



Rnet, intro

V. Batagelj

Networks

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Properties

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networks

igraph in R

Pajek and R

netsJSON
and Nets

Network Analysis

1. Description of networks

Vladimir Batagelj

IMFM Ljubljana, IAM UP Koper, and NRU HSE Moscow

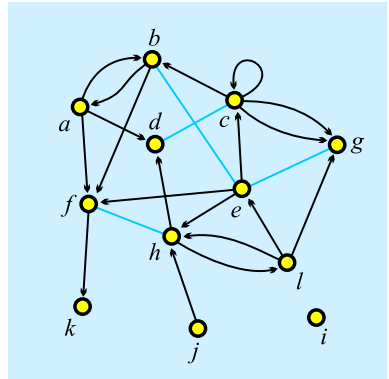
Master's programme

Applied Statistics with Social Network Analysis

International Laboratory for Applied Network Research

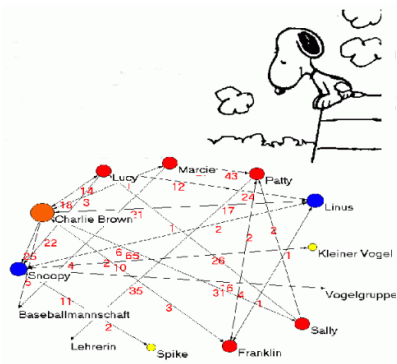
NRU HSE, Moscow 2020

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- 7 Two-mode networks
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Vladimir Batagelj: vladimir.batagelj@fmf.uni-lj.si

Current version of slides (November 17, 2020 at 04 : 56): [slides PDF](#)



Alexandra Schuler/ Marion Laging-Glaser:
Analyse von Snoopy Comics

A *network* is based on two sets – set of *nodes* (vertices), that represent the selected *units*, and 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 can be known – their *properties* (attributes). For example: name/label, type, value, ...

Network = Graph + Data

The data can be measured or computed.



Networks / Formally

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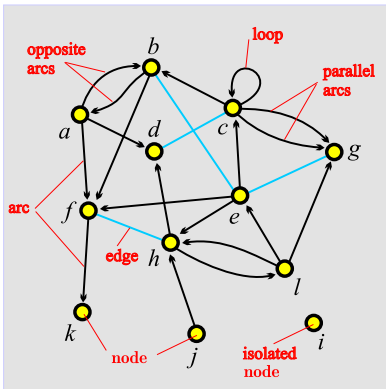
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A **network** $\mathcal{N} = (\mathcal{V}, \mathcal{L}, \mathcal{P}, \mathcal{W})$ consists of:

- 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.

$$n = |\mathcal{V}|, m = |\mathcal{L}|$$

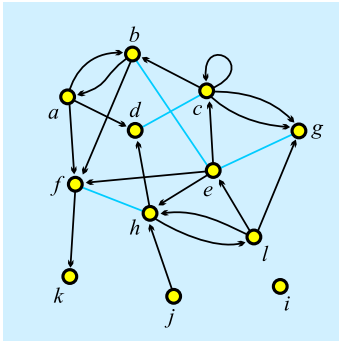
- \mathcal{P} **node value functions** / properties: $p: \mathcal{V} \rightarrow A$
- \mathcal{W} **link value functions** / weights: $w: \mathcal{L} \rightarrow B$



unit, actor – node, vertex
tie, line – link, edge, arc

arc = directed link, (a, d)
 a is the *initial* node,
 d is the *terminal* node.

edge = undirected link,
 $(c: d)$
 c and d are *end* nodes.



$$\mathcal{V} = \{a, b, c, d, e, f, g, h, i, j, k, l\}$$

$$\mathcal{A} = \{(a, b), (a, d), (a, f), (b, a), (b, f), (c, b), (c, c), (c, g)_1, (c, g)_2, (e, c), (e, f), (e, h), (f, k), (h, d), (h, l), (j, h), (l, e), (l, g), (l, h)\}$$

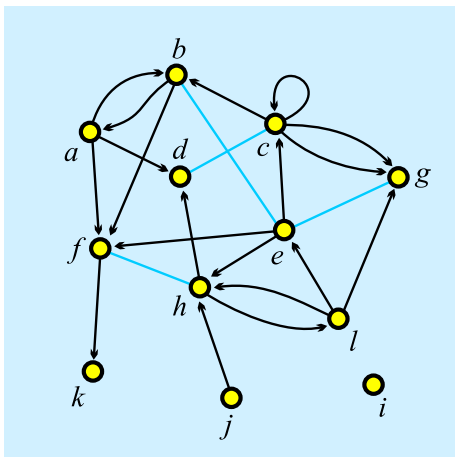
$$\mathcal{E} = \{(b : e), (c : d), (e : g), (f : h)\}$$

$$\mathcal{G} = (\mathcal{V}, \mathcal{A}, \mathcal{E})$$

$$\mathcal{L} = \mathcal{A} \cup \mathcal{E}$$

$\mathcal{A} = \emptyset$ – *undirected* graph; $\mathcal{E} = \emptyset$ – *directed* graph.

