

Perspectives of Network Analysis applied to Social Sciences

Tendenze dell'analisi dei reticoli applicata alle scienze sociali

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Riassunto: il saggio illustra criticamente la specificità dell'analisi dei reticoli applicata alle scienze sociali, ne traccia lo sviluppo, sottolineando come questo approccio possa vantare una tradizione ormai secolare in alcune discipline come l'analisi interorganizzativa, e di oltre mezzo secolo per quanto riguarda la sociologia, la psicologia sociale e l'antropologia culturale. Più recentemente l'analisi dei reticoli ha trovato applicazioni anche in economia, con riferimento ai processi di diffusione delle innovazioni. Nonostante questi sviluppi l'approccio in oggetto è stato a lungo ritenuto come 'un sistema integrato di tecniche in cerca di teorie' (Collins 1988) e solo recentemente lo sviluppo delle teorie del capitale sociale in ambito sociologico, economico e politologico ne hanno rilanciato le potenzialità euristiche, rendendo auspicabili ulteriori sviluppi nelle tecniche di analisi della dinamica dei reticoli.

Keywords: network analysis, social sciences, research methodology, social capital, social structure, exchange theory, structural analysis, innovation, matrix algebra, graph theory.

1. The network approach in social sciences¹

The idea that social phenomena can be interpreted as networks of relations, society itself can be viewed as a web, social action can be explained as the outcome of constraints and opportunities emerging from interpersonal relations enjoys an increasing consent among social scientists. The reasons of this success is in line with a widespread vision of post-industrial society, with its increasing interdependencies, that foster the use of the term network as a metaphor of society: the diffusion of internet as an emblematic representation of globalization, the evolution of the economy based on increasingly open and flexible firms whose efficiency is related to their web like structure, the emergence of a third sector based on informal relations as opposed to a declining welfare state. Be that as it may, in the last decades the success of relational approaches in empirical social sciences has been undoubtedly supported by a fast growing development of network analysis tools.

Network analysis (NA) is a set of integrated techniques to depict relations between actors and to analyze social structures emerging from the recurrence of these relations. The basic assumption is that better explanations of social phenomena should be found in the analysis of the relations between entities, which is carried out through the collection

¹ This paper is an extended and updated version of a synthetic essay written for the International Encyclopedia of the Social and Behavioral Sciences (Chiesi 2001).

of relational data organized in matrix form, rather than in their social characteristics, which are usually surveyed on set of individuals sampled from a larger population.

Traditional sample surveys isolate each actor and reduce his or her social relations to individual characteristics, in order to analyze statistical relations between variables. These causal relations can be only interpreted as useful indicators of underlying mechanisms, which are in fact any kind of encounters and exchanges between real actors who display their every day life strategies. NA concentrates directly its analytical attention on these phenomenological encounters, while traditional surveys can only identify causal connections without explaining effective operating mechanisms (Collins 1988).

For instance, a statistical relation between social origin and status attainment can in no way depict the actual mechanism of social mobility, but it is only a signal of social relations both within relatives and within the larger social milieu of the respondent. The shape and intensity of the network of these relations are the actual explanation of the persistence or changes of social status through generations. Although deterministic approaches usually emphasize that NA allows to study how the social structure of relationships around a person, group or organization affects behaviors and attitudes, social networks are in turn constructed by individual or corporate actors, to the extent to which they can mobilize social resources to chose partners or counterparts and to organize coalitions. In short, structurally bounded purposive actions can interplay with social structure and vice versa.

If actors are depicted as nodes and their relations as lines connecting pairs of nodes, the concept of social network changes from an evocative metaphor, as it has been for a long time since the beginning of the twentieth century, to an operative analytical tool that can take advantage of the mathematical language of graph theory and of matrix and relational algebra. Concepts and theorems of graph theory can be meaningfully applied to NA (Harary et al. 1965). Matrix algebra is a powerful tool in computing distances between nodes and their centrality (Freeman 1978).

Since mid 1970s, the development of algorithms subsequently integrated in statistical packages² and the availability of increasing computation capabilities in the following decade has contributed to the successful application of these techniques to larger and more complex structures than personal networks studied in the 1930s. The foundation of specialized reviews (“Social Networks” and “Connections”) and the publication of manuals of NA in different languages (Scott 1991, Wasserman and Faust 1994, Degenne and Forsé 1994, Chiesi 1999) has contributed to institutionalize this approach that has been increasingly accepted in the literature of disciplines like sociology, anthropology, social psychology, history and political science, while statistics and mathematics constantly contribute to the development of analytical tools. The activity of an interdisciplinary community of scholars is evidenced by the foundation of the International Network for Social Network Analysis in the late 1970s.

