we can go from $i \in \mathcal{I}$ to $j \in \mathcal{J}$ passing through \mathcal{K} .

Multiplication of networks

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The standard matrix multiplication has the complexity $O(|\mathcal{I}| \cdot |\mathcal{K}| \cdot |\mathcal{J}|)$ – it is too slow to be used for large networks. For sparse large networks we can multiply much faster considering only nonzero elements.

In general the multiplication of large sparse networks is a 'dangerous' operation since the result can 'explode' – it is not sparse.

If at least one of the sparse networks \mathcal{N}_A and \mathcal{N}_B has small maximal degree on \mathcal{K} then also the resulting product network \mathcal{N}_C is sparse.

If for the sparse networks \mathcal{N}_A and \mathcal{N}_B there are in \mathcal{K} only few nodes with large degree and no one among them with large degree in both networks then also the resulting product network \mathcal{N}_C is sparse.

Multiplication of networks – details

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From the network multiplication algorithm we see that each intermediate node $k \in \mathcal{K}$ adds to a product network a complete two-mode subgraph $K_{N_A^-(k), N_B(k)}$ (or, in the case $\mathcal{I} = \mathcal{J}$, a complete subgraph $K_{N(k)}$). If both degrees $\deg_A(k) = |N_A^-(k)|$ and $\deg_B(k) = |N_B(k)|$ are large then already the computation of this complete subgraph has a quadratic (time and space) complexity – the result 'explodes'.

For more details see the [paper](#).

Two-mode network analysis by conversion to one-mode network – projections

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Often we transform a two-mode network $\mathcal{N} = (\mathcal{U}, \mathcal{V}, \mathcal{E}, w)$ into an ordinary (one-mode) network $\mathcal{N}_1 = (\mathcal{U}, \mathcal{E}_1, w_1)$ or/and $\mathcal{N}_2 = (\mathcal{V}, \mathcal{E}_2, w_2)$, where \mathcal{E}_1 and w_1 are determined by the matrix $\mathbf{W}^{(1)} = \mathbf{WW}^T$, $w_{uv}^{(1)} = \sum_{z \in \mathcal{V}} w_{uz} \cdot w_{zv}^T$. Evidently $w_{uv}^{(1)} = w_{vu}^{(1)}$. There is an edge $(u : v) \in \mathcal{E}_1$ in \mathcal{N}_1 iff $N(u) \cap N(v) \neq \emptyset$. Its weight is $w_1(u, v) = w_{uv}^{(1)}$.

The network \mathcal{N}_2 is determined in a similar way by the matrix $\mathbf{W}^{(2)} = \mathbf{W}^T \mathbf{W}$.

The networks \mathcal{N}_1 and \mathcal{N}_2 are analyzed using standard methods.

Network/2-Mode Network/2-Mode to 1-Mode/Rows

Authorship networks

Bibliographic networks

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Let **WA** be the works \times authors two mode authorship network;
 $wa_{pi} \in \{0, 1\}$ is describing the authorship of author i of work p .

$$\forall p \in W : \sum_{i \in A} wa_{pi} = \text{outdeg}_{WA}(p) = \# \text{ authors of work } p$$

Let **N** be its normalized version

$$\forall p \in W : \sum_{i \in A} n_{pi} \in \{0, 1\}$$

obtained from **WA** by $n_{pi} = wa_{pi} / \max(1, \text{outdeg}_{WA}(p))$, or by some other rule determining the author's contribution – the *fractional* approach.

Some transformations of networks

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Binarization $b(\mathcal{N})$ is a network obtained from the \mathcal{N} in which all weights are set to 1.

Transposition \mathcal{N}^T or $t(\mathcal{N})$ is a network obtained from \mathcal{N} in which to all arcs their direction is reversed. $\mathbf{AW} = \mathbf{WA}^T$, $\mathbf{KW} = \mathbf{WK}^T$, ...

(Out) normalization $n(\mathcal{N})$ is a network obtained from \mathcal{N} in which the weight of each arc a is divided by the sum of weights of all arcs having the same initial node as the arc a . For binary networks

$$n(\mathbf{A}) = \text{diag}\left(\frac{1}{\max(1, \text{outdeg}_{WA}(i))}\right)_{i \in \mathcal{I}} * \mathbf{A}$$

$$\mathbf{N} = n(\mathbf{WA}), \mathbf{WA} = b(\mathbf{N})$$

First co-authorship network

Bibliographic networks

V. Batagelj,
D. Maltseva

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$$\mathbf{Co} = \mathbf{AW} * \mathbf{WA}$$

$$co_{ij} = \sum_{p \in W} wa_{pi} wa_{pj} = \sum_{p \in N^-(i) \cap N^-(j)} 1$$

co_{ij} = the number of works that authors i and j wrote together

co_{ii} = the total number of works that author i wrote

It holds: $co_{ij} = co_{ji}$.

Using the weights co_{ij} we can determine the Salton's cosine similarity or Ochiai coefficient between authors i and j as

$$\cos(i, j) = \frac{co_{ij}}{\sqrt{co_{ii} co_{jj}}}, \quad \text{for } co_{ij} > 0$$