WWW: [GraphSet / net](#); [TinaSet / net](#), picture [picture](#).



```

*Vertices 12
1 "a" 0.1020 0.3226
2 "b" 0.2860 0.0876
3 "c" 0.5322 0.2304
4 "d" 0.3259 0.3917
5 "e" 0.5543 0.4770
6 "f" 0.1552 0.6406
7 "g" 0.8293 0.3249
8 "h" 0.4479 0.6866
9 "i" 0.8204 0.8203
10 "j" 0.4789 0.9055
11 "k" 0.1175 0.9032
12 "l" 0.7095 0.6475

*Arcs
1 2
2 1
1 4
1 6
2 6
3 2
3 3
3 7
3 7
5 3
5 6
5 8
6 11
8 4
10 8
12 5
12 7
8 12
12 8

*Edges
2 5
3 4
5 7
6 8
    
```

Graph / Neighbors – NET

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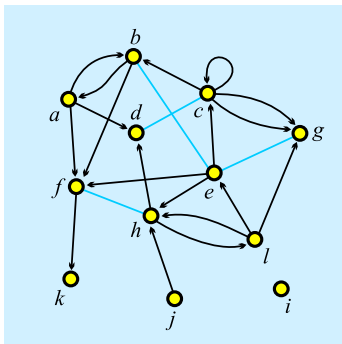
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$$N_A(a) = \{b, d, f\}$$

$$N_A(b) = \{a, f\}$$

$$N_A(c) = \{b, c, g, g\}$$

$$N_A(e) = \{c, f, h\}$$

$$N_A(f) = \{k\}$$

$$N_A(h) = \{d, l\}$$

$$N_A(j) = \{h\}$$

$$N_A(l) = \{e, g, h\}$$

$$N_E(e) = \{b, g\}$$

$$N_E(c) = \{d\}$$

$$N_E(f) = \{h\}$$

WWW: [GraphList / net](#); [TinaList / net](#).

$$N(v) = N_A(v) \cup N_E(v), \quad \text{also } N_{out}(v), N_{in}(v)$$

Star in v , $S(v)$ is the set of all links with v as their initial node.

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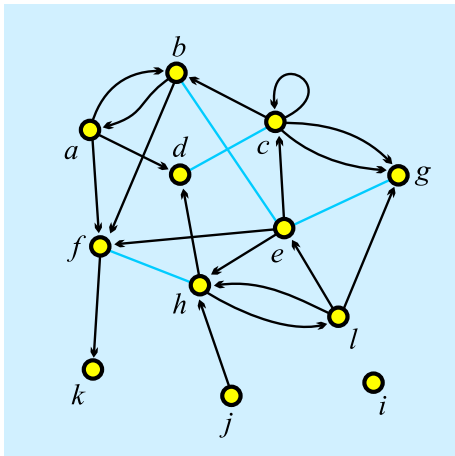
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```
*Vertices 12
1 "a" 0.1020 0.3226
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9 "i" 0.8204 0.8203
10 "j" 0.4789 0.9055
11 "k" 0.1175 0.9032
12 "l" 0.7095 0.6475
```

