Introduction to Social Network Analysis

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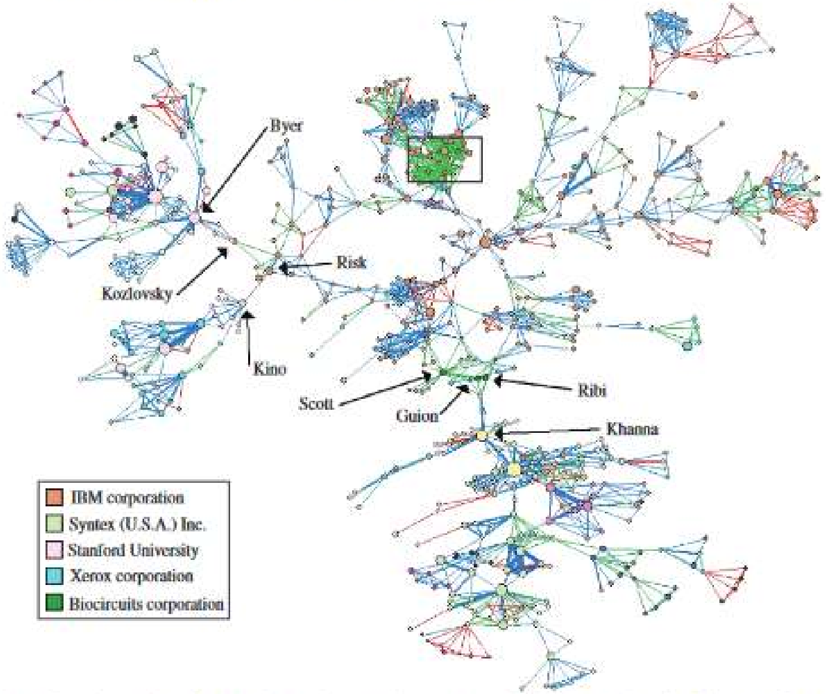
Co-inventorship

Figure 1 Inventors of Silicon Valley's Largest Component in 1986–1990 by Assignee and Importance of Inventions



Notes. Node sizes reflect the number of future prior art cites to an inventor, normalized by the number of collaborators (future prior art cites correlate with value, *see* Albert et al. 1991). Tie width indicates number of collaborations, tie color indicates age of tie (red is five years prior, blue is two to four years prior, and green is prior year), and colors indicate assignee. Boxed area provides example of highly clustered inventors. Note that the figures do not illustrate the thousands of other (by definition) smaller components in each region; inventors need not connect to any extant component – or even another node. They can connect to small components, such as dyads or triads, or work their entire careers in complete isolation. Graphed in Pajek with Kamada-Kawai/Free algorithm (Batagelj and Mrvar 1998). Adapted from Fleming and Marx (2006).

Source: Fleming, King & Juda (2007)

Regional innovation networks

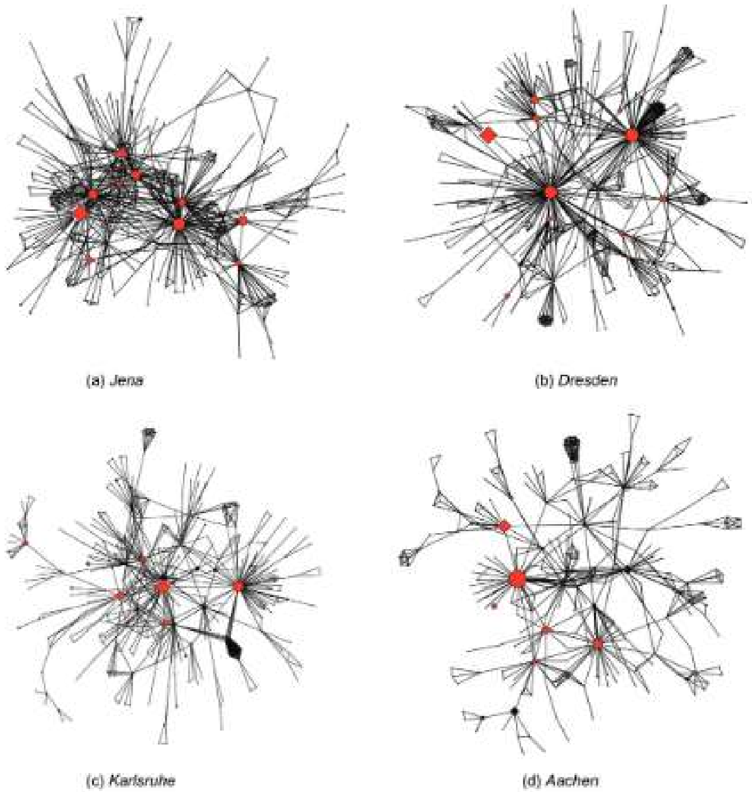


Fig. 2. Main components of regional networks
Note: Actors located within the region (headquarter or subsidiary) are marked in *grey/red* (electronic version), external actors are in black. Squares indicate a private actor; public research organizations are circles. The size of a node is proportional to the number of patents filed.

Source: Fritsch & Graf (2011)