Cores of orders 20–47 in $\text{Co}(\text{SN5})$

Bibliographic networks

V. Batagelj,
D. Maltseva

Networks

Statistics

Citation

Two-mode Ns

Multiplication

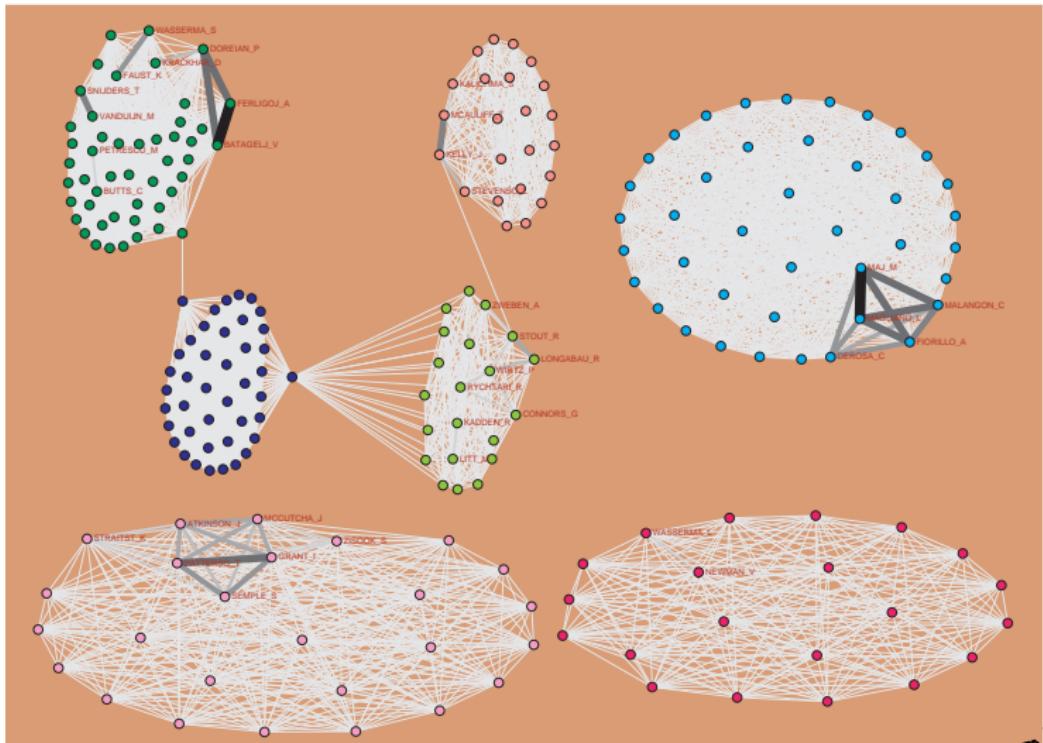
Derived Ns

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Appendix

Network SN5 (2008): for "social network*" + most frequent references + around 100 social networkers;
 $|W| = 193376, |C| = 7950, |A| = 75930, |J| = 14651, |K| = 29267$



Papers by number of authors

Problem: The **Co** network is composed of complete graphs on the set of work's authors. Works with many authors produce large complete subgraphs and are over-represented, thus blurring the collaboration structure.

outdeg	frequency	outdeg	frequency	paper
1	2637	12	8	
2	2143	13	4	
3	1333	14	3	
4	713	15	2	
5	396	21	1	Pierce et al. (2007)
6	206	22	1	Allen et al. (1998)
7	114	23	1	Kelly et al. (1997)
8	65	26	1	Semple et al. (1993)
9	43	41	1	Magliano et al. (2006)
10	24	42	1	Doll et al. (1992)
11	10	48	1	Snijders et al. (2007)

Bibliographic
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Citation

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Snijders et al.(2007): Snijders, T.A.B., Robinson, T., Atkinson, A.C., Riani, M., Gormley, I.C., Murphy, T.B., Sweeting, T., Leslie, D.S., Longford, N.T., Kent, J.T., Lawrence, T., Airoldi, E.M., Besag, J., Blei, D., Fienberg, S.E., Breiger, R., Butts, C.T., Doreian, P., Batagelj, V., Ferligoj, A., Draper, D., van Duijn, M.A.J., Faust, K., Petrescu-Prahova, M., Forster, J.J., Gelman, A., Goodreau, S. M., Greenwood, P.E., Gruenberg, K., Francis, B., Hennig, C., Hoff, P.D., Hunter, D.R., Husmeier, D., Glasbey, C., Krackhardt, D., Kuha, J., Skrondal, A., Lawson, A., Liao, T. F., Mendes, B., Reinert, G., Richardson, S., Lewin, A., Titterington, D.M., Wasserman, S., Werhli, A.V. and Ghazal, P.. *Discussion on the paper by Handcock, Raftery and Tantrum.* Journal of the Royal Statistical Society: Series A - Statistics in Society, 170 (2007), pp. 322-354.

p_S -core at level 20 of **Co(SN5)**

Bibliographic networks

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Statistics

Citation

Two-mode Ns

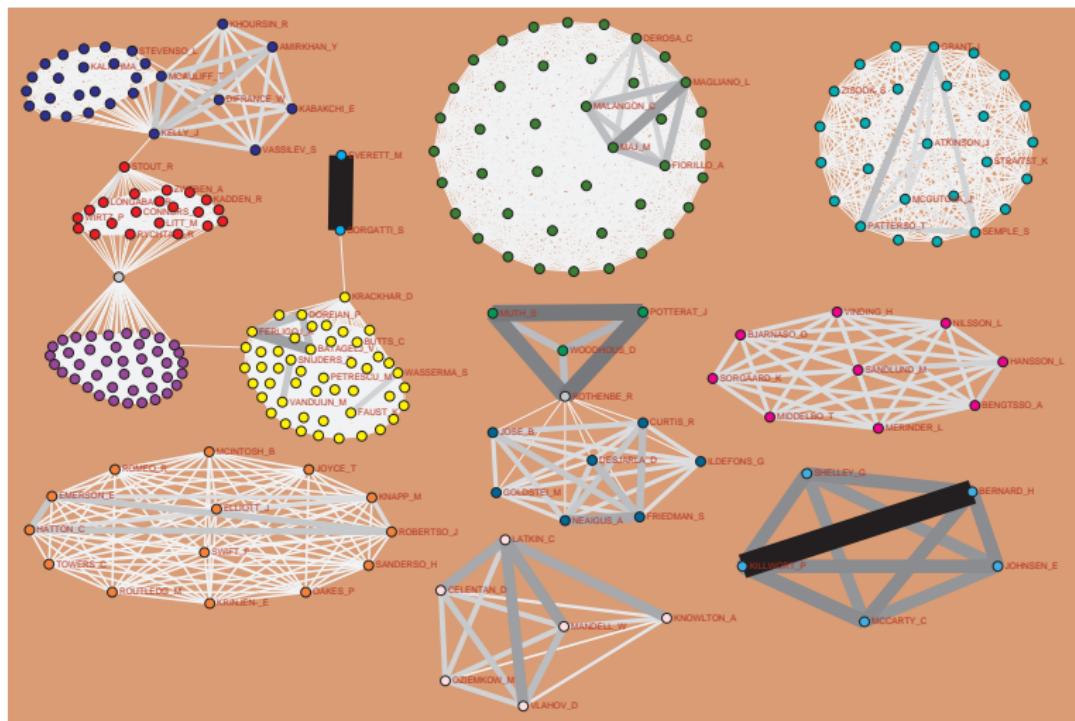
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Second co-authorship network

Bibliographic networks

V. Batagelj,
D. Maltseva

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Appendix

$$\mathbf{Cn} = \mathbf{AW} * \mathbf{N}$$

$$cn_{ij} = \sum_{p \in W} wa_{pi} n_{pj} = \sum_{p \in N^-(i) \cap N^-(j)} n_{pj}$$

cn_{ij} = contribution of author j to works, that (s)he wrote together with the author i .

It holds $\sum_{j \in A} \sum_{p \in A} wa_{pi} n_{pj} = \text{outdeg}_{WA}(p)$ and $\sum_{j \in A} cn_{ij} = \text{indeg}_{WA}(i)$

$cn_{ii} = \sum_{p \in N(i)} n_{pi}$ is the contribution of author i to his/her works.

Self-sufficiency: $S_i = \frac{cn_{ii}}{\text{indeg}_{WA}(i)}$

Collaborativeness: $K_i = 1 - S_i$

$$\sum_{i \in A} \sum_{j \in A} cn_{ij} = \sum_{i \in A} \text{indeg}_{WA}(i) = m_{WA}$$

To compute the table we prepared a macro in Pajek.