These developments have induced some scholars, mostly structural analysts, to identify a new scientific paradigm. Actually NA has something typical of what Khun (1962) has called a paradigm: the formation of a community of scholars who share a special language, controls reviews and meets regularly in congresses where specialized arguments are discussed, concerning applications of technical tools and their theoretical interpretation. It is also evident the cumulative nature of this activity, in spite of the

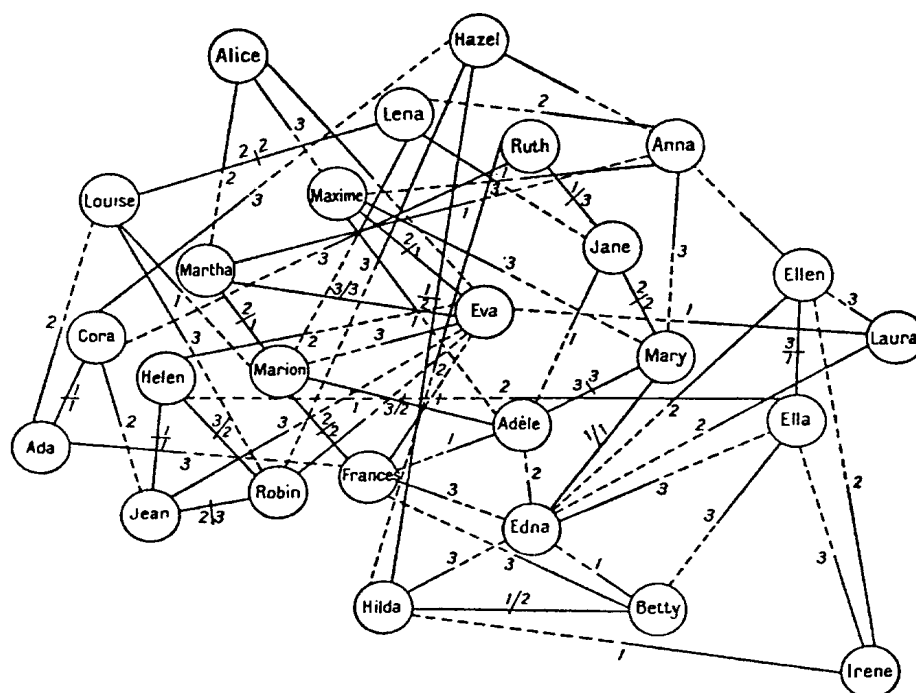
² The most known and used packages are GRADAP (Stokman and Sprenger 1989) and UCINET (Borgatti, Everett, Freeman 1992).

eterogeneity of the disciplines and fields of application. On the other side NA suffers a lack of shared theoretical assumptions and of theories derived from them. Not only NA has showed applications in disciplines that go even beyond social sciences, but has proved its fertility in the application of very different theoretical environments. The idea that society is a set of relations itself and individual actors are embedded in social networks is still a too loose idea to become a theory. For these reasons NA has been sometimes defined a technique in search of a theory and therefore can be considered a set of techniques with a shared methodological perspective, rather than a new paradigm in the realm of the social sciences. These techniques allow to dismiss a metaphor and to undertake substantive research, which can offer good descriptions of complex structures and generate theoretical interpretations.

2. Origins and Developments

The basic intuition that social phenomena can be interpreted as networks of relations has been recurrent since Simmel's formal sociology and his studies on the relations between actors in dyads and triads (Simmel 1908). Nevertheless, attempts to move from theoretical programs to empirical applications have been developed only since the 1930s in different disciplines (Scott 1991).

Figure 1: *A sociogram of choices between pupils depicted by Moreno in the 1930s.*



A first approach has been originally influenced by the *gestalt* theory and has been developed in the United States by a group of social psychologists emigrated from Germany. Moreno (1934), Lewin (1936), and Heider (1946) stress the role played by the structure of interpersonal relations in the construction of cognitive schemes and study information flows and the formation of shared ideas. The sociogram is the main

tool that comes out for the description of empirical networks, together with analytical concepts like symmetrical-asymmetrical relation, centrality and periphery, reciprocity and cognitive balance.