Cluster knowledge network

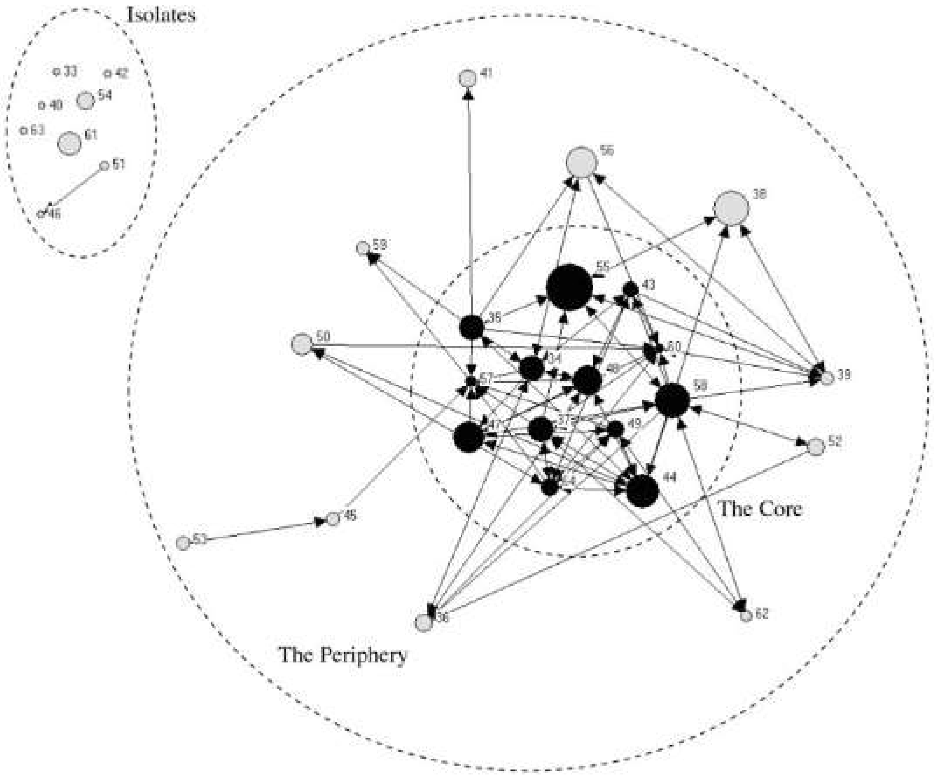
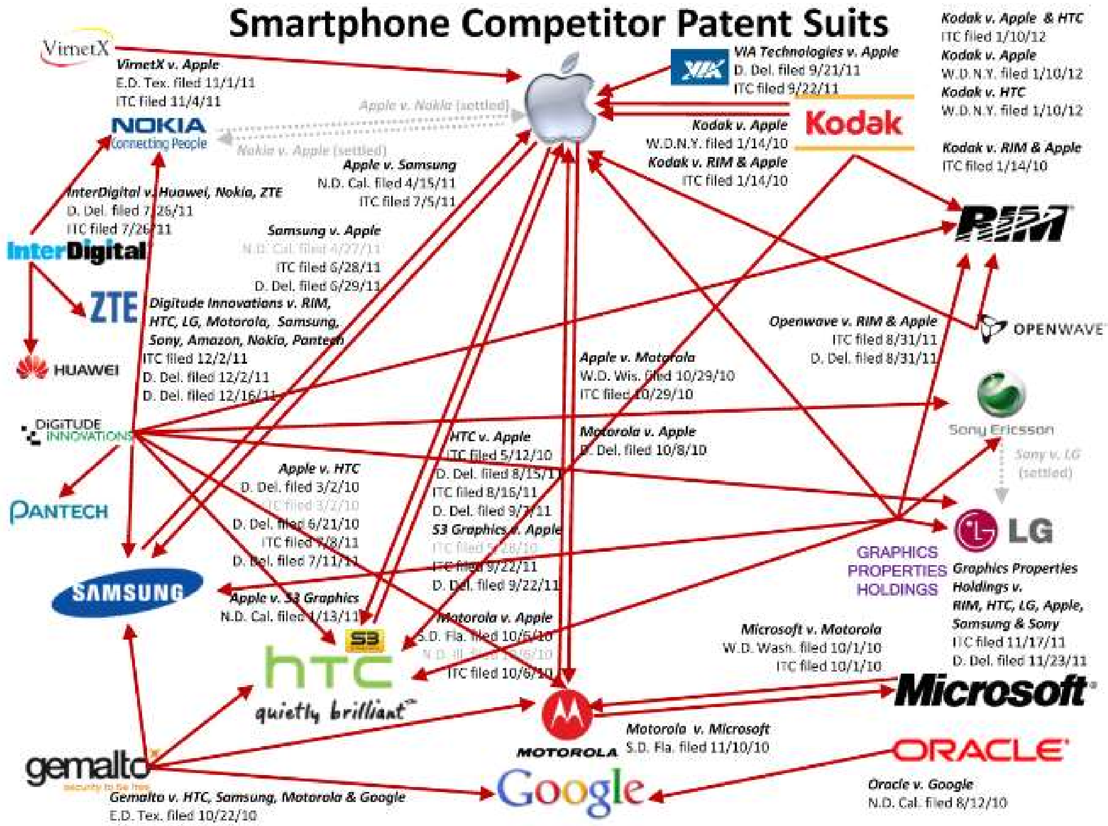


Figure 3. Structure of knowledge network in Valle de Colchagua. The size of the nodes is proportional to the measure of their knowledge base.

Source: Giuliani (2007)

Patent wars



https://uk.pcmag.com/news/116009/infographic-smartphone-patent-wars-explained

Product space

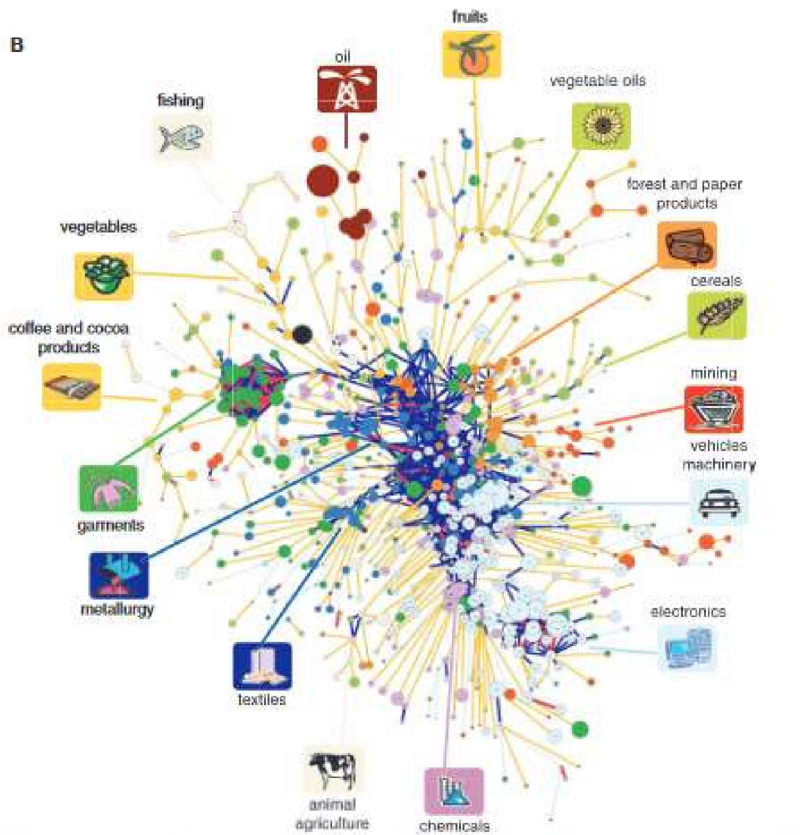


Fig. 1. The product space. (A) Hierarchically clustered proximity (φ) matrix representing the 775 SITC-4 product classes exported in the 1998–2000 period. (B) Network representation of the product space. Links are color coded with their proximity value. The sizes of the nodes are proportional to world trade, and their colors are chosen according to the classification introduced by Leamer.

Source: Hidalgo et al. (2007)

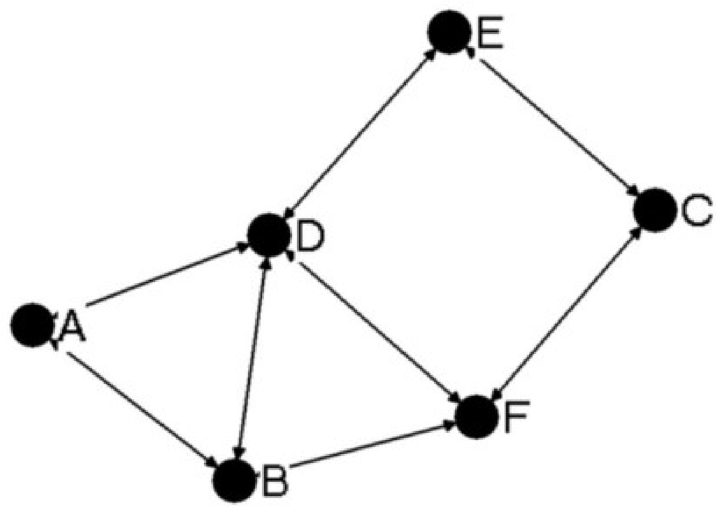
Some basic SNA literature

- Borgatti, SP, Everett, MG, Johnson, JC (2013) Analyzing Social Networks. London: Sage Publications
- Hanneman, RA, Riddle, M (2005) Introduction to social network methods. Riverside, CA: University of California, Riverside (published in digital form at http://faculty.ucr.edu/ hanneman/)
- Jackson, MO (2008) Social and Economic Networks. Princeton University Press
- Scott, J, Carrington, P (eds.) (2011), The SAGE Handbook of Social Network Analysis, London: SAGE Publications
- Wassermann S, Faust K (1994) Social Network Analysis. Methods and Applications. Cambridge: Cambridge University Press

Contents

What is a network?