```
*Arcslist
1 2 4 6
2 1 6
3 2 3 7 7
5 3 6 8
6 11
8 4 12
10 8
12 5 7 8
```

```
*Edgeslist
2 5
3 4
5 7
6 8
```

Graph / Matrix – MAT

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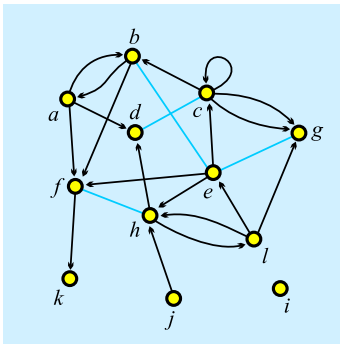
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	a	b	c	d	e	f	g	h	i	j	k	l
a	0	1	0	1	0	1	0	0	0	0	0	0
b	1	0	0	0	1	1	0	0	0	0	0	0
c	0	1	1	1	0	0	2	0	0	0	0	0
d	0	0	1	0	0	0	0	0	0	0	0	0
e	0	1	1	0	0	1	1	1	0	0	0	0
f	0	0	0	0	0	0	0	1	0	0	1	0
g	0	0	0	0	1	0	0	0	0	0	0	0
h	0	0	0	1	0	1	0	0	0	0	0	1
i	0	0	0	0	0	0	0	0	0	0	0	0
j	0	0	0	0	0	0	0	1	0	0	0	0
k	0	0	0	0	0	0	0	0	0	0	0	0
l	0	0	0	0	1	0	1	1	0	0	0	0

WWW: [GraphMat / net](#); [TinaMat / net, paj](#).

Graph G is *simple* if in the corresponding matrix all entries are 0 or 1.

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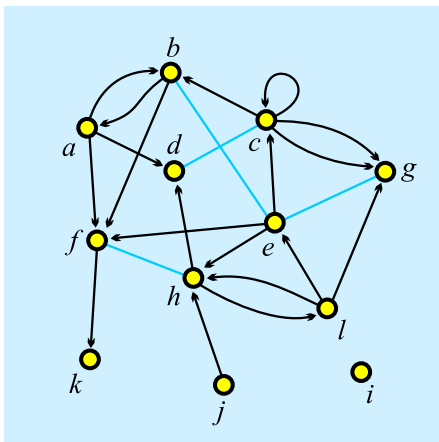
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*Vertices 12

1	"a"	0.1020	0.3226
2	"b"	0.2860	0.0876
3	"c"	0.5322	0.2304
4	"d"	0.3259	0.3917
5	"e"	0.5543	0.4770
6	"f"	0.1552	0.6406
7	"g"	0.8293	0.3249
8	"h"	0.4479	0.6866
9	"i"	0.8204	0.8203
10	"j"	0.4789	0.9055
11	"k"	0.1175	0.9032
12	"l"	0.7095	0.6475

*Matrix

0	1	0	1	0	1	0	0	0	0	0	0
1	0	0	0	1	1	0	0	0	0	0	0
0	1	1	1	0	0	2	0	0	0	0	0
0	0	1	0	0	0	0	0	0	0	0	0
0	1	1	0	0	1	1	1	0	0	0	0
0	0	0	0	0	0	0	1	0	0	1	0
0	0	0	0	1	0	0	0	0	0	0	0
0	0	0	1	0	1	0	0	0	0	0	1
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	1	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	1	0	1	1	0	0	0	0



Node Properties / CLU, VEC, PER

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All three types of files have the same structure:

*vertices n

v_1

...

v_n

n is the number of nodes
node 1 has value v_1

CLustering – partition of nodes – *nominal* or *ordinal* data about nodes

$v_i \in \mathbb{N}$: node i belongs to the cluster/group v_i ;

VEctor – *numeric* data about nodes

$v_i \in \mathbb{R}$: the property has value v_i on node i ;

PErmutation – *ordering* of nodes

$v_i \in \mathbb{N}$: node i is at the v_i -th position.

When collecting the network data consider to provide as much properties as possible.



Example: Wolfe Monkey Data

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inter.net	inter.net	sex.clu	age.vec	rank.per
*Vertices 20		*vertices 20	*vertices 20	*vertices 20
1 *m01"	1 6 5	1	15	1
2 *m02"	1 7 9	1	10	2
3 *m03"	1 8 7	1	10	3
4 *m04"	1 9 4	1	8	4
5 *m05"	1 10 3	1	7	5
6 *f06"	1 11 3	2	15	10
7 *f07"	1 12 7	2	5	11
8 *f08"	1 13 3	2	11	6
9 *f09"	1 14 2	2	8	12
10 *f10"	1 15 5	2	9	9
11 *f11"	1 16 1	2	16	7
12 *f12"	1 17 4	2	10	8
13 *f13"	1 18 1	2	14	18
14 *f14"	2 3 5	2	5	19
15 *f15"	2 4 1	2	7	20
16 *f16"	2 5 3	2	11	13
17 *f17"	2 6 1	2	7	14
18 *f18"	2 7 4	2	5	15
19 *f19"	2 8 2	2	15	16
20 *f20"	2 9 6	2	4	17
*Edges	2 10 2			
1 2 2	2 11 5			
1 3 10	2 12 4			
1 4 4	2 13 3			
- - -	2 14 2			
	...			

Important note: 0 is not allowed as node number.



Pajek's Project File / PAJ

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All types of data can be combined into a single file – Pajek's *project file file.paj*.

The easiest way to do this is:

- read all data files in Pajek,
- compute some additional data,
- delete (dispose) some data,
- save all as a project file with
`File/Pajek Project File/Save`.

Next time you can restore everything with a single
`File/Pajek Project File/Read`.

Wolfe network as a Pajek's project file ([PDF/paj](#)).

Special graphs – path, cycle, star, complete

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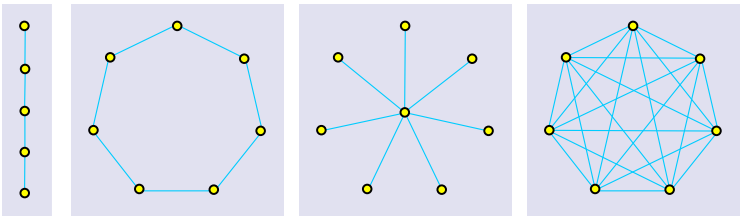
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Graphs: *path* P_5 , *cycle* C_7 , *star* S_8 in *complete graph* K_7 .



Representations of properties

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Properties of nodes \mathcal{P} and links \mathcal{W} can be measured in different scales: numerical, ordinal and nominal. They can be *input* as data or *computed* from the network.

In **Pajek** numerical properties of nodes are represented by *vectors*, nominal properties by *partitions* or as *labels* of nodes. Numerical property can be displayed as *size* (width and height) of node (figure), as its *coordinate*; and a nominal property as *color* or *shape* of the figure, or as a node's *label* (content, size and color).

We can assign in **Pajek** numerical values to links. They can be displayed as *value*, *thickness* or *grey level*. Nominal values can be assigned as *label*, *color* or *line pattern* (see **Pajek manual**, section **5.3**).

Some related operations

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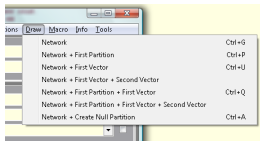
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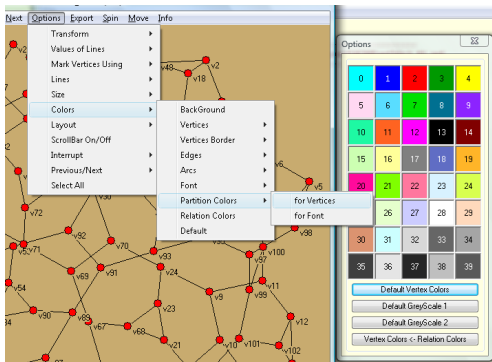
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Operations/Network+Vector/Transform/Put
Network/Create Vector/Get Coordinate
[Draw] Options
[Draw] Layout/Energy/Kamada-Kawai/Free
[Draw] Export/2D/EPS-PS





Display of properties – school (Moody)

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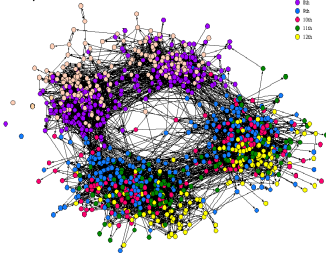
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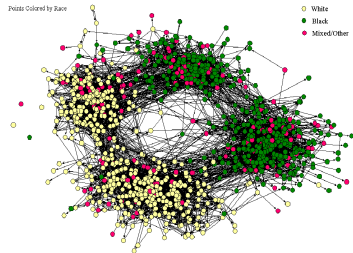
The Social Structure of "Countryside" School District

Points Colored by Grade



The Social Structure of "Countryside" School District

Points Colored by Race





Types of networks

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Besides ordinary (directed, undirected, mixed) networks some extended types of networks are also used:

- *2-mode networks*, bipartite (valued) graphs – networks between two disjoint sets of nodes.
- *multi-relational networks*.
- *temporal networks*, dynamic graphs – networks changing over time.
- specialized networks: representation of genealogies as *p-graphs*, *Petri's nets*, ...

The network (input) file formats should provide means to express all these types of networks. All interesting data should be recorded (respecting privacy).

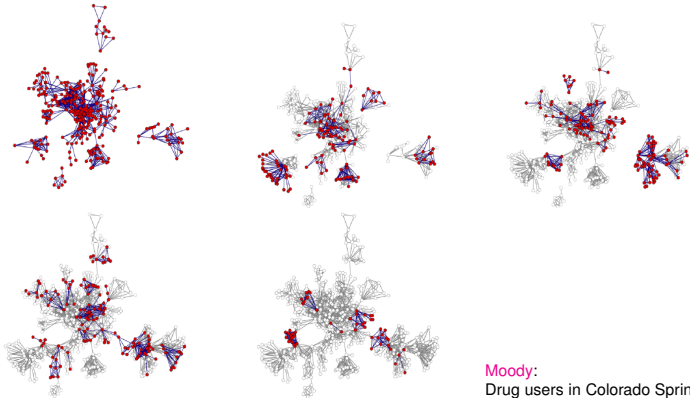


Temporal networks

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In a *temporal network* the presence/activity of node/link can change through time. **Pajek** supports two types of descriptions of temporal networks based on *presence* and on *events*.



Moody:

Drug users in Colorado Springs, 5 years





Temporal network

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Temporal network

$$\mathcal{N}_T = (\mathcal{V}, \mathcal{L}, \mathcal{P}, \mathcal{W}, T)$$

is obtained if the *time* T is attached to an ordinary network. T is a set of *time points* $t \in T$.

In temporal network nodes $v \in \mathcal{V}$ and links $l \in \mathcal{L}$ are not necessarily present or active in all time points. If a link $l(u, v)$ is active in time point t then also its endnodes u and v should be active in time t .

We will denote the network consisting of links and nodes active in time $t \in T$ by $\mathcal{N}(t)$ and call it a *time slice* in time point t . To get time slices in **Pajek** use

Network/Temporal Network/Generate in time



Temporal networks – presence

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```
*Vertices 3
1 "a" [5-10, 12-14]
2 "b" [1-3, 7]
3 "e" [4-*]
*Edges
1 2 1 [7]
1 3 1 [6-8]
```