The "best" authors in Social Networks

Bibliographic networks

	i	author	cn_{ii}	total	K_i		i	author	cn_{ii}	total	K_i
V. Batagelj, D. Maltseva	1	Burt,R	43.83	53	0.173		26	Latkin,C	10.14	37	0.726
	2	Newman,M	36.77	60	0.387		27	Morris,M	9.98	20	0.501
Networks	3	Doreian,P	34.44	47	0.267		28	Rothenberg,R	9.82	28	0.649
Statistics	4	Bonacich,P	30.17	41	0.264		29	Kadushin,C	9.75	11	0.114
	5	Marsden,P	29.42	37	0.205		30	Faust,K	9.72	18	0.460
Citation	6	Wellman,B	26.87	41	0.345		31	Batagelj,V	9.69	20	0.516
	7	Leydesdorf,L	24.37	35	0.304		32	Mizruchi,M	9.67	15	0.356
Two-mode Ns	8	White,H	23.50	33	0.288		33	[Anon]	9.00	9	0.000
Multiplication	9	Friedkin,N	20.00	23	0.130		34	Johnson,J	8.89	21	0.577
	10	Borgatti,S	19.20	41	0.532		35	Fararo,T	8.83	16	0.448
Derived Ns	11	Everett,M	16.92	31	0.454		36	Lazega,E	8.50	12	0.292
	12	Litwin,H	16.00	21	0.238		37	Knoke,D	8.33	11	0.242
Temporal Ns	13	Freeman,L	15.53	20	0.223		38	Ferligoj,A	8.19	19	0.569
References	14	Barabasi,A	14.99	35	0.572		39	Brewer,D	8.03	11	0.270
	15	Snijders,T	14.99	30	0.500		40	Klov Dahl,A	7.96	17	0.532
Appendix	16	Valente,T	14.80	34	0.565		41	Hammer,M	7.92	10	0.208
	17	Breiger,R	14.44	20	0.278		42	White,D	7.83	15	0.478
	18	Skvoretz,J	14.43	27	0.466		43	Holme,P	7.42	14	0.470
	19	Krackhardt,D	13.65	25	0.454		44	Boyd,J	7.37	13	0.433
	20	Carley,K	12.93	28	0.538		45	Kilduff,M	7.25	16	0.547
	21	Pattison,P	12.10	27	0.552		46	Small,H	7.00	7	0.000
	22	Wasserman,S	11.72	26	0.549		47	Iacobucci,D	7.00	12	0.417
	23	Berkman,L	11.21	30	0.626		48	Pappi,F	6.83	10	0.317
	24	Moody,J	10.83	15	0.278		49	Chen,C	6.78	12	0.435
	25	Scott,J	10.47	15	0.302		50	Seidman,S	6.75	9	0.250

Third co-authorship network

$$\mathbf{Ct} = \mathbf{N}^T * \mathbf{N}$$

ct_{ij} = the total contribution of ‘collaboration’ of authors i and j to works.

It holds $ct_{ij} = ct_{ji}$ and

$$\sum_{i \in A} \sum_{j \in A} n_{pi} n_{pj} = 1$$

The total contribution of a complete subgraph corresponding to the authors of a work p is 1.

$\sum_{j \in A} ct_{ij} = \sum_{p \in W} n_{pi}$ = the total contribution of author i to works from W .

$$\sum_{i \in A} \sum_{j \in A} ct_{ij} = |W|$$

Components in $\text{Ct}(\text{SN5})$ cut at level 0.5

Bibliographic networks

V. Batagelj,
D. Maltseva

Networks

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Two-mode Ns

Multiplication

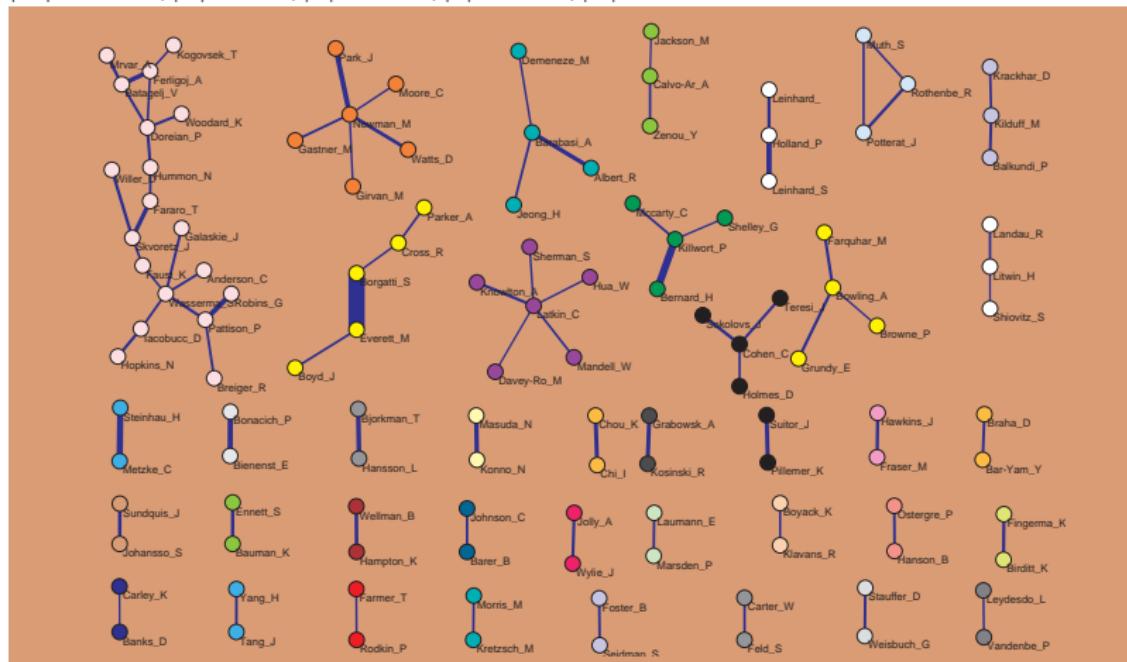
Derived Ns

Temporal Ns

References

Appendix

Network SN5 (2008): for "social network*" + most frequent references + around 100 social networkers;
 $|W| = 193376, |C| = 7950, |A| = 75930, |J| = 14651, |K| = 29267$