- A set of dyadic ties, all of the same type, among a set of actors
- Actors can be persons, organizations . . .
- A tie is an instance of a social relation



Relations among persons

Relational states							Relational events	
Similarities			Relational roles		Relational cognition		Relational events	
Location	Participation	Attribute	Kinship	Other role	Affective	Perceptual	Interactions	Flows
Same spatial and temporal space	Same clubs, same events	Same gender, same attitude	Mother of, sibling of	Friend of, boss of, student of, competitor	Likes, hates	Knows, knows of, sees as happy	Sold to, talked to, helped, fought with	Information, beliefs, money

Note: Content matters!

Each relation yields a different structure & has different effects

Relations among organizations

Type	Firms as entities	Via Individuals
Similarities	Joint membership in trade association; co-located in Silicon Valley	CEO of organization A sits on same board as CEO of organization B
Relations	Joint ventures; alliances; distribution agreements; own shares in; regards as competitor	Chief scientist of A is friend with chief scientist of B
Interactions	Sells products to; makes competitive move in response to	Representatives of A attend same conference as representatives of B
Flows	Technology transfers; cash infusions	Employee of A leaks information to employee of B

Relations among other entities

- Patents
  - Patents citing other patents
  - Co-occurence of technological classes
- Research fields
  - Citations between fields
  - Co-classifications of publications or patents
  - People who publish in different fields
- Sectors
  - Input-output relations
  - Labour flows

Level of analysis

Level of analysis	Research question
Dyad level	Are firms with overlapping technological knowledge bases more likely to form research collaborations?
Node level	Do firms with more diverse technology partners innovate more?
Network level	Are centralized regional networks more innovative?

Contents

Data for social networks

- Network data typically as a quadratic $n \times n$ matrix **A**, with rows and columns as observations

→Cell aij gives the relation between i and j.

	A	B	C	D	E	F
A	-	1	0	1	0	0
B	1	-	0	1	0	1
C	0	0	-	0	1	1
D	1	1	0	-	1	1
E	0	0	1	1	-	0
F	0	1	1	1	0	-

- Tie strength: Strength of relationship, frequency of interaction, …
- Actors and attributes vs. actors and their relations

Direction of ties

Ties can be directed or undirected

- **Undirected ties:** A and B write a joint paper, go to lunch together
- **Directed ties:** A cites B, A gives information to B

Logically vs empirically directed ties

- logically undirected relations can be empirically non-symmetric due to measurement error;
- logically ties might be directed, but we can only observe an undirected version.

Contents

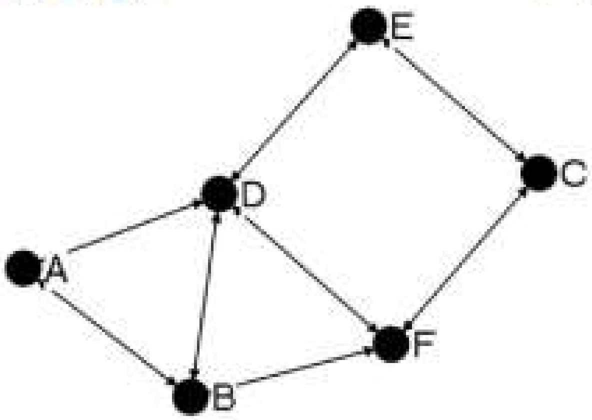
Incidence and adjacency matrices

Set of vertices (nodes): $\mathcal{V} = \{A, B, C, D, E, F\}$
Set of edges (ties): $\mathcal{E} = \{(A,B), (A,D), (B,D), (B,F), (C,E), (C,F), (D,E), (D,F)\}$

$$\mathbf{I} = \begin{array}{c} \\ A \\ B \\ C \\ D \\ E \\ F \end{array} \begin{array}{c} \begin{matrix} 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 \end{matrix} \\ \begin{pmatrix} 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 1 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 1 & 0 \\ 0 & 1 & 1 & 0 & 1 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 \end{pmatrix} \end{array}$$

$$\mathbf{A} = \mathbf{II}' = \begin{array}{c} \\ A \\ B \\ C \\ D \\ E \\ F \end{array} \begin{array}{c} \begin{matrix} A & B & C & D & E & F \end{matrix} \\ \begin{pmatrix} - & 1 & 0 & 1 & 0 & 0 \\ 1 & - & 0 & 1 & 0 & 1 \\ 0 & 0 & - & 0 & 1 & 1 \\ 1 & 1 & 0 & - & 1 & 1 \\ 0 & 0 & 1 & 1 & - & 0 \\ 0 & 1 & 1 & 1 & 0 & - \end{pmatrix} \end{array}$$

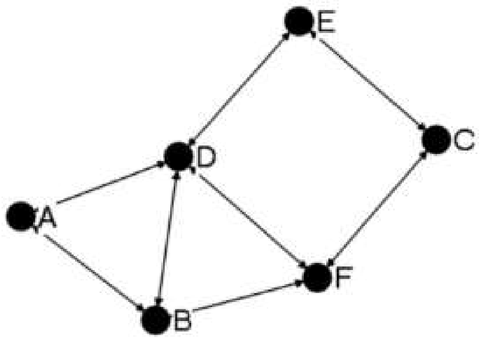
Graphical representation:



Length and distance

- Length of a path is the number of links
- Distance (dij) between two nodes is length of the shortest path (aka geodesic) between two nodes
- Distance matrix:

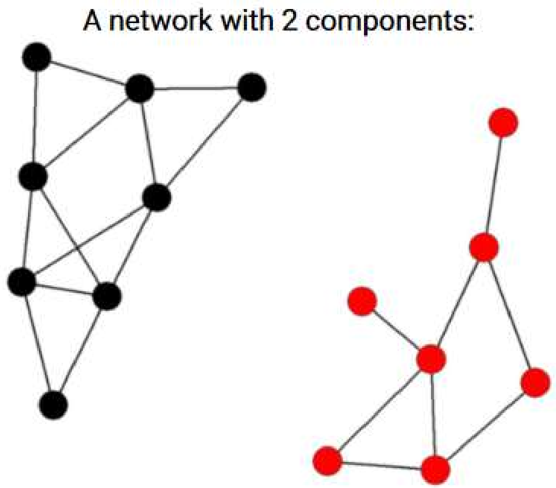
$$\mathbf{D} = \begin{array}{c} \\ A \\ B \\ C \\ D \\ E \\ F \end{array} \begin{array}{c} \begin{array}{cccccc} A & B & C & D & E & F \end{array} \\ \begin{pmatrix} - & 1 & 3 & 1 & 2 & 2 \\ 1 & - & 2 & 1 & 2 & 1 \\ 3 & 2 & - & 2 & 1 & 1 \\ 1 & 1 & 2 & - & 1 & 1 \\ 2 & 2 & 1 & 1 & - & 2 \\ 2 & 1 & 1 & 1 & 2 & - \end{pmatrix} \end{array}$$



