Introduction to Network Analysis

1. Description of networks

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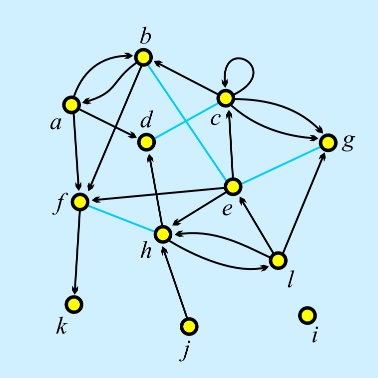
Outline



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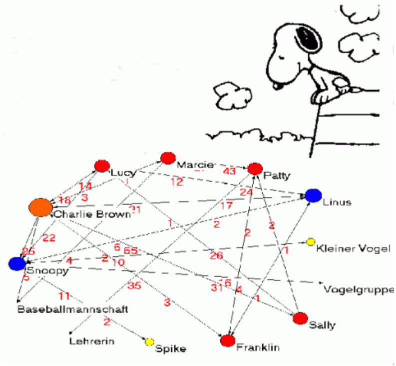
Current version of slides (December 4, 2018 at 11 : 49): slides PDF

Networks



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

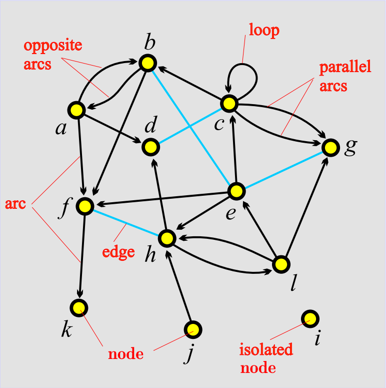
The data can be measured or computed.

Networks / Formally

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: $p : \mathcal{V} \to A$
- $\mathcal{W}$ link value functions / weights: $w : \mathcal{L} \to B$

Graph

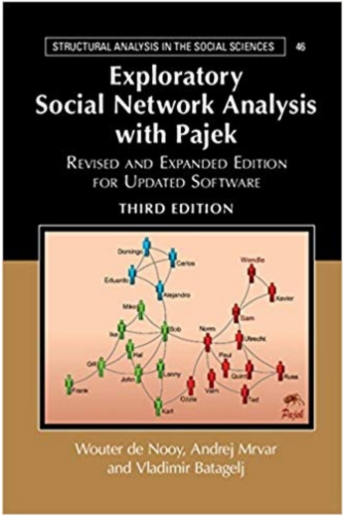


unit, actor – node, vertex
tie, line – link, edge, arc

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.

ESNA Pajek



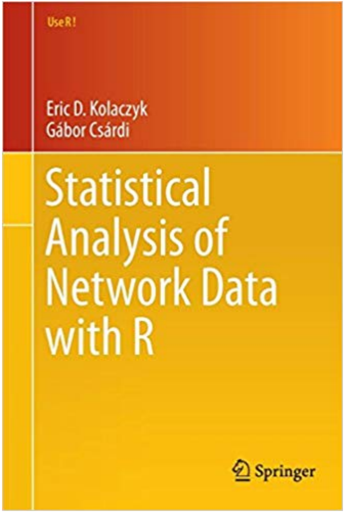
An introduction to social network analysis with **Pajek** is available in the book ESNA 3 (de Nooy, Mrvar, Batagelj, CUP 2005, 2011, 2018).

ESNA in Japanese was published by Tokyo Denki University Press in 2010; and in Chinese by Beijing World Publishing in November 2012.

Pajek – program for analysis and visualization of large networks is freely available, for noncommercial use, at its web site.

http://mrvar.fdv.uni-lj.si/pajek/

igraph



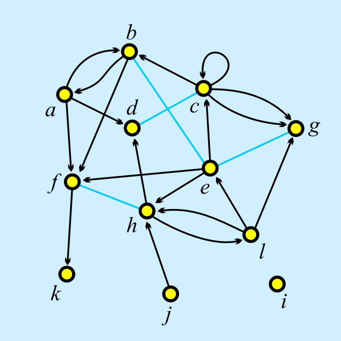
A book on Statistical Analysis of Network Data with R using the package igraph was written by Kolaczyk, Eric D. and Csárdi, Gábor (Springer 2014).