Time.net
netsJSON

Node *a* is present in time points 5, 6, 7, 8, 9, 10 and 12, 13, 14.

Edge (1 : 3) is present in time points 6, 7, 8.

* means 'infinity'.

A link is present, if both its endnodes are present.



Temporal networks – events

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Event	Explanation
TI t	initial events – following events happen when time point t starts
TE t	end events – following events happen when time point t is finished
AV $v n s$	add vertex v with label n and properties s
HV v	hide node v
SV v	show node v
DV v	delete node v
AA $u v s$	add arc (u, v) with properties s
HA $u v$	hide arc (u, v)
SA $u v$	show arc (u, v)
DA $u v$	delete arc (u, v)
AE $u v s$	add edge $(u : v)$ with properties s
HE $u v$	hide edge $(u : v)$
SE $u v$	show edge $(u : v)$
DE $u v$	delete edge $(u : v)$
CV $v s$	change property of node v to s
CA $u v s$	change property of arc (u, v) to s
CE $u v s$	change property of edge $(u : v)$ to s
CT $u v$	change (un)directedness of link (u, v)
CD $u v$	change direction of arc (u, v)
PE $u v s$	replace pair of arcs (u, v) and (v, u) by single edge $(u : v)$ with properties s
AP $u v s$	add pair of arcs (u, v) and (v, u) with properties s
DP $u v$	delete pair of arcs (u, v) and (v, u)
EP $u v s$	replace edge $(u : v)$ by pair of arcs (u, v) and (v, u) with properties s

s can be empty.

In case of parallel links : k denotes the k -th link – HE:3 14 37 hides the third edge linking nodes 14 and 37.