- Diameter of a connected graph is the length of largest distance between any nodes

Components

- Maximal sets of nodes in which every node can reach every other by some path (no matter how long)
- A connected graph has just one component



- For directed networks, we have to distinguish weak and strong components

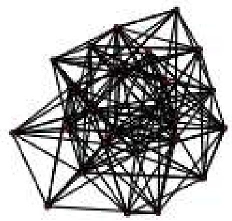
Contents

Characterizing Networks

- Measures of cohesion
  - Density
  - Average degree / mean degree
  - Connectedness / fragmentation
- Average distance
- Clustering and transitivity
- Centralization

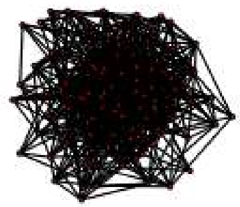
Density and mean degree

- Density – number of ties, expressed as percentage of potential ties
- Mean degree – average number of ties
- Density is highly size sensitive!



n = 25; density = 0.26; mean degree = 12.8

n = 25; density = 0.08; mean degree = 4



n = 100; density = 0.06; mean degree = 12.7

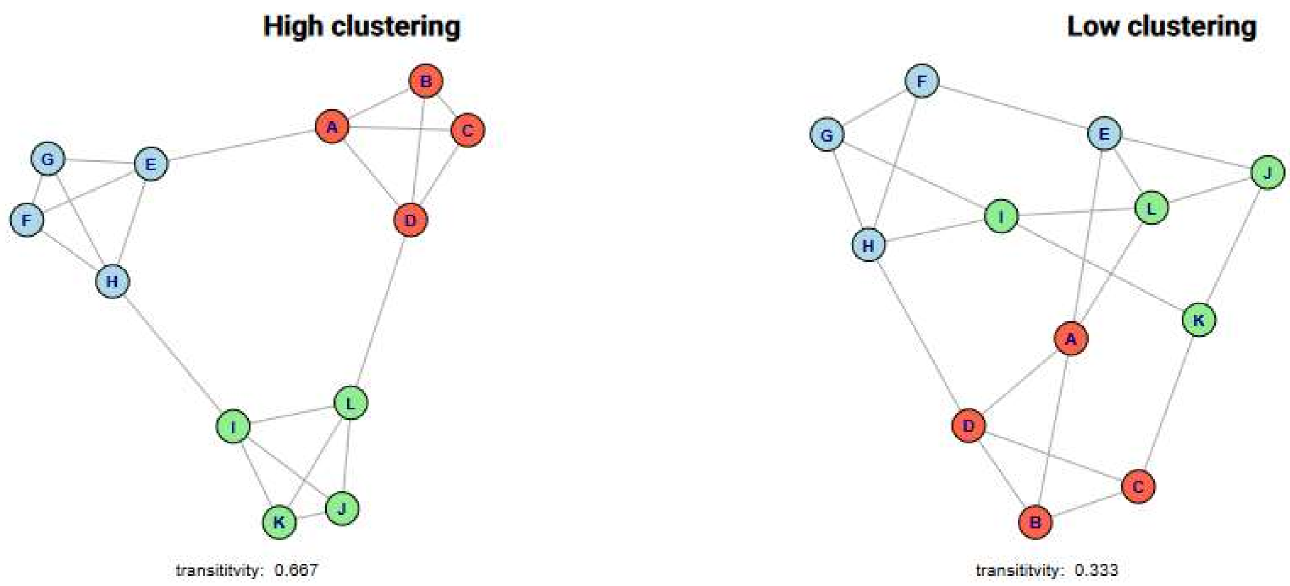
Connectedness and average distance

Connectedness measures use the distribution of links to measure cohesion:

- Share of actors in the main component
- Connectedness – proportion of pairs that can reach each other, i.e. which are members of the same component
- Fragmentation – the number of pairs that cannot reach each other
- Average distance: $L = \frac{\sum_{i \neq j} d_{ij}}{n(n-1)}$

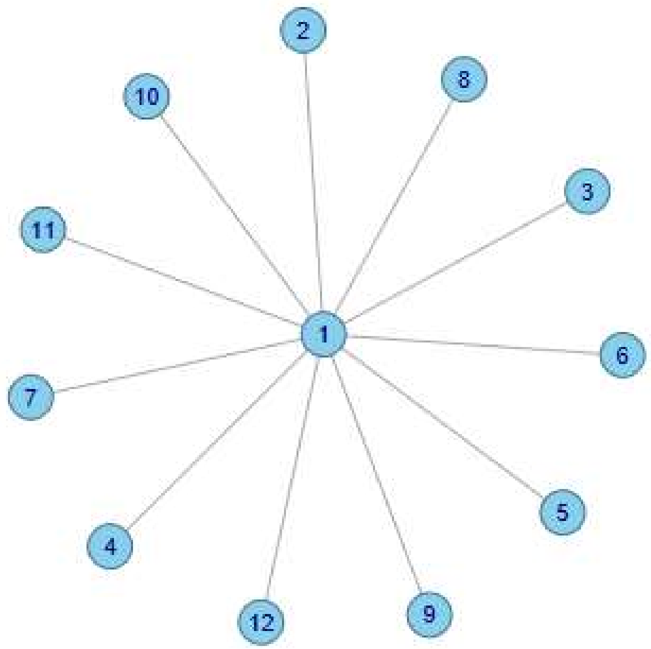
Clustering coefficient

- Clustering coefficient – cohesion of the neighborhood
- Transitivity – proportion of triples with 3 ties as a proportion of triples with 2 or more ties