Another book on igraph is prepared by Gábor Csárdi, Tamás Nepusz and Edoardo M. Airoldi draft.

igraph can be installed from CRAN

`https://cran.r-project.org/web/packages/igraph/index.html`

Graph / Sets – NET



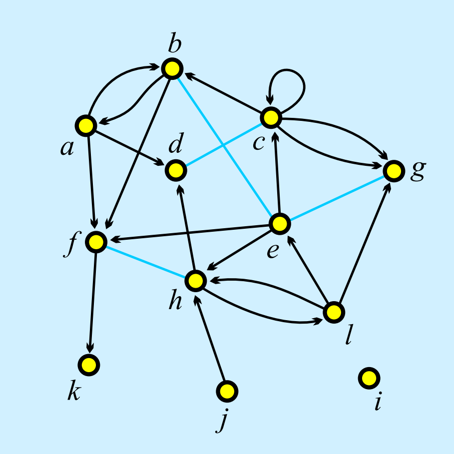
$$
\begin{aligned}
\mathcal{V} &= \{a, b, c, d, e, f, g, h, i, j, k, l\} \\
\mathcal{A} &= \{(a, b), (a, d), (a, f), (b, a), \\
&\quad (b, f), (c, b), (c, c), (c, g)_1, \\
&\quad (c, g)_2, (e, c), (e, f), (e, h), \\
&\quad (f, k), (h, d), (h, l), (j, h), \\
&\quad (l, e), (l, g), (l, h)\} \\
\mathcal{E} &= \{(b{:}\ e), (c{:}\ d), (e{:}\ g), (f{:}\ h)\} \\
\mathcal{G} &= (\mathcal{V}, \mathcal{A}, \mathcal{E}) \\
\mathcal{L} &= \mathcal{A} \cup \mathcal{E}
\end{aligned}
$$

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

Pajek: local: `GraphSet`; `TinaSet`;

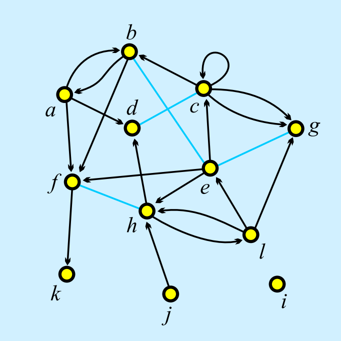
WWW: `GraphSet` / `net`; `TinaSet` / `net`, picture `picture`.

Graph / Sets – NET




```
*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



$N_A(a) = \{b, d, f\}$
$N_A(b) = \{a, f\}$
$N_A(c) = \{b, c, g, g\}$
$N_A(e) = \{c, f, h\}$
$N_A(f) = \{k\}$
$N_A(h) = \{d, l\}$
$N_A(j) = \{h\}$
$N_A(l) = \{e, g, h\}$

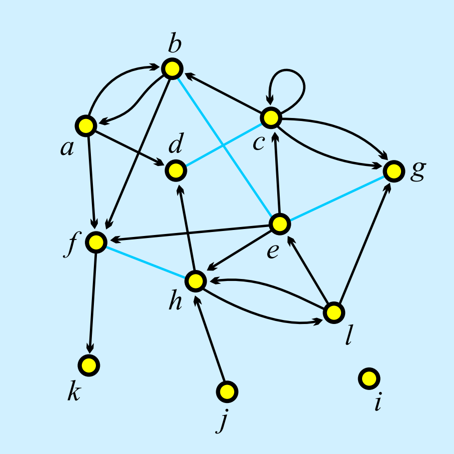
$N_E(e) = \{b, g\}$
$N_E(c) = \{d\}$
$N_E(f) = \{h\}$

Pajek: local: `GraphList`; `TinaList`;
WWW: `GraphList` / `net`; `TinaList` / `net`.

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

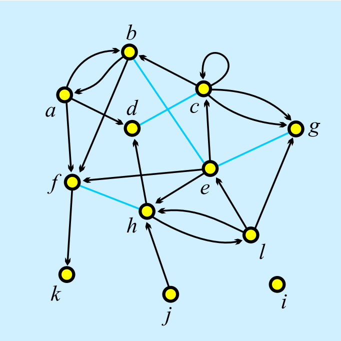
Star in v, $S(v)$ is the set of all links with v as their initial node.

Graph / Neighbors – NET