*Vertices 3

*Events

```

TI 1
AV 2 "b"
TE 3
HV 2
TI 4
AV 3 "e"
TI 5
AV 1 "a"
TI 6
AE 1 3 1
TI 7
SV 2
AE 1 2 1
TE 7
DE 1 2
DV 2
TE 8
DE 1 3
TE 10
HV 1
TI 12
SV 1
TE 14
DV 1

```

Time.tim. Friends.tim.

File/Network/Read Time Events





Temporal networks / September 11

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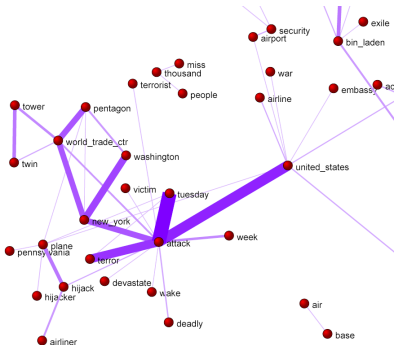
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Pictures in SVG: *66 days*.

Steve Corman with collaborators from Arizona State University transformed, using his Centering Resonance Analysis (*CRA*), daily Reuters news (66 days) about September 11th into a temporal network of words coappearance.



Multi-relational networks

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A *multi-relational network* is denoted by

$$\mathcal{N} = (\mathcal{V}, (\mathcal{L}_1, \mathcal{L}_2, \dots, \mathcal{L}_k), \mathcal{P}, \mathcal{W})$$

and contains different relations \mathcal{L}_i (sets of links) over the same set of nodes. Also the weights from \mathcal{W} are defined on different relations or their union.

Examples of such networks are: Transportation system in a city (stations, lines); **WordNet** (words, semantic relations: synonymy, antonymy, hyponymy, meronymy, ...), **KEDS** networks (states, relations between states: Visit, Ask information, Warn, Expel person, ...), ...



... Multi-relational networks

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The relation can be assigned to a link as follows:

- add to a keyword for description of links (`*arcs`, `*edges`, `*arcslist`, `*edgeslist`, `*matrix`) the number of relation followed by its name:

```
*arcslist :3 "sent a letter to"
```

All links controlled by this keyword belong to the specified relation. (**Sampson**, **SampsonL**)

- Any link controlled by `*arcs` or `*edges` can be assigned to selected relation by starting its description by the number of this relation.

```
3: 47 14 5
```

Link with endnodes 47 and 14 and weight 5 belongs to relation 3.



Computer-assisted text analysis

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An often used way to obtain networks is the *computer-assisted text analysis* (CaTA).

Terms considered in TA are collected in a *dictionary* (it can be fixed in advance, or built dynamically). The main two problems with terms are *equivalence* (different words representing the same term) and *ambiguity* (same word representing different terms). Because of these the *coding* – transformation of raw text data into formal *description* – is done often manually or semiautomatically. As *units* of TA we usually consider clauses, statements, paragraphs, news, messages, . . .

Till now the thematic and semantic TA mainly used statistical methods for analysis of the coded data.

In thematic TA the units are coded as rectangular matrix $\textit{Text units} \times \textit{Concepts}$ which can be considered as a two-mode network.

Examples: M.M. Miller: *VBPro*, H. Klein: *Text Analysis/TextQuest*.



... approaches to CaTA

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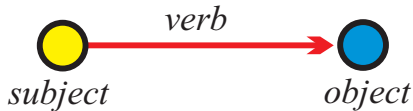
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In semantic TA the units (often clauses) are encoded according to the S-V-O (*Subject-Verb-Object*) model or its improvements.



Examples: **Roberto Franzosi**; **KEDS**, **Tabari**, **KEDS / Gulf**.

This coding can be directly considered as network with *Subjects* \cup *Objects* as nodes and links (arcs) labeled with *Verbs*.

See also **RDF** triples in **semantic web**, **SPARQL**.