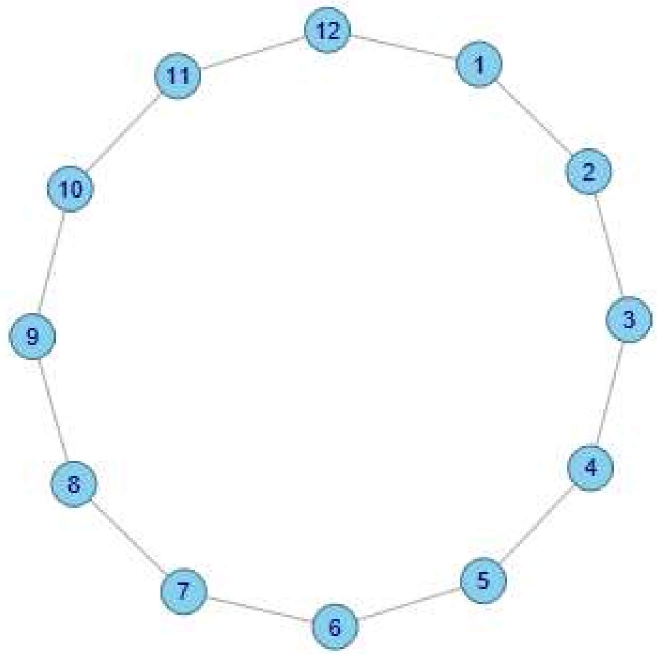


Centralization

Star – centralized



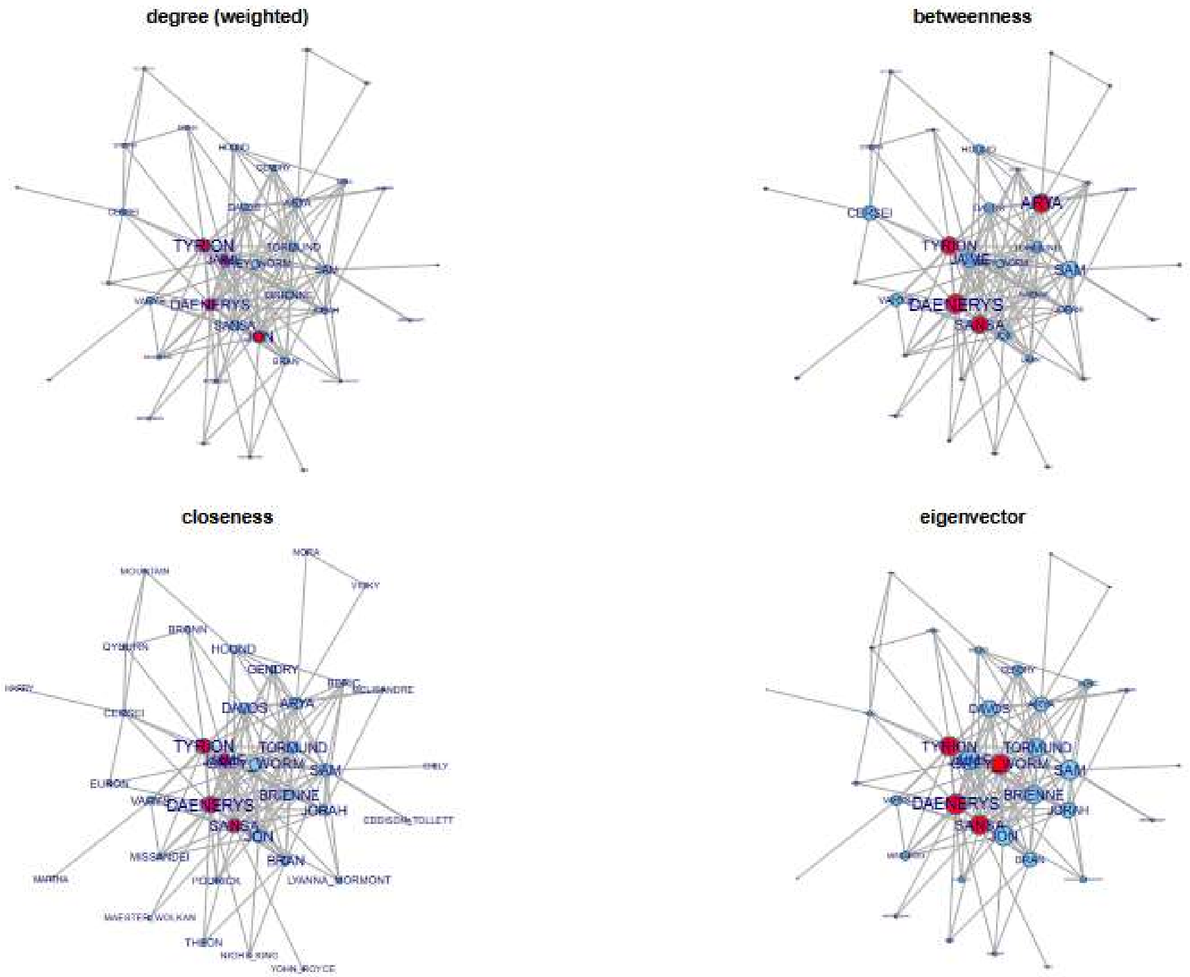
Ring – not centralized



Contents

Different concepts of centrality

- **Degree centrality**
  - Which actor has most relations?
  - Degree centrality as share of all possible relations
- **Closeness centrality**
  - Which actor is closest (least distant) to all other actors?
  - Inverse of the sum of distances to all other nodes
- **Betweenness centrality**
  - Idea: who ‘controls’ information flows?
  - High-betweenness vertices lie on a large number of non-redundant shortest paths between other vertices
    → ‘bridges’ or ‘boundary spanners’
  - Loosely: number of times that a node lies along the shortest path between two others
- **Eigenvector centrality**
  - Idea: connections to well connected actors are more important
  - Centrality of each actor is proportional to the sum of the centralities of those actors to whom he or she is connected



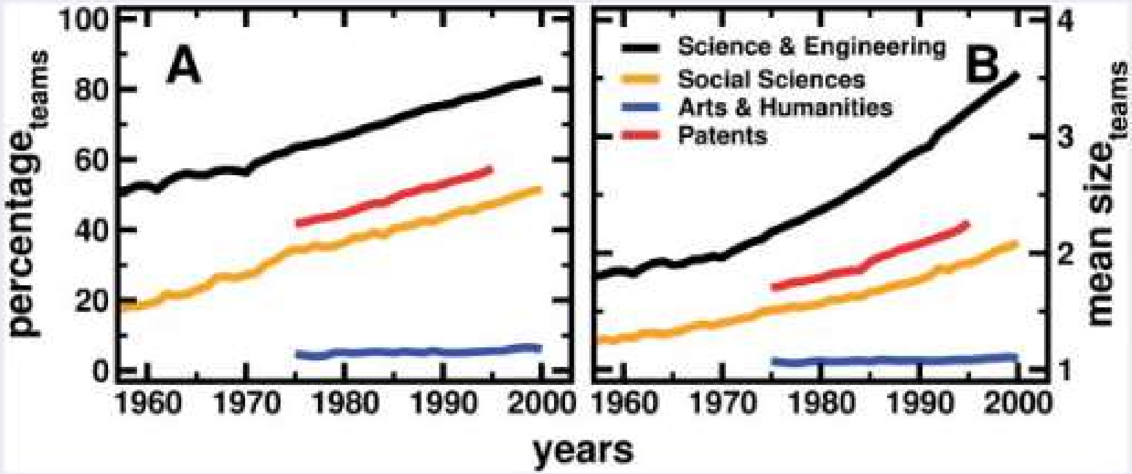
Node and label size proportional to respective centrality measure

Contents

Interaction in the innovation process

Research is increasingly teamwork

- Changes in the organization of innovative activities
- General trend: increasing team size in research



Source: Wuchty, Jones & Uzzi (2007)

Innovation and interaction → networks

Innovation and interaction

- Collective invention (Allen 1983)
- Knowledge spillovers as major drivers of economic growth (Romer 1990, Aghion & Howitt 1992)
- Localized knowledge spillovers (LKS) (Jaffe et al. 1993)

Networks as structure of knowledge diffusion

- Knowledge as a latent public good
- Knowledge is only partly codifiable → tacit components
- Learning and exchange of knowledge through personal interaction
- Social proximity as an explanation for LKS (Breschi & Lissoni 2009)
- Consequence
  - → Access to external knowledge restricted by position within the network
  - → Network structure influences rate and direction of knowledge flows