p_S -core at level 0.75 in $\mathbf{Ct}(\mathbf{SN5})$

Bibliographic networks

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Networks

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Citation

Two-mode Ns

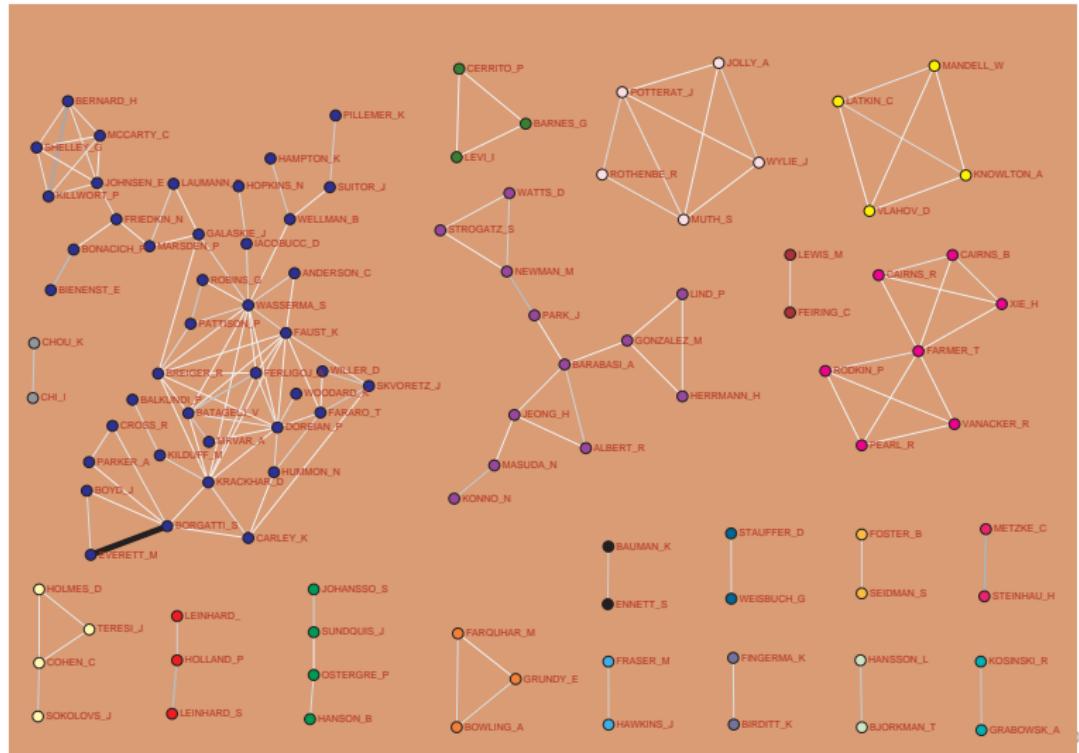
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Some link islands [5,20] in $\mathbf{Ct}(\mathbf{SN5})$

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Two-mode Ns

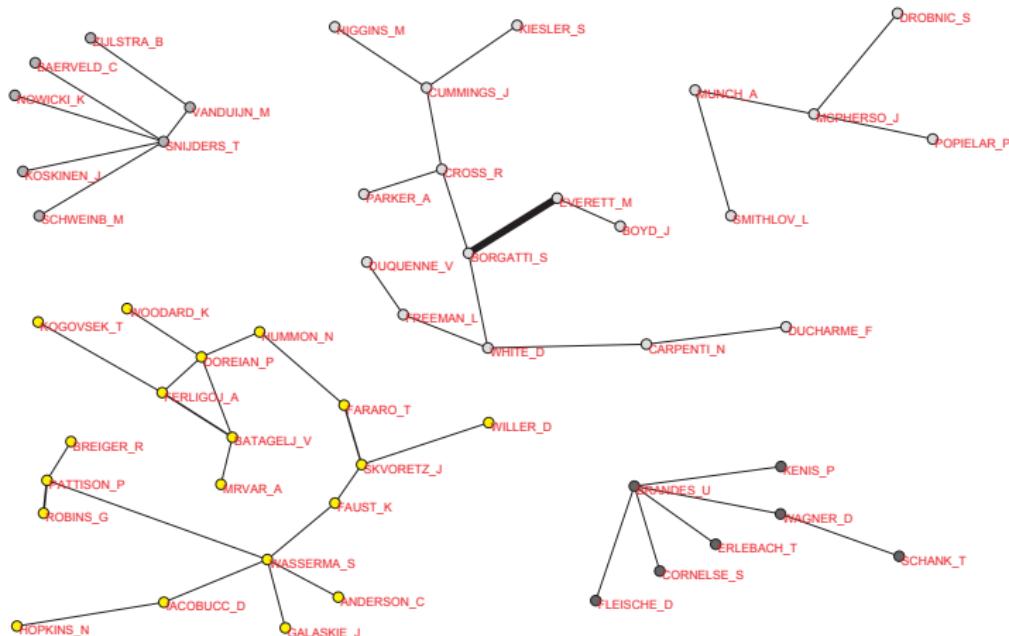
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Fourth co-authorship network

Bibliographic networks

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$\mathbf{Ct}' = \mathbf{N}^T * \mathbf{N}'$, where $n'_{pi} = wa_{pi} / \max(1, \text{outdeg}_{WA}(p) - 1)$

ct'_{ij} = the total contribution of 'strict collaboration' of authors i and j to works.

In Pajek we can use macros to save sequences of commands to produce different co-authorship networks.

The final result is returned as an undirected simple network with weights (for $i \neq j$)

$$ct'_{ij} = \sum_p \frac{2 \cdot wa_{pi} \cdot wa_{pj}}{\max(1, \text{outdeg}_{WA}(p)) \cdot \max(1, \text{outdeg}_{WA}(p) - 1)}$$

Authors' citations network

Bibliographic networks

V. Batagelj,
D. Maltseva

Networks

Statistics

Citation

Two-mode Ns

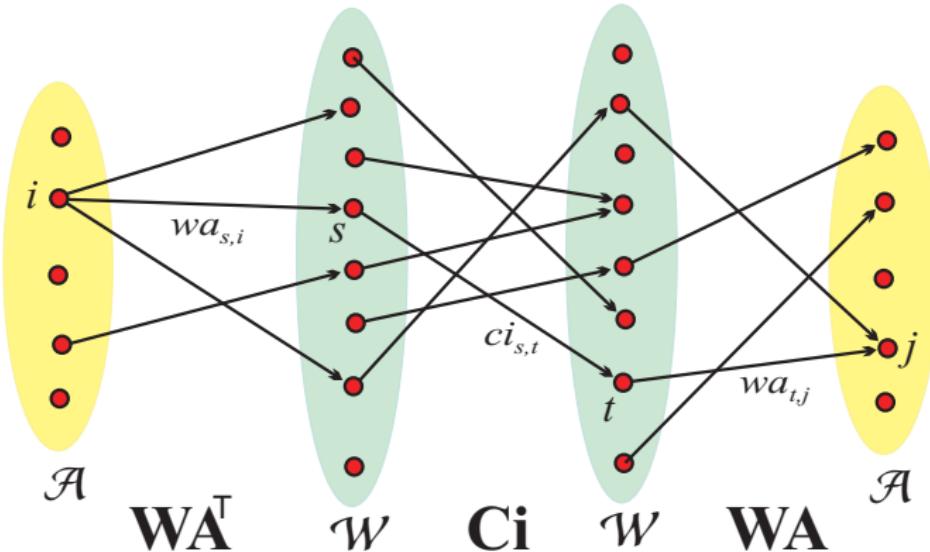
Multiplication

Derived Ns

Temporal Ns

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Appendix



Ca = AW * Ci * WA is a network of citations between authors.
The weight $w(i,j)$ counts the number of times a work authored by i is citing a work authored by j .