Multi-relational temporal network – KEDS/WEIS

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```
% Recoded by WEISmonths, Sun Nov 28 21:57:00 2004
% from http://www.ku.edu/~keds/data.dir/balk.html
*vertices 325
1 "AFG" [1-*]
2 "AFR" [1-*]
3 "ALB" [1-*]
4 "ALBMED" [1-*]
5 "ALG" [1-*]
...
318 "YUGGOV" [1-*]
319 "YUGMAC" [1-*]
320 "YUGMED" [1-*]
321 "YUGMTN" [1-*]
322 "YUGSER" [1-*]
323 "ZAI" [1-*]
324 "ZAM" [1-*]
325 "ZIM" [1-*]
*arcs :0 "*** ABANDONED"
*arcs :10 "YIELD"
*arcs :11 "SURRENDER"
*arcs :12 "RETREAT"
...
*arcs :223 "MIL ENGAGEMENT"
*arcs :224 "RIOT"
*arcs :225 "ASSASSINATE TORTURE"
*arcs
224: 314 153 1 [4] 890402 YUG KSV 224 (RIOT) RIOT-TORN
212: 314 83 1 [4] 890404 YUG ETHALB 212 (ARREST PERSON) ALB ET
224: 3 83 1 [4] 890407 ALB ETHALB 224 (RIOT) RIOTS
123: 83 153 1 [4] 890408 ETHALB KSV 123 (INVESTIGATE) PROBIN
...
42: 105 63 1 [175] 030731 GER CYP 042 (ENDORSE) GAVE S
212: 295 35 1 [175] 030731 UNWCT BOSSER 212 (ARREST PERSON) SENTEN
43: 306 87 1 [175] 030731 VAT EUR 043 (RALLY) RALLIED
13: 295 35 1 [175] 030731 UNWCT BOSSER 013 (RETRACT) CLEARE
121: 295 22 1 [175] 030731 UNWCT BAL 121 (CRITICIZE) CHARGE
122: 246 295 1 [175] 030731 SER UNWCT 122 (DENIGRATE) TESTIF
121: 35 295 1 [175] 030731 BOSSER UNWCT 121 (CRITICIZE) ACCUSE
```

Kansas Event Data System **KEDS**



V. Batagelj

Rnet, intro



Two-mode networks

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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 endnode 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).

A two-mode network is announced by `*vertices n nU`.

Authors and works.



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

Davis.paj. Freeman's overview.

NAMES OF PARTICIPANTS OF GROUP I	CODE NUMBERS AND DATES OF SOCIAL EVENTS REFERRED IN <i>Old City Herald</i>													
	(1) 6/27	(2) 3/2	(3) 4/12	(4) 9/26	(5) 2/25	(6) 5/19	(7) 3/15	(8) 9/16	(9) 4/8	(10) 6/10	(11) 2/23	(12) 4/7	(13) 11/21	(14) 8/3
1. Mrs. Evelyn Jefferson.....	X	X	X	X	X	X	X	X	X					
2. Miss Laura Mandeville.....	X	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	X					
5. Miss Charlotte McDowd.....			X	X	X	X	X	X	X					
6. Miss Frances Anderson.....			X		X	X	X	X	X					
7. Miss Eleanor Nye.....					X	X	X	X	X					
8. Miss Pearl Oglethorpe.....						X	X	X	X					
9. Miss Ruth DeSand.....					X	X	X	X	X					
10. Miss Verne Sanderson.....						X	X	X	X					
11. Miss Myra Liddell.....								X	X	X		X	X	
12. Miss Katherine Rogers.....								X	X	X		X	X	X
13. Mrs. Sylvia Avondale.....								X	X	X		X	X	X
14. Mrs. Nora Fayette.....						X	X	X	X	X		X	X	X
15. Mrs. Helen Lloyd.....							X	X	X	X		X	X	X
16. Mrs. Dorothy Murchison.....								X	X	X		X	X	X
17. Mrs. Olivia Carleton.....									X	X	X			
18. Mrs. Flora Price.....									X	X	X			



igraph Example

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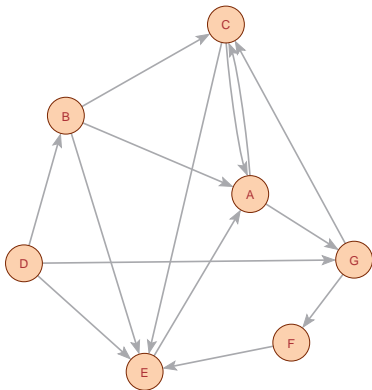
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```
> library(igraph)
> links <- c("A", "C", "A", "G",
+ "B", "C", "B", "A", "B", "E",
+ "C", "A", "C", "E", "D", "B",
+ "D", "G", "D", "E", "E", "A",
+ "F", "E", "G", "C", "G", "F")
> L <- graph(links)
> L
IGRAPH bb7e45b DN-- 7 14 --
+ attr: name (v/c)
+ edges from bb7e45b (vertex names):
 [1] A->C A->G B->C B->A B->E C->G
> plot(L)
> vcount(L)
[1] 7
> ecount(L)
[1] 14
> L <- L + vertex("H")
> plot(L)
```

igraph is a library for analyzing networks. It has also an R interface.

For other R libraries for solving network analysis problems see: Ian McCulloh, Alexander Perrone: R Packages for Social Network Analysis. **ESNAM**. Springer 2018.

See also: [sna](#), [network](#), [statnet](#), [ggnet](#)



igraph object display

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D/U 'D' – directed / 'U' – undirected.

N/- 'N' – named (labeled). A dash means that the network is not named.

W/- 'W' – weighted (has values on links). Unweighted networks have a dash in this position.

B/- 'B' – bipartite (two-mode). A dash means that the network is one-mode.