```
*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
*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
```

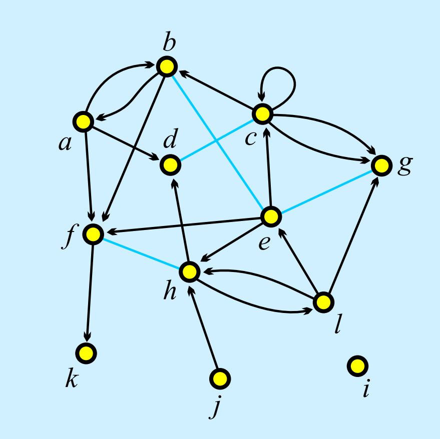
Graph / Matrix – MAT



	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

Pajek: local: `GraphMat`; `TinaMat`, picture `picture`;
WWW: `GraphMat` / `net`; `TinaMat` / `net`, `paj`.
Graph *G* is *simple* if in the corresponding matrix all entries are 0 or 1.

Graph / Matrix – MAT




```
*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

All three types of files have the same structure:

`*vertices` n	n is the number of nodes
v_1	node 1 has value v_1
...	
v_n	

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

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`

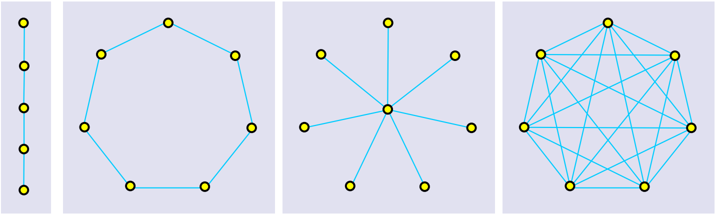
All types of data can be combined into a single file – Pajek's *project* file *file*`.paj`.
The easiest way to do this is:

- 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



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

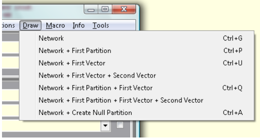
Representations of properties

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.

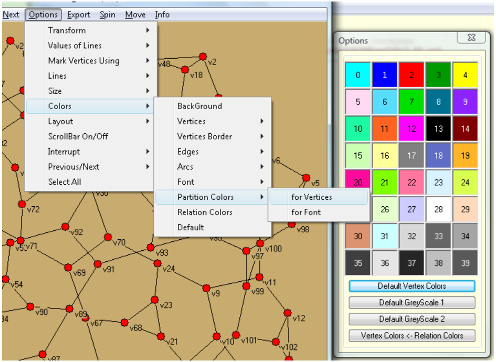
In **Pajek** numerical properties of nodes are represented by *vector*s, nominal properties by *partitions* or as *label*s of nodes. Numerical property can be displayed as *size* (width and height) of node (figure), as its *coordinate*; and a nominal property as *color* or *shape* of the figure, or as 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 vales can be assigned as *label*, *color* or *line pattern* (see Pajek manual, section ***4.3***).

