Title:	Sources of network data
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Sources of network data

Synonyms

Networks, boundary problem, ethics, copyrights, ego-centered networks, observation, surveys, archives, databases, almost network data, semantic web, random networks.

Glossary

Network analysis: a study of networks as a representation of relations between discrete objects.

Social network: a social structure based on a set of actors (individuals or organizations) and the ties between these actors.

Genealogy: a study of families and tracing of their lineages.

Web crawler: an Internet bot that automatically browses the World Wide Web.

Computer-assisted text analysis – CATA: techniques that model and structure the information content of textual sources.

Cloud technology: a use of hardware and software that are delivered as a service over a network (usually the Internet).

Introduction

We can find the network data almost everywhere in our live:

- the cities are linked with roads,

- people in a group are linked by exchange of messages (mail, phone),

- works from a field of research are linked with citations,

- researchers are linked with their collaborations,

- atoms in molecules are linked with their chemical bonds,

- words are linked according to their coappearance in sentences of some text,

- in genealogies people are linked by marriage and parent-child ties.

A **graph** $\mathcal{G}$ is an ordered pair of sets $(\mathcal{V}, \mathcal{L})$ with the set of **nodes** $\mathcal{V}$ and the set of **links** $\mathcal{L}$. Every link has two end-nodes. It is either directed – an **arc**, or undirected – an **edge**. A **network** $\mathcal{N} = (\mathcal{V}, \mathcal{L}, \mathcal{P}, \mathcal{W})$ consists of a graph $\mathcal{G} = (\mathcal{V}, \mathcal{L})$, describing the structure of network, and additional data: **properties** $\mathcal{P}$ of nodes and **weights** $\mathcal{W}$ on links. There are different types of networks beside ordinary networks.

A **two-mode** network is a network $\mathcal{N} = ((\mathcal{I}, \mathcal{J}), \mathcal{L}, \mathcal{P}, \mathcal{W})$, where the set of nodes $\mathcal{V} = \mathcal{I} \cup \mathcal{J}$ is split into two disjoint sets of nodes $\mathcal{I}$ and $\mathcal{J}$ and each link from $\mathcal{L}$ has one end-node in $\mathcal{I}$ and the other end-node in $\mathcal{J}$.

A **multi-relational** network $\mathcal{N} = (\mathcal{V}, \mathcal{L}, \mathcal{P}, \mathcal{W})$ allows multiple relations to exist in the network $\mathcal{L} = (\mathcal{L}_1, \mathcal{L}_2, \ldots, \mathcal{L}_r)$.

In a **temporal** network $\mathcal{N} = (\mathcal{V}, \mathcal{L}, \mathcal{P}, \mathcal{W}, T)$ the time T is attached to a network. For all nodes and links we have to specify the time intervals in which the element is active (present) in the network. Also properties and weights can change through time.

When constructing a network we must first specify what are the nodes and which relation is linking them – the **network boundary** problem [Wasserman et al (1994), Marsden (2011)]. According to the plan of network analyses we need to bound

the set of nodes to those that we need. Along with nodes and links we select also their properties. We have to decide whether the network is one-mode or two-mode and which node properties are important for our intended analyses. About the links we have to answer to several questions: Are the links directed? Are there different types of links (relations)? Can a pair of nodes be linked with multiple links? What are the weights on the links? Is the network static, or is it changing through time?

Sometimes the list of nodes is known in advance (for example, students in the class). But often the set of nodes is constructed during the network data collection process. In this case we have to specify the membership criteria determining for each potential node whether it belongs to the network or not.

For collecting the network data the **snowball** procedure is often used. We first choose a (small) set of nodes as initial candidates. Then we collect the data about each candidate and determine its neighboring nodes. The new ones among them we add to the list of candidates. The inclusion of the new nodes can be ruled also by some other criteria, for example, by the distance from the closest initial node. We end this process when the list of candidates is exhausted or the limit to the number of inspected nodes is reached.