Islands in SN5 authors citation network

Bibliographic
networks

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Multiplication

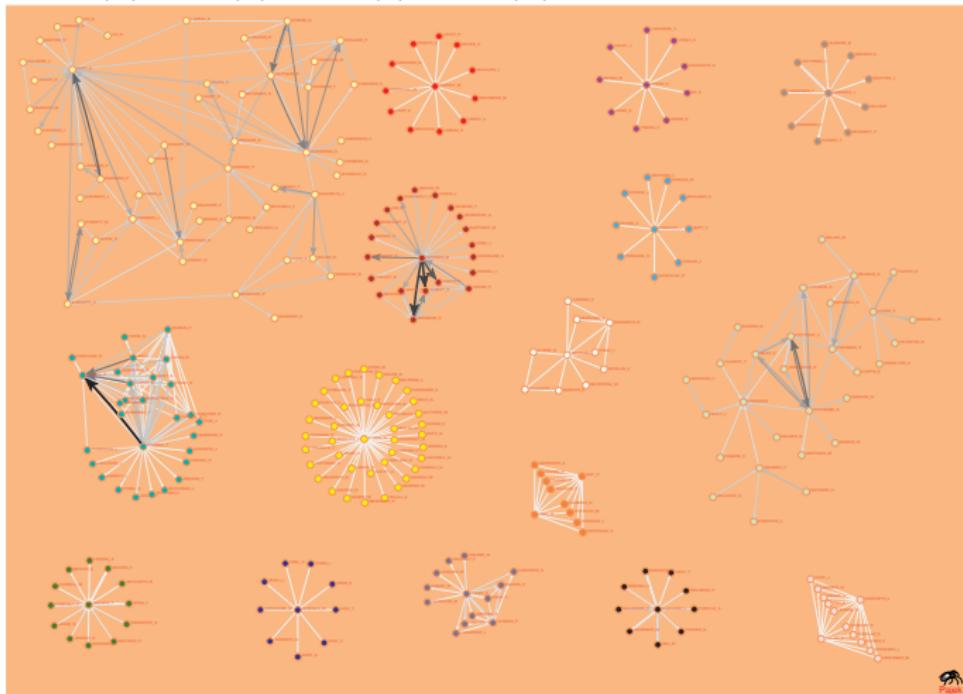
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Appendix

Network SN5 (2008): for "social network*" + most frequent references + around 100 social networkers;
 $|W| = 193376, |C| = 7950, |A| = 75930, |J| = 14651, |K| = 29267$



Bibliographic Coupling

Bibliographic networks

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In WoS2Pajek the citation relation means $p\mathbf{Ci}q \equiv$ work p cites work q . Therefore the *bibliographic coupling* network **biCo** can be determined as

$$\mathbf{biCo} = \mathbf{Ci} * \mathbf{Ci}^T$$

$bico_{pq} = \# \text{ of works cited by both works } p \text{ and } q$. $bico_{pq} = bico_{qp}$.

Again we have problems with works with many citations, especially with review papers. To neutralize their impact we can introduce a normalized measure such as

$$\mathbf{biCon} = \frac{1}{2}(n(\mathbf{Ci}) * \mathbf{Ci}^T + \mathbf{Ci} * n(\mathbf{Ci})^T)$$

It is easy to verify that $bicon_{pq} \in [0, 1]$ and $bicon_{pq} = bicon_{qp}$ (symmetry). It also holds: $bicon_{pq} = 1$ iff the works p and q are referencing the same works.

Co-Citation and others

Bibliographic
networks

V. Batagelj,
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The *co-citation* network **coCi** can be determined as

$$\mathbf{coCi} = \mathbf{Ci}^T * \mathbf{Ci}$$

$coci_{pq} = \#$ of works citing both works p and q .

$coci_{pq} = cocici_{qp}$.

The weight $w(a, p)$ in the *author citation* network

$$\mathbf{ACi} = \mathbf{AW} * \mathbf{Ci}$$

counts the number of times author a cited work p .

The *author co-citation* network can be obtained as

$$\mathbf{ACo} = b(\mathbf{ACi}) * t(b(\mathbf{ACi}))$$

Authors using keywords **AK** = **AW** * **WK**.

Temporal quantities

Bibliographic
networks

V. Batagelj,
D. Maltseva

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We introduce a notion of a *temporal quantity*

$$a(t) = \begin{cases} a'(t) & t \in T_a \\ \text{\#} & t \in \mathcal{T} \setminus T_a \end{cases}$$

where T_a is the *activity time set* of a and $a'(t)$ is the value of a in an instant $t \in T_a$, and \# denotes the value *undefined*.

We assume that the values of temporal quantities belong to a set A which is a *semiring* $(A, +, \cdot, 0, 1)$ for binary operations $+ : A \times A \rightarrow A$ and $\cdot : A \times A \rightarrow A$.

Let $A_{\text{\#}}(\mathcal{T})$ denote the set of all temporal quantities over $A_{\text{\#}}$ in time \mathcal{T} . To extend the operations to networks and their matrices we first define the *sum* (parallel links) $a + b$ as

$$(a + b)(t) = a(t) + b(t) \quad \text{and} \quad T_{a+b} = T_a \cup T_b.$$

The *product* (sequential links) $a \cdot b$ is defined as

$$(a \cdot b)(t) = a(t) \cdot b(t) \quad \text{and} \quad T_{a \cdot b} = T_a \cap T_b.$$

Sum and product of temporal quantities

Bibliographic
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```
a = [(1, 5, 2), (6, 8, 1), (11, 12, 3), (14, 16, 2),  
      (17, 18, 5), (19, 20, 1)]  
b = [(2, 3, 4), (4, 7, 3), (9, 10, 2), (13, 15, 5), (16, 21, 1)]
```

The following are the sum $s = a + b$ and the product $p = a \cdot b$ of temporal quantities a and b over combinatorial semiring.