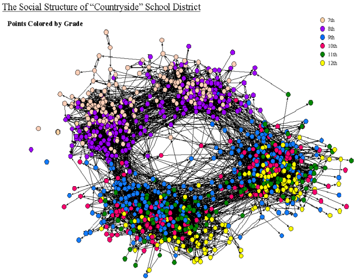
Some related operations

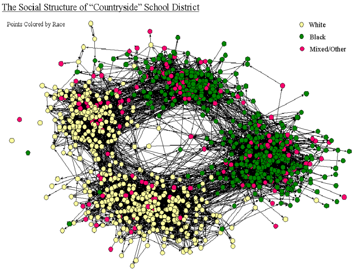



```
Operations/Network+Vector/Transform/Put C
Network/Create Vector/Get Coordinate
[Draw] Options
[Draw] Layout/Energy/Kamada-Kawai/Free
[Draw] Export/2D/EPS-PS
```



Display of properties – school (Moody)





Types of networks

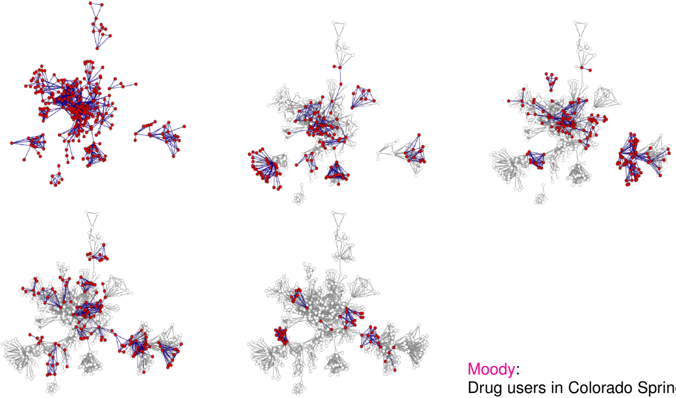
Besides ordinary (directed, undirected, mixed) networks some extended types of networks are also used:

- *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

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

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

```
*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.

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.

$\star$ means 'infinity'.

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

Temporal networks – events

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

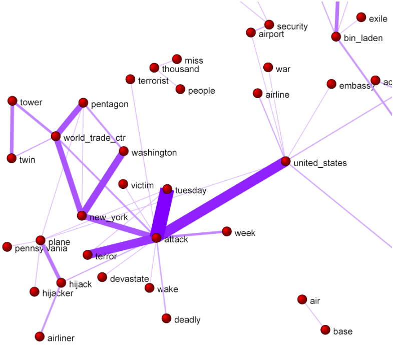
s can be empty.
In case of parallel links $:k$ denotes the k-th link – `HE:3 14 37` hides the third edge linking nodes `14` and `37`.

```
*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



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

A *multi-relational network* is denoted by

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

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

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

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 semiautomaticly. 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 *Text units* $\times$ *Concepts* which can be considered as a two-mode network.

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

. . . approaches to CaTA

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* ∪ *Objects* as nodes and links (arcs) labeled with *Verbs*.

See also RDF triples in semantic web, SPARQL.

Multi-relational temporal network – KEDS/WEIS

```
% 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*

Two-mode networks

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* $w : \mathcal{L} \to \mathbb{R} \in \mathcal{W}$ 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 $\mathbf{A} = [a_{uv}]_{\mathcal{U} \times \mathcal{V}}$.

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

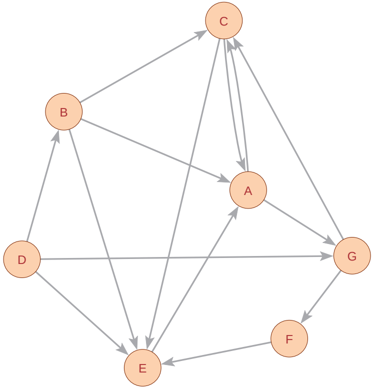
Examples: (persons, societies, years of membership), (buyers/consumers, goods, quantity), (parlamentarians, problems, positive vote), (persons, journals, reading).
A two-mode network is announced by `*vertices` n $n_{\mathcal{U}}$.
Authors and works.

Deep South

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 Reported in *Old City Herald*													
	(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	×	×	×	×	×	×		×	×					
2. Miss Laura Mandeville	×	×	×		×	×	×	×						
3. Miss Theresa Anderson		×	×	×	×	×	×	×	×					
4. Miss Brenda Rogers	×		×	×	×	×	×	×						
5. Miss Charlotte McDowd			×	×	×		×							
6. Miss Frances Anderson			×		×	×		×						
7. Miss Eleanor Nye					×	×	×	×						
8. Miss Pearl Oglethorpe						×		×	×					
9. Miss Ruth DeSand					×		×	×	×					
10. Miss Verne Sanderson							×	×	×			×		
11. Miss Myra Liddell								×	×	×		×		
12. Miss Katherine Rogers								×	×	×		×	×	×
13. Mrs. Sylvia Avondale							×	×	×	×		×	×	×
14. Mrs. Nora Fayette						×	×		×	×	×	×	×	×
15. Mrs. Helen Lloyd							×	×		×	×	×		
16. Mrs. Dorothy Murchison								×	×					
17. Mrs. Olivia Carleton									×		×			
18. Mrs. Flora Price									×		×			

igraph Example