Another problem that often occurs when defining the set of nodes is the **identification** of nodes. The unit corresponding to a node can have different names (**synonymy**), or the same name can denote different units (**homonymy** or **ambiguity**). For example in a bibliography on mathematics from Zentralblatt MATH the names; Borštnik, N. S. Mankoč; Mankoč Borštnik, N.; Mankoč-Borštnik, Norma; Mankoč Borštnik, Norma Susana; Mankoc-Borstnik, N.S. and Mankoč Borštnik, N.S. belong to the same author. On the other hand, in Zentralblatt MATH at least two different Smith, John W. are recorded, because publications of the author(s) with this name spanned from 1868 to 2007. There are at least 57 different mathematicians with the

name Wang, Li in the MathSciNet Database. Its editors are trying hard, from the year 1985, to resolve the authors identification problem [Martin et al (2013)] during the data entry phase. In the future the problem could be eliminated by general adoption of initiatives such as ResearcherID or ORCID.

The identification problem appears also when the units are extracted from the plain text. For example "the President of US" and "Barack Obama". To resolve it we have to provide lists of equivalent terms. Another source of identification problems are the grammar rules of the language used in text. For example the action "go" can appear in the text in different forms "go", "goes", "gone", "going", "went". To resolve these problems we apply the stemming or lemmatization procedures from natural language processing toolkits such as NLTK or MontyLingua.

A special approach of collecting data for a network analysis is by forming **ego-centered** networks [Lozar Manfreda et al (2004)]. This approach is used when the population of our interest is too large. From the population we select a sample of units (**egos**) and collect the data about them and their neighbors (**alters**) and links among them. An example are the friendship networks of selected persons from Facebook.

Collecting the network data we have to respect legal (copyright) and ethical constraints [Borgatti et al (2003), Eynon (2008), Charlesworth (2008), Breiger (2005)].

The network data can be obtained in many ways:

- by observation,

- with surveys or interviews,

- from archives and databases,

- from data organized in a network form,

- derived from the data,

- from semantic web,

- with generating random networks, . . .

Each of the above methods for gathering the network data is described in more details in the following subsections. For details additional references are provided.

Observation

To form a network we must first obtain the data. The ways of obtaining the data have been changing through history following the development of the technology. A basic approach is the observation [Mitchell (1969)]. The observation is a human activity consisting of receiving information about the outside world through the senses, or the recording of data using scientific instruments and includes also any data collected during this activity. Scientific instruments were developed to amplify human powers of observation, such as weighing scales, clocks, telescopes, microscopes, thermometers, cameras, tape recorders, and also to translate into perceptible form events that are unobservable by human senses, such as voltmeters, spectrometers, infrared cameras, oscilloscopes, interferometers, geiger counters, x-ray machines, and radio receivers [Shipman et al (2009)].

Making direct measurements is the most accurate method for many variables but can be limited by the technology available. The main alternative to direct observation is to require others to report their activities.

An example of the observational network data collection is described in PhD thesis of Samuel F. Sampson [Sampson(1968)]. He did an ethnographic study of community structure in a New England monastery – he divided 18 novices into four groups at five time points based on his observations and analyses. Another example is the detection of molecular structure of organic molecules.

Surveys

Survey is a data gathering method that actively includes the observeds [Marsden (1990)]. They allow us to study attitudes, beliefs, behaviours and other characteristics. With carefully prepared questionaires one can collect vast amounts of quality data. A **questionaire** is a list of questions. Answers can be **closed** – selected from a given list. They are easier to analyze. But the **open** answers, that are not given in advance, allow the analysists to get wider amount of information. A survey can take different forms: face-to-face, paper and pencil, telephone, e-mail, or on-line. Nowadays questionnaires are mostly digital (on-line surveys) that allows them to be adaptable, immediate checking of the entered data, and also collecting some contextual (observational) data.

The use of direct observation in combination with surveys can provide additional information. It can confirm or negate information gained from surveys. As observation itself also the observation in combination with surveys must be prepared. The observant might use appropriate scales, checklists, and other observation materials that are chosen in accordance with the questions and possible closed answers in the survey.

An interesting network obtained by interviewing is the Edinburgh Associative Thesaurus.

Surveys are the most commonly used methods to gather social network data. They are also used to study interorganizational relations [Mizruchi et al (1993)]. For details on surveys and questionnaires see the essay "Questionnaires for Measuring Social Network Contacts".