igraph attributes

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```
> V(L)
+ 8/8 vertices, named, from 84e744b:
[1] A C G B E D F H
> E(L)
+ 14/14 edges from 84e744b (vertex names):
[1] A->C A->G B->C B->A B->E C->A C->E D->B D->G D->E E->A F->E
> V(L)$name
[1] "A" "C" "G" "B" "E" "D" "F" "H"
> V(L)$name[5] <- "John"
> V(L)$color <- sample(c("yellow", "cyan"), vcount(L), rep=TRUE)
> plot(L)
> ye <- V(L)[color=="yellow"]; cy <- V(L)[color=="cyan"]
> E(L)[ye %--% cy]$color <- "red"
> E(L)[ye %--% ye]$color <- "blue"
> E(L)[cy %--% cy]$color <- "blue"
> L$name <- "Example"
> E(L)$weight <- sample(1:10, ecount(L), rep=TRUE)
> graph_attr_names(L)
[1] "name"
> graph_attr(L)
$name
[1] "Example"
> vertex_attr_names(L)
[1] "name" "color"
> edge_attr_names(L)
[1] "color" "weight"
> w <- E(L)$weight; plot(L, edge.width=w)
> write.graph(L, "Links.net", format="pajek")
```



Description of networks using a spreadsheet

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How to describe a network \mathcal{N} ? In principle the answer is simple – we list its components \mathcal{V} , \mathcal{L} , \mathcal{P} , and \mathcal{W} .

The simplest way is to describe a network \mathcal{N} by providing $(\mathcal{V}, \mathcal{P})$ and $(\mathcal{L}, \mathcal{W})$ in a form of two tables.

As an example, let us describe a part of network determined by the following works:

Generalized blockmodeling, Clustering with relational constraint, Partitioning signed social networks, The Strength of Weak Ties

There are nodes of different types (modes): persons, papers, books, series, journals, publishers; and different relations among them: author_of, editor_of, contained_in, cites, published_by.

Both tables are often maintained in Excel. They can be exported as text in **CSV** (Comma Separated Values) format.



bibNodes.csv

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```
name;mode;country;sex;year;vol;num;fPage;lPage;x;y
"Batagelj, Vladimir";person;SI;m;;;;;809.1;653.7
"Doreian, Patrick";person;US;m;;;;;358.5;679.1
"Ferligoj, Anuška";person;SI;f;;;;;619.5;680.7
"Granovetter, Mark";person;US;m;;;;;145.6;660.5
"Moustaki, Irini";person;UK;f;;;;;783.0;228.0
"Mrvar, Andrej";person;SI;m;;;;;478.0;630.1
"Clustering with relational constraint";paper;;;1982;47;;413;426
"The Strength of Weak Ties";paper;;;1973;78;6;1360;1380;111.3;32
"Partitioning signed social networks";paper;;;2009;31;1;1;11;408
"Generalized Blockmodeling";book;;;2005;24;;1;385;533.0;445.9
"Psychometrika";journal;;;;;741.8;086.1
"Social Networks";journal;;;;;321.4;236.5
"The American Journal of Sociology";journal;;;;;111.3;168.9
"Structural Analysis in the Social Sciences";series;;;;;310.4
"Cambridge University Press";publisher;UK;;;;;534.3;238.2
"Springer";publisher;US;;;;;884.6;174.0
```

bibNodes.csv

In large networks, to avoid the empty cells, we split a network to some subnetworks – a collection.



bibLinks.csv

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```
from;relation;to
"Batagelj, Vladimir";authorOf;"Generalized Blockmodeling"
"Doreian, Patrick";authorOf;"Generalized Blockmodeling"
"Ferligoj, Anuška";authorOf;"Generalized Blockmodeling"
"Batagelj, Vladimir";authorOf;"Clustering with relational constraint"
"Ferligoj, Anuška";authorOf;"Clustering with relational constraint"
"Granovetter, Mark";authorOf;"The Strength of Weak Ties"
"Granovetter, Mark";editorOf;"Structural Analysis in the Social Sciences"
"Doreian, Patrick";authorOf;"Partitioning signed social networks"
"Mrvar, Andrej";authorOf;"Partitioning signed social networks"
"Moustaki, Irini";editorOf;"Psychometrika"
"Doreian, Patrick";editorOf;"Social Networks"
"Generalized Blockmodeling";containedIn;"Structural Analysis in the Social Sciences"
"Clustering with relational constraint";containedIn;"Psychometrika"
"The Strength of Weak Ties";containedIn;"The American Journal of Sociology"
"Partitioning signed social networks";containedIn;"Social Networks"
"Partitioning signed social networks";cites;"Generalized Blockmodeling"
"Generalized Blockmodeling";cites;"Clustering with relational constraint"
"Structural Analysis in the Social Sciences";publishedBy;"Cambridge University Press"
"Psychometrika";publishedBy;"Springer"
```

bibLinks.csv





Factorization and description of large networks

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To save space and improve the computing efficiency we often replace values of categorical variables with integers. In R this encoding is called a *factorization*.

We enumerate all possible values of a given categorical variable (coding table) and afterwards replace each its value by the corresponding index in the coding table.

This approach is used in most programs dealing with large networks. Unfortunately the coding table is often a kind of meta-data.



CSV2Pajek.R

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```
# transforming CSV file to Pajek files
# by Vladimir Batagelj, June 2016
# setwd("C:/Users/batagelj/work/Python/graph/SVG/EUSN")
# colC <- c(rep("character",4),rep("numeric",7)); nas=c("", "NA", "NaN")
colC <- c(rep("character",4),rep("numeric",5)); nas=c("", "NA", "NaN")
nodes <- read.csv2("bibNodes.csv", encoding='UTF-8', colClasses=colC, na.strings=nas)
n <- nrow(nodes); M <- factor(nodes$mode); S <- factor(nodes$sex)
mod <- levels(M); sx <- levels(S); S <- as.numeric(S); S[is.na(S)] <- 0
links <- read.csv2("bibLinks.csv", encoding='UTF-8', colClasses="character")
F <- factor(links$from, levels=nodes$name, ordered=TRUE)
T <- factor(links$to, levels=nodes$name, ordered=TRUE)
R <- factor(links$relation); rel <- levels(R)
net <- file("bib.net", "w"); cat('*vertices ', n, '\n', file=net)
clu <- file("bibMode.clu", "w"); sex <- file("bibSex.clu", "w")
cat('%', file=clu); cat('%', file=sex)
for(i in 1:length(mod)) cat(' ', i, mod[i], file=clu)
cat('\n*vertices ', n, '\n', file=clu)
for(i in 1:length(sx)) cat(' ', i, sx[i], file=sex)
cat('\n*vertices ', n, '\n', file=sex)
for(v in 1:n) {
  cat(v, ' ', nodes$name[v], '\n', sep='', file=net);
  cat(M[v], '\n', file=clu); cat(S[v], '\n', file=sex)
}
for(r in 1:length(rel)) cat('*arcs :', r, ' ', rel[r], '\n', sep='', file=net)
cat('*arcs\n', file=net)
for(a in 1:nrow(links))
  cat(R[a], ': ', F[a], ' ', T[a], ' 1 1 ', rel[R[a]], '\n', sep='', file=net)
close(net); close(clu); close(sex)
```