Types of innovation networks

Examples of networks from the literature

	Nodes	Edges	Application
Cooperation networks	Firms	Cooperations	Powell et al. 1996
Co-funding networks	Organizations	Cooperations	Broekel & Graf 2012
Regional networks	Regions	Cooperations	Wanzenböck et al. 2015
Co-authorship networks	Individuals	Publications	Barabasi et al. 2002
Inventor networks	Individuals	Patents	Fleming et al. 2007
Innovator networks	Patent applicants	Inventors	Cantner & Graf 2006
Citation networks	Authors, patents, publications	Citation	Sorenson et al. 2006
Product space	Product classes	Co-occurence	Hidalgo et al. 2007
Knowledge base	Industries	Labour flow	Neffke et al. 2011

Research topics

Network formation and dynamics

- Network formation
- Mechanisms of formation and evolution

Networks and economic performance

- Individual ties / position and individual performance: relational embeddedness
- Creative potentials versus trust relations: structural embeddedness
- The influence of network structure on system performance

Research topics: network formation and dynamics

- Network formation
  - Motives to cooperate / engage in network (Baum et al. 2003)
  - Innovation network dynamics and the stability of network structures (Schilling & Phelps 2007)
  - Persistence of relations (Giuliani 2011)
  - Global properties (degree distributions, small-worlds) (Watts & Strogatz 1998, Baum et al. 2003, Schilling & Phelps 2007)
- Mechanisms of formation and evolution (Cantner & Graf 2006, Barabasi at al. 2002)
  - Preferential attachment and path dependency (possible lock-in) (Abbasi et al. 2012)
  - Homophily: not too much similarity (Tomasello et al. 2017)
  - Triadic closure: creative potential vs. generating trust (ter Wal 2014)

Research topics: networks and economic performance

- Individual ties / position and individual performance: relational embeddedness (Graf & Krüger 2011,Rowley et al. 2000)
  - Direct and indirect ties matter (Ahuja 2000)
  - Strong vs. weak ties (Rost 2011)
  - Problems of overembeddedness (Uzzi 1997)
  - Influence of more sophisticated centrality measures with mixed results
- Creative potentials versus trust relations: structural embeddedness
  - Burt–Coleman debate: structural holes vs. dense neighborhood (Gilsing & Duysters 2008)
  - Dependent on context: exploration (structural holes) – exploitation (density) (Rowley et al. 2000)
- The influence of network structure on system performance (Owen-Smith et al. 2002, Fritsch & Graf 2011)
  - Small-world as a ubiquitous structural phenomenon (Watts & Strogatz 1998, Baum et al. 2003)
  - Simulations show superiority in terms of knowledge diffusion (Cowan & Jonard 2004)
  - Centralized national research networks are less embedded in the global knowledge network (Graf & Kalthaus 2018)

Review articles

- **ter Wal, A. L. J. & Boschma, R. (2009)**, Applying social network analysis in economic geography: framing some key analytic issues, Annals of Regional Science, 43, 3, 739-756
- **Ozman, M. (2009)**, Inter-firm networks and innovation: a survey of literature, Economics of Innovation and New Technology, 18, 1, 39-67
- **Cantner, U. & Graf, H. (2011),** Innovation Networks: formation, performance and dynamics, in: Antonelli, C. (ed.) Handbook on the Economic Complexity of Technological Change, Edward Elgar, 366-394
- **Phelps, C.; Heidl, R. & Wadhwa, A. (2012),** Knowledge, Networks, and Knowledge Networks: A Review and Research Agenda, Journal of Management, 38, 1115-1166
- **Jackson, M. O. (2014)**, Networks in the Understanding of Economic Behaviors, Journal of Economic Perspectives, 28, 4, 3-22
- **Hidalgo, C. A. (2016)** Disconnected, fragmented, or united? A trans-disciplinary review of network science, Applied Network Science, 1, 6, DOI: 10.1007/s41109-016-0010-3

Contents

Software

UCINET Easy to learn, comprehensive menu, many users (groups.io/g/ucinet/ for questions), good help files, flexible visualization with NetDraw (included), no batch mode, best for smaller networks ($n < 1000$), only for MS Windows
`https://sites.google.com/site/ucinetsoftware/home`

R (igraph) Batch mode for repetitive tasks, tables and graphics can be easily exported, platform independent, integration with other statistical packages
`http://cran.r-project.org/`, `https://igraph.org/`

R (sna, network) Similar to igraph package, some algorithms are slow for large networks, might run out of memory for large networks ($n > 5000$), some functions that are not in igraph

Pajek Tough menu but the right choice if your network is really large, import data with txt2pajek
`http://mrvar.fdv.uni-lj.si/pajek/`

RSiena Tools for testing hypotheses about network evolution
`http://www.stats.ox.ac.uk/~snijders/siena/`

Gephi `https://gephi.org/`

For qualitative analysis

VennMaker `https://www.vennmaker.com/?lang=en`

mynetworkmap `https://mynetworkmap.com/`

R and igraph package

- Small example with igraph

```
library(igraph)
```

- Character Interaction Networks for the HBO Series "Game of Thrones" from https://github.com/mathbeveridge/gameofthrones
- We read the data and select only the most important relations

```
#import datafile
got.edges <- read.csv("got-s8-edges.csv")
got.edges <- got.edges[got.edges$Weight >= 35,1:3]
```

- and turn the edgelist into an igraph object

```
got.ig <- graph_from_data_frame(got.edges, directed=FALSE)
```

R and igraph package

- Let us retrieve some information about the created object

```
print(got.ig)

## IGRAPH bf322bf UN-- 20 31 --
## + attr: name (v/c), Weight (e/n)
## + edges from bf322bf (vertex names):
##  [1] DAENERYS--JON        DAENERYS--TYRION    JAIME    --TYRION
##  [4] JAIME   --BRIENNE    JON      --TYRION    TYRION   --VARYS
##  [7] TYRION  --SANSA      TYRION   --DAVOS     DAENERYS--SANSA
## [10] ARYA    --GENDRY     JON      --ARYA      JON      --SANSA
## [13] JON     --SAM        ARYA     --HOUND     TYRION   --BRAN
## [16] SANSA   --ARYA       DAENERYS--JORAH     JON      --GREY_WORM
## [19] JON     --TORMUND    JON      --VARYS     JON      --DAVOS
## [22] BRIENNE --TYRION     DAENERYS--VARYS     CERSEI   --QYBURN
## + ... omitted several edges
```