Archives and Databases

An archive is a collection of historical data, or the physical place where they are located [Schmidt(2011)]. Archives have a historical, cultural, and evidentiary value. Archives

exist everywhere, where data has been stored. Every organization has an archive of past activities, universities have archives of past students achievements and research, backup on the personal computer is an archive of past usage of the computer, etc. With the transition of office work to computers and the spread of internet many archives became digital. A database is an organized collection of data, mostly in digital form. Database is organized in records and for each record it has stored some properties [Ullman et al (2008)]. Because data is organized, it is very easy to transform it in a collection of (often two-mode) networks which are then used in the network analysis. Smaller amounts of data can be presented in a tabular form as spreadsheets.

For example there exist many bibliographic databases (Web of Science, Scopus, Zentralblatt Math, etc.) that are keeping data about published papers and books. Even World Wide Web is being partially collected and preserved as an archive for future researchers, historians, and the public.

As a source of data the archives of various kinds are inexpensive, and advantageous for studying especially social networks in the past [Marsden (1990)]. The network data can be derived from archived data. For example, relations between corporations can be studied based on information about persons in the boards of directors of the corporations.

Historical archives help researchers to gain knowledge about the development of some field – economics, scholar, military, etc. For example with data from World War II one can study the military movement through the war, the transfer of refugees or prisoners, transfer of weapons etc. Another example is the analysis of alliances between the most powerful countries over selected time period.

Archived data about the inhabitants of a city or an area can be used for genealogical analysis. In genealogy we can search for typical marriage patterns and their irregularities. For example, marriages among relatives to keep the family's wealth, or on

the other hand marriages outside the family to increase its influence. The genealogical data are often available in the GEDCOM format. Large collection of family genealogies is available at the Genealogy Forum. For "scientific" genealogies used in anthropological research see the site KinSource.

Activities on the internet, such as e-mail, chat and forums, leave their traces that can be used as sources for network data. A notorious example are the Enron e-mail data.

Especially interesting for network analysis is the World Wide Web as archive. The web crawlers visit the page with URL from the list of URLs, identify all hyperlinks on it and add the URL of these hyperlinks to the list. The largest web archiving organization based on crawling approach is the Internet Archive, but also national libraries, national archives and other organizations are involved in archiving mostly culturally important Web content.

Enormous archives are being formed by different social networking services such as Facebook, Twitter, LinkedId and Google+. These organisations are collecting the data about users, their posts or tweets. Data about users are not publicly available. The user can download only the data about his/her past activity and the data that other users declared visible for him.

A large amount of data is stored in Internet Movie Database (IMDb) and services such as Amazon or lastFM. Converting data in multiple two-mode networks and combining them in network analysis allows us to obtain information about collaboration between actors, producers and composers, similarity of the movies according to different measures, etc.

With the developement of technology different types of databases occured, where the type of the database is defined with the way the data is stored in a database. With growth of available data the data warehouses were developed. A data warehouses

archive data directly from the source. It is a central source of data for use by managers for creating statistical dashboards and reports about it. The other very popular type of database is cloud database that relies on the cloud technology [Voorsluys (2011)].

A graph database [Angles et al (2008)] is also useful in the network analysis and it is interesting because of the way the data is stored in it. It uses graph structure to represent and store information. Specialized graph database uses a network model, which is concieved as a flexible way of representing objects and their relationships.

Every day large amounts of data are being collected. So big data [White (2012)] emerged as being a collection of large data sets. These data sets are so large and complex that it is very difficult to be processed using traditional data processing applications. Also suitable technologies are required such as cluster analysis, machine learning, neural networks, pattern recognition and anomaly detection.

Many repositories of networks and datasets of other types are available: Repositories of Datasets, KDnuggets Datasets for Data Mining, Data Surfing on the World Wide Web, Public Data Sets on Amazon Web Services, TunedIT, The Internet2 Observatory Data Collections, Infochimps, CAIDA (The Cooperative Association for Internet Data Analysis) Data and Network Data Sources on Pajek's web page.

Different activities are traced by their logs. Mobile network operators record the usage of the phones by their users, the data from weather stations is collected, online social network providers collect the data about their users [Abdesslem et al (2012)], different sensor networks are being established, peer-to-peer (P2P) networks are more and more interesting, using the Radio-frequency identification (RFID) tags we can follow the movement of their owners, etc. Such data can be used for prediction or just for the behavioral analysis of the users.