CSV2Pajek.R



```
*vertices 16
1 "Batagelj, Vladimir"
2 "Doreian, Patrick"
3 "Ferligoj, Anuška"
4 "Granovetter, Mark"
5 "Moustaki, Irini"
6 "Mrvar, Andrej"
7 "Clustering with relational constraint"
8 "The Strength of Weak Ties"
9 "Partitioning signed social networks"
10 "Generalized Blockmodeling"
11 "Psychometrika"
12 "Social Networks"
13 "The American Journal of Sociology"
14 "Structural Analysis in the Social Sciences"
15 "Cambridge University Press"
16 "Springer"
*arcs :1 "authorOf"
*arcs :2 "cites"
*arcs :3 "containedIn"
*arcs :4 "editorOf"
*arcs :5 "publishedBy"

*arcs
1: 1 10 1 1 "authorOf"
1: 2 10 1 1 "authorOf"
1: 3 10 1 1 "authorOf"
1: 1 7 1 1 "authorOf"
1: 3 7 1 1 "authorOf"
1: 4 8 1 1 "authorOf"
4: 4 14 1 1 "editorOf"
1: 2 9 1 1 "authorOf"
1: 6 9 1 1 "authorOf"
4: 5 11 1 1 "editorOf"
4: 2 12 1 1 "editorOf"
3: 10 14 1 1 "containedIn"
3: 7 11 1 1 "containedIn"
3: 8 13 1 1 "containedIn"
3: 9 12 1 1 "containedIn"
2: 9 10 1 1 "cites"
2: 10 7 1 1 "cites"
5: 14 15 1 1 "publishedBy"
5: 11 16 1 1 "publishedBy"
```

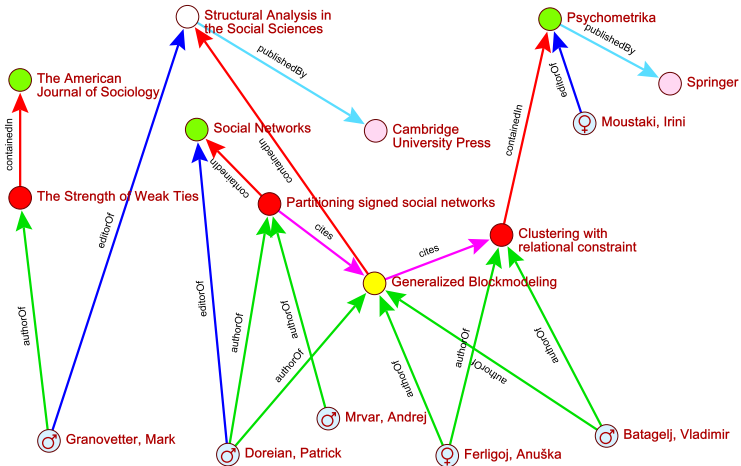
[bib.net](#), [bibMode.clu](#), [bibSex.clu](#); [bib.paj](#), [bib.ini](#).

Bibliographic network – picture / Pajek

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Reading Pajek files in R

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Temporal network data

netsJSON format

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For describing temporal networks we initially, extending Pajek format, defined and used a lanus format.

Recently we started to develop a new format based on JSON – we named it netsJSON (see [EDA: Data on files](#), slides 46-57).

netsJSON has two formats: a *basic* and a *general* format. Current implementation of the TQ library supports only the basic format. netsJSON format is supported by a Python library [Nets](#).



Informal description of the basic netsJSON format

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```
{
  "netsJSON": "basic",
  "info": {
    "org":1, "nNodes":n, "nArcs":mA, "nEdges":mE,
    "simple":TF, "directed":TF, "multirel":TF, "mode":m,
    "network":fName, "title":title,
    "time": { "Tmin":tm, "Tmax":tM, "Tlabs": {labs} },
    "meta": [events], ...
  },
  "nodes": [
    { "id":nodeId, "lab":label, "x":x, "y":y, ... },
    ***
  ]
  "links": [
    { "type":arc/edge, "n1":nodeID1, "n2":nodeID2, "rel":r },
    ***
  ]
}
```

where ... are user defined properties and *** is a sequence of such elements.



Basic netsJSON format

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An event description can contain fields:

```
{  "date": date,  
  "title": short description,  
  "author": name,  
  "desc": long description,  
  "url": URL,  
  "cite": reference,  
  "copy": copyright  
}
```

for describing temporal networks a node element and a link element has an additional required property t_q

Example 1, Franzosi's violence network / UTF-8 no sig