R and igraph package

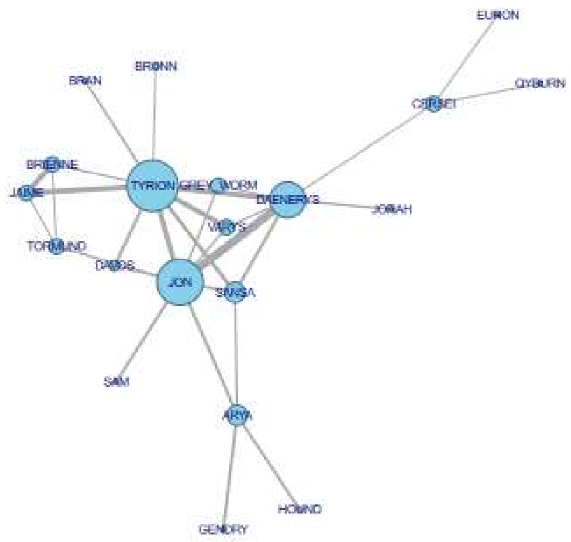
- We can have a look at the adjacency matrix

```
get.adjacency(got.ig)

## 20 x 20 sparse Matrix of class "dgCMatrix"

##    [[ suppressing 20 column names 'DAENERYS', 'JAIME', 'BRIENNE' ...  ]]

##
## DAENERYS  . . . 1 1 1 . . . 1 1 . 1 . . . 1 . . .
## JAIME     . . 1 . 1 . . . . . . . . . . . . 1 . .
## BRIENNE   . 1 . . 1 . . . . . . . . . . . . 1 . .
## JON       1 . . . 1 1 1 1 . 1 . . 1 . 1 . . 1 . .
## TYRION    1 1 1 1 . 1 1 . 1 1 . 1 1 . . . . . . .
## SANSA     1 . . 1 1 . . 1 . . . . . . . . . . . .
## DAVOS     . . . 1 1 . . . . . . . . . . . . . . .
## ARYA      . . . 1 . 1 . . . . . . . 1 . 1 . . . .
## BRAN      . . . . 1 . . . . . . . . . . . . . . .
## GREY_WORM 1 . . 1 1 . . . . . . . . . . . . . . .
## CERSEI    1 . . . . . . . . . . . . . . . . . 1 1
## BRONN     . . . . 1 . . . . . . . . . . . . . . .
## VARYS     1 . . 1 1 . . . . . . . . . . . . . . .
## GENDRY    . . . . . . . 1 . . . . . . . . . . . .
## SAM       . . . 1 . . . . . . . . . . . . . . . .
## HOUND     . . . . . . . 1 . . . . . . . . . . . .
## JORAH     1 . . . . . . . . . . . . . . . . . . .
## TORMUND   . 1 1 1 . . . . . . . . . . . . . . . .
## QYBURN    . . . . . . . . . . 1 . . . . . . . . .
## EURON     . . . . . . . . . . 1 . . . . . . . . .
```

R and igraph package

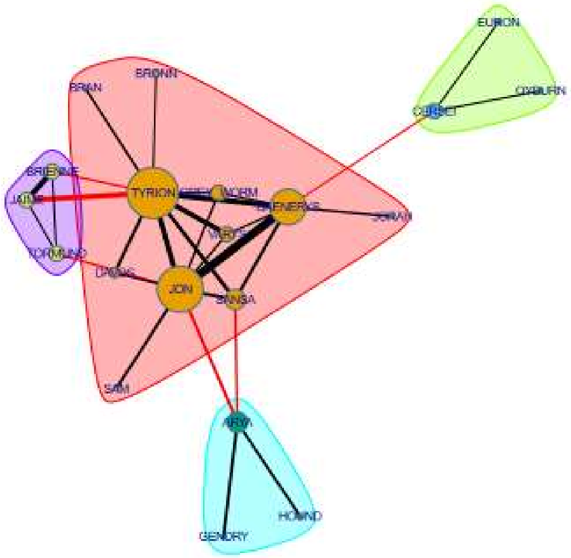
- Plot the graph with labels, size proportional to degree and weighted edges

```
plot(got.ig,vertex.size=degree(got.ig)*2, edge.width=E(got.ig)$Weight/25)
```



R and igraph package

- The package also has community detection algorithms, e.g. to identify densely connected subgraphs (clusters)



Contents

Data collection – Sampling

- Snowball methods – sampling actors
  - begin with a focal actor or set of actors
  - each of these actors is asked to name some or all of their ties to other actors

    →ego-network(s)
  - actors who are not connected (i.e. "isolates") are not identified
  - no guaranteed way of finding all of the connected individuals in the population
- Full network methods – sampling relations
  - require that we collect information about each actor's ties with all other actors: census of ties in a population of actors
  - Full network data is necessary to properly define and measure many of the structural concepts of network analysis (e.g. betweenness)
  - allows for very powerful descriptions and analyses of social structures

Relational data sources

- Primary data
  - Snowball
  - Roster recall
  - Open list
- Patents (or publications)
  - Co-inventor networks
  - Co-applications
  - Innovator networks: applicants linked by common inventors
  - Citation networks
- Collaboration data
  - Commercial data (e.g. SDC Platinum - Refinitiv)
  - Funding data (Förderkatalog in GER, CORDIS for EU)
  - . . .

Boundaries of the Network

- Defining boundaries in primary data collection
  - What type of relation?
  - Intensity of relation?
  - Who are the focal actors?
  - Open or closed list?
- Defining boundaries with patents or publications:
  - Technological: IPC-classes, keywords or aggregates thereof (e.g. IPC4, technologies [concordance])
  - Time window: usually up to 10 years, assumption of link decay!
  - Regions: all patents (publications) with at least one inventor (author) located in the focal region

Example for primary data collection – SCW-Networks

Questionnaire

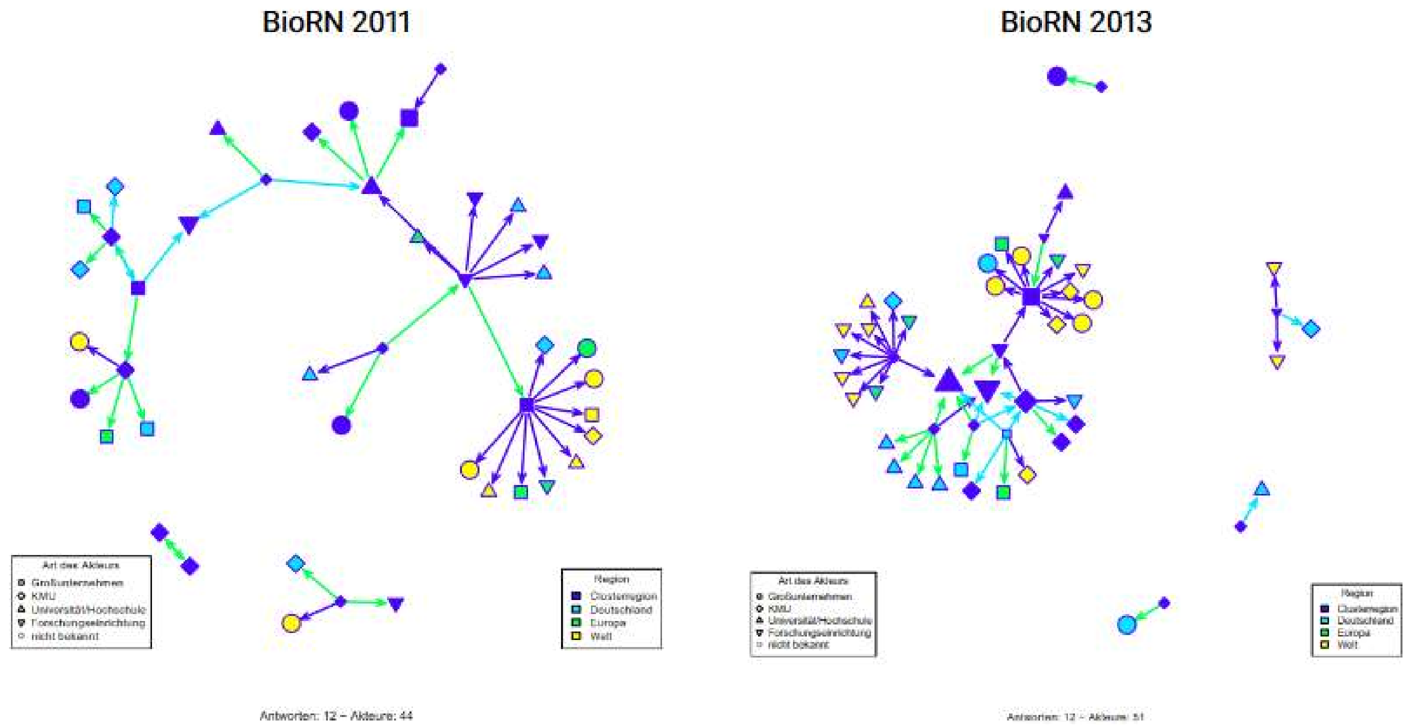
- Regional clusters of actors who receive funding
- Only relations of funded actors can be observed (firms, universities, research institutes)
- We ask for the maximum of **ten most important** R&D partners along with link attributes