```
s = [(1, 2, 2), (2, 3, 6), (3, 4, 2), (4, 5, 5), (5, 6, 3),  
      (6, 7, 4), (7, 8, 1), (9, 10, 2), (11, 12, 3),  
      (13, 14, 5), (14, 15, 7), (15, 16, 2), (16, 17, 1),  
      (17, 18, 6), (18, 19, 1), (19, 20, 2), (20, 21, 1)]  
p = [(2, 3, 8), (4, 5, 6), (6, 7, 3), (14, 15, 10),  
      (17, 18, 5), (19, 20, 1)]
```

They are visually displayed at the bottom half of figures on the following slides.

Addition of temporal quantities.

Bibliographic
networks

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Two-mode Ns

Multiplication

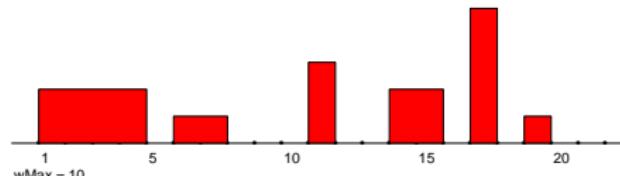
Derived Ns

Temporal Ns

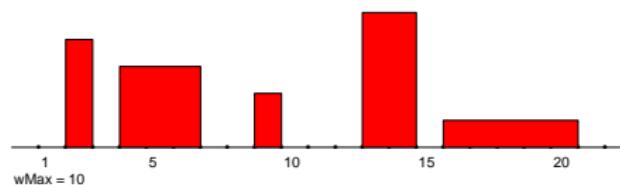
References

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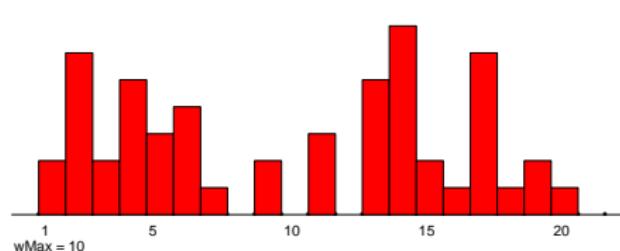
$a :$



$b :$



$a + b :$



Multiplication of temporal quantities.

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Two-mode Ns

Multiplication

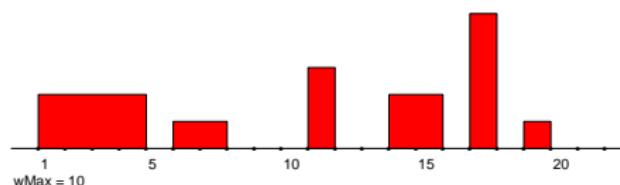
Derived Ns

Temporal Ns

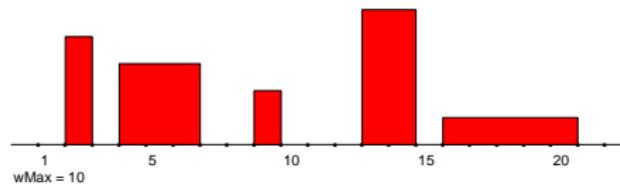
References

Appendix

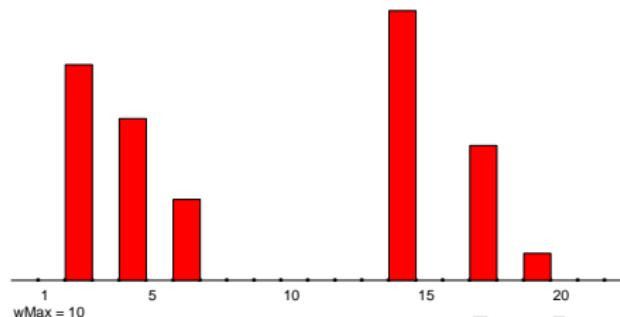
$a :$



$b :$



$a \cdot b :$



Temporal affiliation networks

Bibliographic
networks

V. Batagelj,
D. Maltseva

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Appendix

Let the binary **affiliation** matrix $\mathbf{A} = [a_{ep}]$ describe a two-mode network on the set of events E and the set of participants P :

$$a_{ep} = \begin{cases} 1 & p \text{ participated in the event } e \\ 0 & \text{otherwise} \end{cases}$$

The function $d : E \rightarrow \mathcal{T}$ assigns to each event e the date $d(e)$ when it happened. $\mathcal{T} = [\text{first}, \text{last}] \subset \mathbb{N}$. Using these data we can construct two temporal affiliation matrices:

- **instantaneous Ai** = $[ai_{ep}]$, where

$$ai_{ep} = \begin{cases} [(d(e), d(e) + 1, 1)] & a_{ep} = 1 \\ [] & \text{otherwise} \end{cases}$$

- **cumulative Ac** = $[ac_{ep}]$, where

$$ac_{ep} = \begin{cases} [(d(e), last + 1, 1)] & a_{ep} = 1 \\ [] & \text{otherwise} \end{cases}$$

Multiplication of temporal affiliation networks

Instantaneous

Bibliographic
networks

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D. Maltseva

Networks

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Appendix

Instantaneous **A** on $P \times A$ and **B** on $P \times B$. $\mathbf{C} = \mathbf{A}^T \cdot \mathbf{B}$ on $A \times B$.

$$c_{ij}(t) = \sum_{p \in P} a_{pi}(t)^T \cdot b_{pj}(t)$$

$a_{pi} = [(d_{pi}, d_{pi} + 1, v_{pi})]$ and $b_{pj} = [(d_{pj}, d_{pj} + 1, v_{pj})]$
for $t = d$ we get

$$c_{ij} = [(d, d + 1, \sum_{p \in P: d_{pi}=d_{pj}=d} v_{pi} \cdot v_{pj})]_{d \in \mathcal{T}}$$

for $v_{pi} = v_{pj} = 1$ we finally get

$$v_{ij}(d) = |\{p \in P : d_{pi} = d_{pj} = d\}|$$

For binary temporal two-mode networks **A** and **B** the value $v_{ij}(d)$ of the product $\mathbf{A}^T \cdot \mathbf{B}$ is equal to the number of different members of P with which both i and j have contact in the instant d .

Multiplication of temporal affiliation networks

Cumulative

Bibliographic
networks

V. Batagelj,
D. Maltseva

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Appendix

Cumulative **A** on $P \times A$ and **B** on $P \times B$. $\mathbf{C} = \mathbf{A}^T \cdot \mathbf{B}$ on $A \times B$.

$$c_{ij}(t) = \sum_{p \in P} a_{pi}(t)^T \cdot b_{pj}(t)$$

$a_{pi} = [(d_{pi}, \text{last} + 1, v_{pi})]$ and $b_{pj} = [(d_{pj}, \text{last} + 1, v_{pj})]$
for $t = d$ we get