Almost network data

Some data is already organized in a network form. A transportation network is a network of roads, pipes, streets, or any other similar structure that allow trasportation of some kind. They are represented as links, and crossings are preresented as nodes. Another area that deals with a lot of data in a network form is chemistry. The structure of every molecule is a network with atoms as nodes and covalent chemical bonds as links between them. The most interesting for network analysis are organic molecules as proteins, lipids, hydrocarbons, and DNA. A lot of molecular data is available at Protein Data Bank.

To analyze such data using the selected network analysis tool we usually have to transform them into the corresponding input network data format. These issues are elaborated in details in the essay "Network Data File Formats".

Sometimes special programming solutions should be developed to perform the required transformation. For example, the transformation of the ESRI shape file describing the map of borders between country's administrative units (states, counties) into the neigborhood relation of the administrative units can be done with a short program in R using the function `poly2nb` from the package `spdep`.

Networks derived from data

Some data sources require more sofisticated procedures to transform them into corresponding networks.

Very interesting data source are also the daily news archives of the news agencies (Agence France-Presse, Reuters, United Press International, American Press Agency, Xinhua, ITAR-TASS, etc.). A single news is essentially a (tagged) plain text that can be analyzed with ***computer-assisted text analysis*** [Popping(2000)]. One of the

main approaches to this type of text analysis is the semantic text analysis. The units of the text are encoded according to the Chomsky's **subject-verb-object** model which can be directly transformed into temporal multi-relational networks with subjects and objects as nodes and verbs as relations. Examples of applications of this approach are the Kansas Event Data System, Paul Hensel's International Relations Data Site, or Correlates of War. An elaboration of this approach is given in the Franzosi's book "From Words to Numbers" [Franzosi (2004)]. See also the Centering Resonance Analysis approach proposed by Steve Corman.

Another example are the neighbors networks. Let $\mathcal{V}$ be a set of (multivariate) units and $d(u,v)$ a **dissimilarity** on it. They determine two types of networks: the k-**nearest neighbors** network: $\mathcal{N}(k) = (\mathcal{V}, \mathcal{A}, w)$

$$(u,v) \in \mathcal{A} \Leftrightarrow v \text{ is among } k \text{ nearest neighbors of } u, \quad w(u,v) = d(u,v)$$

and the r-**neighbors** network: $\mathcal{N}(r) = (\mathcal{V}, \mathcal{E}, w)$

$$(u:v) \in \mathcal{E} \Leftrightarrow d(u,v) \leq r, \quad w(u,v) = w(v,u) = d(u,v)$$

These networks provide a link between (multivariate) data analysis and network analysis. For larger sets of units a problem of an efficient algorithm for determining the nearest neighbors arise. David M. Mount wrote the Approximate Nearest Neighbor Library with fast algorithms for the (approximate) nearest neighbor search. In R these algorithms are available through the function `ann` in package `yaImpute`.

Semantic web

Semantic web [Berners-Lee et al (2001)] is an upgrade and an extension of the ordinary web. It provides a data layer in WWW to be used by web services. The basis for semantic web is the semantic description of the web content with the use of metadata and ontologies. The aim is to convert web of unstructured documents into a web of

data. This would make also easier to analyze this data, because it would be already in a network form.

Semantic web is based on Uniform Resource Identifier (URI), Resource Description Framework (RDF), and Web Ontology Language (OWL). The URI is a string used to identify a name or a resource and enables interaction with representations of the resource over a network using specific protocols. RDF is a W3C standard for encoding knowledge. It is used for conceptual description or modeling of information from web resources, and by computers to seek the knowledge. RDF is actually foundation for processing metadata; it provides interoperability between applications that exchange machine-understandable information on the Web. The OWL is a family of knowledge representation languages for authoring ontologies.

A piece of knowledge in RDF is represented as a triple subject-predicate-object. A subject denotes the resource, the predicate denotes aspects of the resource and expresses a relationship between the subject and the object. The resources are always named by URIs plus optional anchor IDs (URL and URN are its subsets). The triples form a multirelational network with subjects and objects represented as nodes and predicates determining types of ties – relations. There are large collections of RDF triples: Linked Data - Connect Distributed Data across the Web, Freebase, and DBpedia.

Different syntax formats exist and are quite varying by their complexity: N3, N-Triples, TRiG, TRiX, Turtle, RDF/XML, RDFa, JSON-LD. The purpose of RDF is to provide an encoding and interpretation mechanism so that resources can be described in a way that a compatible software can understand it. Some formats are not human friendly but more machine friendly. See also SPARQL – an RDF query language.