23. Bitte nennen Sie uns Ihre strategisch wichtigsten FuE-Partner.

Unter strategisch wichtigen FuE-Partnern verstehen wir Partner (andere Unternehmen, und/oder nicht kommerzielle Einrichtungen), mit denen Sie gemeinsam neue Produkte, Fertigungsverfahren und sonstige Innovationen entwickeln, welche für die strategische Ausrichtung Ihres Unternehmens von großer Bedeutung sind. Eine reine Auftragsvergabe ohne aktive Zusammenarbeit wird nicht als Kooperation betrachtet.

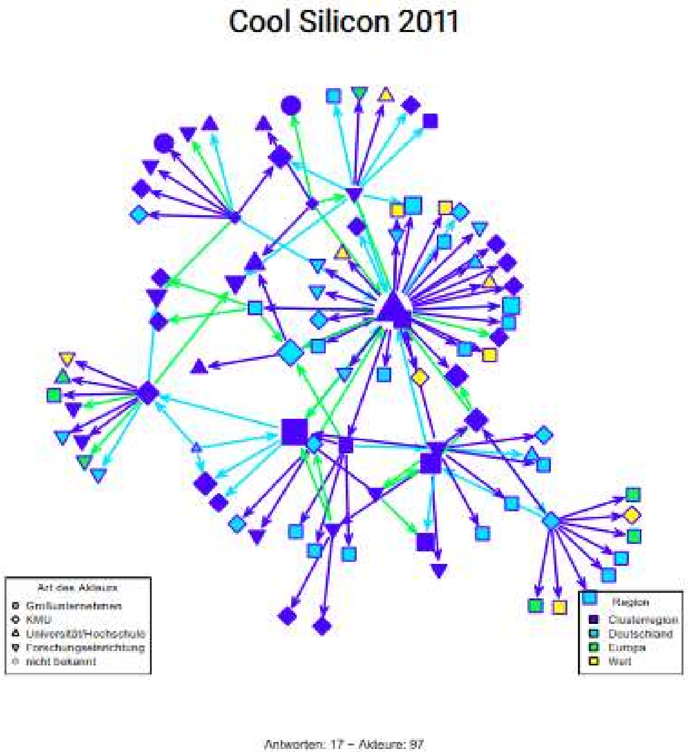
Strategisch wichtigste FuE-Partner (Name und Standort)	Haben Sie bereits vor September 2007 mit diesem Partner gemeinsame FuE betrieben?		Wurde diese Beziehung durch den „Spitzencluster-Wettbewerb" angestoßen bzw. intensiviert?	
	ja	nein	ja	nein
1.	❑	❑	❑	❑
2.	❑	❑	❑	❑
3.	❑	❑	❑	❑
4.	❑	❑	❑	❑

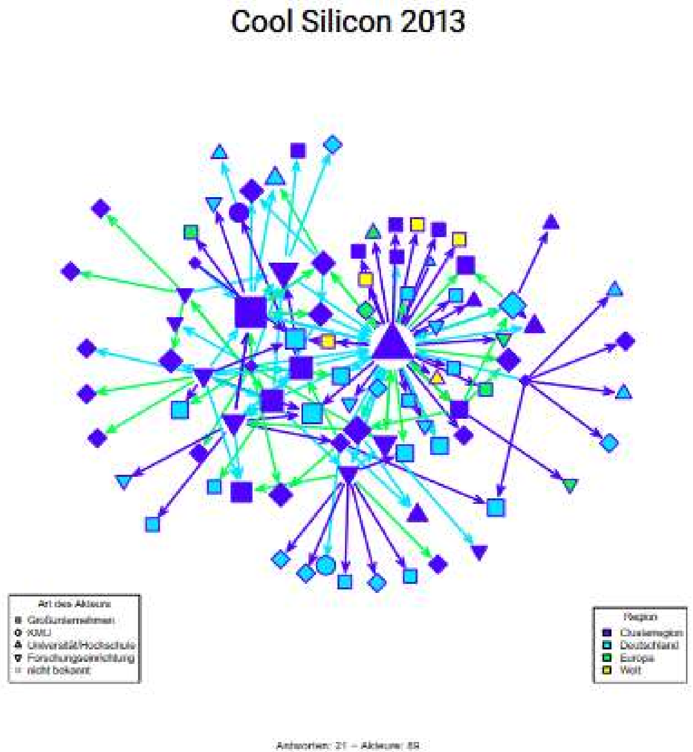
Example networks



green = initiated by LECC
lightblue = intensified by LECC
blue = no LECC influence

Example networks





green = initiated by LECC
lightblue = intensified by LECC
blue = no LECC influence

Data cleaning

The "names game"

- The problem: If the character string for two nodes is **exactly** the same (simple string matching), we assume that they refer to the same person.
- However, this might not be the case:
  - Databases are not perfect, names might change (e.g. academic titles, middle names) or spelled differently. 'Ronald S. Burt' and 'Ronald Burt' are grouped as different nodes even though it is one person.
  - → **Type I error** (false negatives, different nodes refer to the same person)
  - Some names are very common. Two nodes named 'John Smith' might refer to different persons.
  - → **Type II error** (false positives, one node refers to more than one person)
- Parsing: reducing noise by changing case, removing double blanks, symbols, accents, etc.
- Matching: SSM or other algorithms
- Filtering: using additional information to reject false positives
- Manual check for small data
- See Raffo & Lhuillery (2009)

Short network survey

- visit https://forms.gle/qDmxEBYddLybPNMP8

- Please take the survey, results will be discussed in the feedback session
- Homework
  - Develop your own survey including network questions
  - Form 4 teams to work on a survey that could help you understand specific aspects of your cluster
  - Questionnaire should be finished by Workshop 3 (combined task with “data gathering” by Matthias Hügel)

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