$$c_{ij} = [(d, d + 1, \sum_{p \in P: (d_{pi} \leq d) \wedge (d_{pj} \leq d)} v_{pi} \cdot v_{pj})]_{d \in \mathcal{T}}$$

for $v_{pi} = v_{pj} = 1$ we finally get

$$v_{ij}(d) = |\{p \in P : (d_{pi} \leq d) \wedge (d_{pj} \leq d)\}|$$

For binary temporal two-mode networks **A** and **B** the value $v_{ij}(d)$ of the product $\mathbf{A}^T \cdot \mathbf{B}$ is equal to the number of different members of P with which both i and j have contact in all instants up to including the instant d .

Temporal co-authorship networks

Bibliographic
networks

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Networks

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Appendix

Using the multiplication of temporal matrices over the combinatorial semiring we get the corresponding instantaneous and cumulative co-occurrence matrices

$$\mathbf{Ci} = \mathbf{Ai}^T \cdot \mathbf{Ai} \quad \text{and} \quad \mathbf{Cc} = \mathbf{Ac}^T \cdot \mathbf{Ac}$$

A typical example of such a matrix is the papers authorship matrix **WA** where E is the set of papers W , P is the set of authors A and d is the publication year.

The triple (s, f, v) in a temporal quantity ci_{pq} tells that in the time interval $[s, f)$ there were v events in which both p and q took part.

The triple (s, f, v) in a temporal quantity cc_{pq} tells that in the time interval $[s, f)$ there were in total v accumulated events in which both p and q took part.

The diagonal matrix entries ci_{pp} and cc_{pp} contain the temporal quantities counting the number of events in the time intervals in which the participant p took part.

Temporal co-authorship network for SN5

Bibliographic
networks

V. Batagelj,
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Appendix

BibTime

SN5 (2008)

	W	A	K	J
raw	193376	75930	29267	14651
DC=1	7950	12458		

In Pajek we extract a subnetwork **WAc** and a corresponding partition **SN5yearC**. Using a program twoMode2netJSON we transform them into temporal network in the netJSON format.

Bibliographic networks are usually sparse. The network **WAcInst** has 19488 arcs. The co-authorship network

ColInst = **WAcInst**^T * **WAcInst** has 64980 edges; the corresponding matrix in the package **TQ** has $12458^2 = 155201764$ entries. Using a package **Graph** the co-authorship network is computed in a second and half – a big speed-up.

multiply.py

Bibliographic networks

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```
gdir = 'c:/users/batagelj/work/python/graph/graph'
wdir = 'c:/users/batagelj/work/python/graph/JSON/SN5'
cdir = 'c:/users/batagelj/work/python/graph/chart'
import sys, os, datetime, json
sys.path = [gdir]+sys.path; os.chdir(wdir)
import TQ
from GraphNew import Graph
# file = 'C:/Users/batagelj/work/Python/graph/JSON/WAtest.json'
file = 'C:/Users/batagelj/work/Python/graph/JSON/SN5/WAcInst.json'
# file = 'C:/Users/batagelj/work/Python/graph/JSON/SN5/WAcCum.json'
# file = 'C:/Users/batagelj/work/Python/graph/JSON/Gisela/papInst.json'
t1 = datetime.datetime.now()
print("started: ",t1.ctime(),"\n")
G = Graph.loadNetJSON(file)
t2 = datetime.datetime.now()
print("\nloaded: ",t2.ctime(),"\n time used: ", t2-t1)
# T = G.transpose()
# Co = Graph.TQmultiply(T,G,True)
# CR = G.TQtwo2oneRows()
CC = G.TQtwo2oneCols()
t3 = datetime.datetime.now()
print("\ncomputed: ",t3.ctime(),"\n time used: ", t3-t2)
ia = { v[3]['lab']: k for k,v in CC._nodes.items() }
# CC._links[(ia['BORGATTI_S'],ia['EVERETT_M'])][4]['tq']
# CC._links[(ia['IDI/B'],ia['HCL/B'])][4]['tq']
```