Generating random networks

Generation of random networks [Batagelj et al (2005), van der Hofstad(2011)] has become important for studies of complex systems such as electrical power grid, social relations, the World Wide Web and Internet, collaboration and citation networks of scientists, etc. Random networks are used for modeling classes of graphs.

Paul Erdős and Alfréd Rényi proposed in [Erdős et al (1959)] an approach to formalize the notion of a random graph. The ***Erdős-Rényi*** model, denoted by $\mathcal{G}(n, m)$, where n is the number of nodes and m is the number of edges, generates a random graph on n nodes and m edges (uniformly) randomly selected among the $\frac{n(n-1)}{2}$ potential edges.

Another, closely related to Erdős-Rényi model, is the ***Gilbert's*** model $\mathcal{G}(n, p)$ [Gilbert (1959)], where n is the number of nodes and p is the probability that an edge is included in the random graph. In this model the $\frac{n(n-1)}{2}$ potential edges of a simple undirected graph $G(n, p) \in \mathcal{G}(n, p)$ are included independently with the probability p.

A model called ***small worlds*** was introduced by Watts and Strogatz [Watts et al (1998)]. This class of random graphs depends on two structural features. The clustering coefficient is high and the average distance between pairs of nodes is short. Networks such as social networks, the Internet, and gene networks all exhibit small world network characteristics.

The degree distribution of random graph from Erdős-Rényi's or Gilbert's model is sharply concentrated around its average degree. In most real-life networks it roughly follows the power-law. Such networks are called ***scale free***. Barabási and Albert [Barabási et al (1999)] described a process of ***preferential attachment*** that generates graphs with this property. The preferential attachment process creates one node at a time and each newly created node is attached to a fixed number of already exist-

ing nodes. The probability of selecting a specific neighbor is proportional to its current degree.

Different classes of random graphs can be described also as ***probabilistic inductive classes*** of graphs [Kejžar et al (2008)].

Cross-References

Network Data File Formats

Questionnaires for Measuring Social Network Contacts

Network Data Collected via Web

Collection and Analysis of Relational Data in Organizational and Market Settings

Quality of Social Network Data

Ethics of Social Networks and Mining

Ethical Issues Surrounding Data Collection in Online Social Networks

Web references

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Web Archiving Service: `http://webarchives.cdlib.org/`

Enron E-mail Data: `http://www.isi.edu/~adibi/Enron/Enron.htm`

Internet Archive: `http://archive.org/index.php`

Repositories of Datasets:

`http://www.trustlet.org/wiki/Repositories_of_datasets`

KDnuggets Datasets for Data Mining:

`http://www.kdnuggets.com/datasets/index.html`

Data Surfing on the World Wide Web:

`http://it.stlawu.edu/~rlock/datasurf.html`

Public Data Sets on Amazon Web Services:

`http://aws.amazon.com/publicdatasets/`

TunedIT: `http://tunedit.org/repo`

The Internet2 Observatory Data Collections:

`http://www.internet2.edu/observatory/archive/data-collections.html`

Infochimps: `http://infochimps.com/`

CAIDA (The Cooperative Association for Internet Data Analysis) Data:

`http://www.caida.org/data/`

Network Data Sources on Pajek's web page:

`http://pajek.imfm.si/doku.php?id=data:urls:index`

Protein Data Bank: `http://www.rcsb.org/pdb/home/home.do`

Internet Movie Database: `http://www.imdb.com/`

The Kansas Event Data System: `http://web.ku.edu/keds/`

Paul Hensel's International Relations Data Site:

`http://www.paulhensel.org/data.html`

Correlates of War: `http://www.correlatesofwar.org/`

Centering Resonance Analysis approach proposed by Steve Corman:

    http://www.crawdadtech.com/

Approximate Nearest Neighbor Library: http://www.cs.umd.edu/~mount/ANN

Linked Data - Connect Distributed Data across the Web:

    http://linkeddata.org/

Freebase: http://www.freebase.com/

DBpedia: http://en.wikipedia.org/wiki/DBpedia

KinSource: http://kinsource.net/csac/wiki/kinsrc/KinSources/

Genealogy Forum: http://www.genealogyforum.com/gedcom/

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