```
> 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 name
 [1] A->C A->G B->C B->A B->E C->
> 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

D/U ‘D’ – directed / ‘U’ – undireted.

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

```
> 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

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

```
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

```
from;relation;to
"Batagelj, Vladimir";authorOf;"Generalized Blockmodeling"
"Doreian, Patrick";authorOf;"Generalized Blockmodeling"
"Ferligoj, Anuška";authorOf;"Generalized Blockmodeling"
"Batagelj, Vladimir";authorOf;"Clustering with relational constr
"Ferligoj, Anuška";authorOf;"Clustering with relational constrai
"Granovetter, Mark";authorOf;"The Strength of Weak Ties"
"Granovetter, Mark";editorOf;"Structural Analysis in the Social
"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
"Clustering with relational constraint";containedIn;"Psychometri
"The Strength of Weak Ties";containedIn;"The American Journal of
"Partitioning signed social networks";containedIn;"Social Networ
"Partitioning signed social networks";cites;"Generalized Blockmo
"Generalized Blockmodeling";cites;"Clustering with relational co
"Structural Analysis in the Social Sciences";publishedBy;"Cambri
"Psychometrika";publishedBy;"Springer"
```

bibLinks.csv

Factorization and description of large networks

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

```
# 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 l "',rel[R[a]],'"\n',sep='',file=net)
close(net); close(clu); close(sex)
```

CSV2Pajek.R

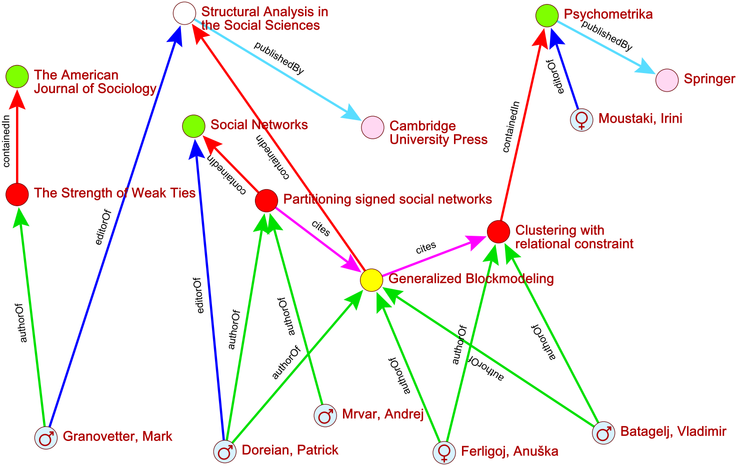
bib.net

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

bib.net, bibMode.clu, bibSex.clu; bib.paj, bib.ini.

Bibliographic network – picture / Pajek



Reading Pajek files in R

wiki

Temporal network data

netJSON format

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

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

netJSON has two formats: a *basic* and a *general* format. Current implementation of the TQ library supports only the basic format. netJSON format is supported by a Python library Nets.

Informal description of the basic netJSON format

```
{
"netJSON": "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 netJSON format

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 `tq`

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