Temporal co-authorship network for SN5

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```
===== RESTART: C:\Users\batagelj\work\Python\graph\graph\multiply.py =====
started: Sun Nov 20 00:26:51 2016
loaded: Sun Nov 20 00:26:51 2016
time used: 0:00:00.425024
computed: Sun Nov 20 00:26:52 2016
time used: 0:00:01.165066
>>> BB = CC._links[(ia['BORGATTI_S'],ia['BORGATTI_S'])][4]['tq']
>>> BE = CC._links[(ia['BORGATTI_S'],ia['EVERETT_M'])][4]['tq']
>>> BB
[(1988, 1990, 2), (1990, 1991, 4), (1991, 1992, 2), (1992, 1993, 4),
(1993, 1994, 2), (1994, 1995, 3), (1996, 1997, 1), (1997, 1998, 2),
(1998, 1999, 1), (1999, 2000, 3), (2001, 2002, 2), (2002, 2003, 1),
(2003, 2004, 4), (2005, 2006, 3), (2006, 2007, 2), (2007, 2008, 3)]
>>> BE
[(1988, 1989, 1), (1989, 1990, 2), (1990, 1991, 4), (1991, 1992, 1),
(1992, 1995, 2), (1996, 1998, 1), (1999, 2000, 3), (2003, 2004, 1),
(2005, 2007, 1)]
>>> TQmax = 8; Tmin = 1970; Tmax = 2009; w = 600; h = 120
>>> tit = 'BORGATTI_S'
>>> Graph.TQshow(BB,cdir,TQmax,Tmin,Tmax,w,h,tit,fill='orange')
>>> tit = 'BORGATTI_S - EVERETT_M'
>>> Graph.TQshow(BE,cdir,TQmax,Tmin,Tmax,w,h,tit,fill='orange')
>>> NN = CC._links[(ia['NEWMAN_M'],ia['NEWMAN_M'])][4]['tq']
>>> NN
[(1999, 2000, 2), (2000, 2001, 4), (2001, 2002, 7), (2002, 2003, 8),
(2003, 2004, 7), (2004, 2005, 11), (2005, 2006, 7), (2006, 2007, 11),
(2007, 2008, 3)]
>>> tit = 'NEWMAN_M'; TQmax = 12; h = 150
>>> Graph.TQshow(NN,cdir,TQmax,Tmin,Tmax,w,h,tit,fill='orange')
```

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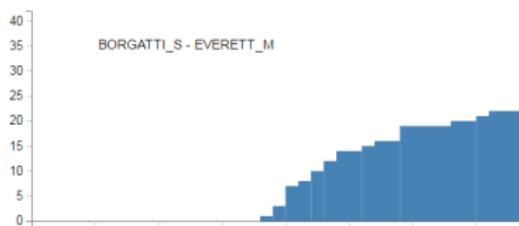
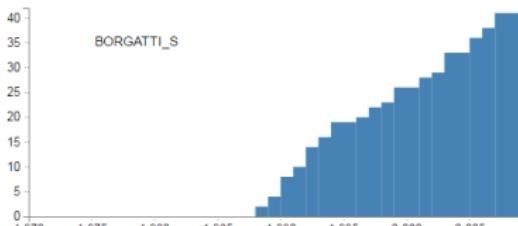
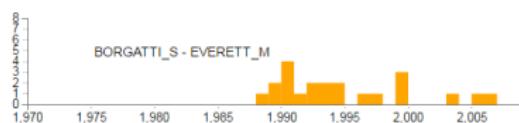
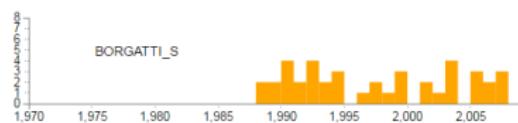
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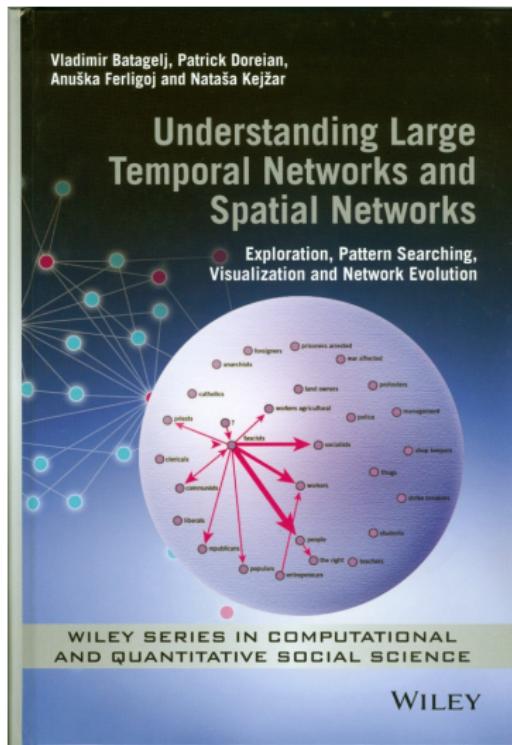
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This lecture is closely related to chapters 2 and 3 in the book:

Vladimir Batagelj, Patrick Doreian, Anuška Ferligoj and Nataša Kejžar: Understanding Large Temporal Networks and Spatial Networks: Exploration, Pattern Searching, Visualization and Network Evolution. Wiley Series in Computational and Quantitative Social Science. **Wiley**, October 2014.

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Pajek's wiki. <http://pajek.imfm.si>



Vladimir Batagelj, Andrej Mrvar: [Pajek manual](#).



Wouter De Nooy, Andrej Mrvar, Vladimir Batagelj: Exploratory Social Network Analysis with Pajek; Revised and Expanded Second Edition. Structural Analysis in the Social Sciences, Cambridge University Press, September 2011.

Names of works in WoS2Pajek

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

LEFKOVITCH LP, 1985, THEOR APPL GENET, V70, P585

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: LEFKOVIT_L(1985)70:585

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

Unusual names start with character * or \$.

... Names of works

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In the CR field other forms of ISI names and several errors and inconsistencies can be found:

NEWMAN MEJ, 2004, PHYS REV E 2, V69, ARTN 066133
PALLA G, 2005, NATURE, V435, P814, DOI 10.1038/nature03607
PAPIN JA, 2004, TRENDS BIOCHEM SCI, V29, P641, DOI
10.1016/j.tibs.2004.10.001
DOLCINI MM, 2005, J ADOLESCENT HEALTH, V36, UNSP 267.E6-15
EVANS JD, 2001, GENOME BIOL, V2, UNSP RESEARCH0001
NEWMAN MEJ, 2001, IN PRESS COMPLEX NETUNSP 215239
GRANOVET MS, 1973, AM J SOCIOLOG, V78, P1360
GRANOVETTER M, 1983, SOCIOLOGICAL THEORY, V1, P203
BORGATTI SP, 2002, UGINET WINDOWS SOFTW
BORGATTI S, 1999, UCINET V USERS GUIDE
CANTAZARO M, 2005, PHYS REV E, V71, UNSP 027103
CANTAZARO M, 2005, PHYS REV E, V71, UNSP 056104
CATANZARO M, 2005, PHYS REV E 2, V71, ARTN 056104
BRICKER PD, 1968, OCT M PSYCH SOC ST L : BRICKER

We decided to treat in short names the ARTN and UNSP values as BP values.
We also remove the DOI parts. There are also irregular names in AU field:

AU BENSON, , C
KULHAVY, , W
AU SCHONEMÄ.PH

The user can correct the typing errors and nonuniformities on the WoS file.

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For converting WoS file into networks in Pajek's format a program **WoS2Pajek** was developed (in Python). It produces the following files:

- citation network: works \times works, **Ci**;
- authorship (two-mode) network: works \times authors, **WA**; for works without complete description only the first author is known;
- keywords (two-mode) network: works \times keywords, **WK**; only for works with complete description;
- journals (two-mode) network: works \times journals, **WJ**; field J9;
- partition of works by the publication year, **year**;
- partition of works, **DC** – complete description (1) / ISI name only (0);
- vector number of pages, **np**; PG or EP – BP + 1.

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The keywords are obtained from the fields TI (title), ID, DE and AB (abstract). From the text the **stopwords** are removed and a list of words is produced. The words are lemmatized using **MontyLingua** package.

In future versions additional networks can be derived: works × discipline, works × countries, ...

In version 0.7 a GUI support (based on Tkinter) for specifying the program parameters was implemented.

Similar package of programs was produced also by **Loet Leydesdorff**.

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The current version of WoS2Pajek requires 7 parameters to be given by the user:

- MontyLingua directory: path to the directory in which the MontyLingua package is installed (put it also in the PATH env-variable);
- project directory: where the output files are saved;
- WoS file;
- maxnum – estimate of the number of all vertices (number of records + number of cited Works) – $30 * \text{number of records}$;
- step – prints info about each $k * \text{step}$ record as a trace; $\text{step} = 0$ – no trace.
- use ISI name / short name;
- make a clean WoS file without duplicates;
- boolean list [DE, ID, TI, AB] specifying which fields are sources of keywords.

Collecting the data from Web of Science

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When preparing for exploration of selected topic we first search the WoS for records matching selected keys. WoS allows storing the hits on a file, but only 500 at once.

For the list of hits we can in the **Citation report**, using the option **View citing articles**, get also the list of all works citing the works from the first list. We also save these records and join all the files into a single file to which we apply WoS2Pajek.

Using Pajek we identify the important only cited works – out-degre = 0 and large in-degree. We search for them in WoS and try to add their descriptions.

In this way we produce the final source data set for our analysis.

Types on DC file

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When we combine partial files with saved records from WoS into a single file required by the program WoS2Pajek we can include into this file some additional lines:

Comments have the form

**** comment**

Besides this we can specify different types of input records using the lines of the form

***T n**

where n is a type number (1, 2, ...). Since the same record can appear in different parts of the file its class is determined as the set of all corresponding types transformed in integer. For example:
 $\{3, 1\} \rightarrow 2^2 + 2^0 = 5$.