Another approach is directly linked to structural functionalism and has been initiated in the reshaping of the classical research on work organization in the wiring room of the Western Electric plant at Hawthorne (Roethlisberger and Dickson 1939). In this case the application of observation techniques taken from anthropology had evidenced the importance of informal relations in the performance of workers. Some years later Homans (1950) reorganized the same data in matrix form handling them in an analysis very similar to what will be called “block model” in the 1970s.

The so called Manchester school of social anthropology, whose main figures are Gluckman, Barnes, Mitchell and Bott, also started from structural functionalism but developed NA concepts to study conflict and power relations, in opposition to the traditional stress on social integration and cohesion. A shift of the research subject from African communities to next door neighbors relations in European cities led to the discovery of the importance of informal relations in urban setting. Concepts like density, connectivity, reachability and parameters related to the intensity and strength of ties have been applied at length, but the unique attention to informal relations and a mere descriptive approach has contributed to the decline of this school since the 1970s.

In that period the main technical developments are already settled at Harvard, where White develops mathematical concepts of structural analysis after the pioneering works by Harary and Cartwright during the 1950s. From then on the main stream program is to model formal properties of social structures based on graph theory and matrix algebra. The approach is then analytical and deductive rather than descriptive and inductive. Different types of graphs are defined and their properties studied. Field research and applications give place to the statistical debate about centrality, centralization, the identification of cliques and other types of subgroups. Important concepts like structural equivalence are proposed.

The main theoretical assumption that fostered these technical developments was called structural analysis, according to which the actor's behavior and attitudes are interpretable in terms of his or her structural position in the network. This deterministic and static approach has been criticized since the end of the 1970s and has led a second generation of authors to investigate also the structural opportunities that actors can enjoy using relations that can be mobilized from specific positions. Especially in sociology this reorientation has led to theoretical results that can be subdivided both in the domain of analytical models, whose application is useful in suggesting explanations of social phenomena, and in substantive theories pertaining to different fields.

As far as the first domain is concerned, different analytical types of ties, as well as concepts of point centrality, network centralization and structural balance have been proposed as well as many criteria for subgroup detection. The concept of structural equivalence, introduced by Lorrain and White (1971) has been directly inspired by role theory, while the concept of structural holes (Burt 1992) has been derived from information theory. On the side of substantial research, a number of middle range theories can be grouped into five different fields of empirical application:

1. the relation between network structure and actors' behavior and attitudes has evidenced that the density of ego centered networks is correlated with mental disorders (Kadushin 1982), the efficiency of task oriented groups depends on their structure (Bavelas 1950), members of cohesive networks tend to share common opinions (Epstein

1969), innovation diffusion is influenced by personal relations between actors (Coleman et al. 1957).

2. the role played by networks in keeping and creating social inequalities has been detected in research on social mobility, where macro outcomes at the level of social stratification and micro strategies can be analyzed together through network techniques. Moreover, studies on the labor market have evidenced that actors' strategies in getting a job are mainly based on informal relations through which strong ties and weak ties give different opportunities to find a job according to the segmentation of the labor market (Granovetter 1973, Grieco 1987).

3. the role played by networks in economic behavior and market mechanisms has inspired studies in interlocking directorates (Stokman et al. 1985) and other more general interorganizational relationships and has suggested a theory where market itself is seen as a network in which cliques of producers establish reciprocal strategies watching one another (White 1981). In spite of a long standing tradition of interlocking directorates studies, there still exist a number of competing theories about the way these interlocks work.

4. applications to political phenomena enjoy their inherent advantage of being close to the relational concept of power derived from Weber (1922). It has been found that in negatively connected exchange networks power is not a function of centrality, and exchange choices can originate structural transformations of the overall network because of changes in power dependency relations (Cook et al. 1983).

5. the idea to measure social capital through NA is more recent and has given increasing interest to these techniques. Extensive empirical research on social capital has begun in political science in the early 1990s (Putnam 1993) and developed in other social science fields through the analysis of its political and economic consequences, which have been correlated to proxies of social capital like variables measuring civicness or opinions about generalized or interpersonal trust. In spite of interesting results, this approach has been criticized because it is not based on a straightforward application of the definition of social capital itself, upon which all scholars agree: 'a set of interpersonal relations that are used by actors to fulfil their goals'. Authors like Lin (2001) and Flap (1999) have applied NA techniques to study the performance of interpersonal relations structures in the realization of one's goals. Chiesi has shown (2006) that some structural features of personal networks and their changes over time predict business success of entrepreneurs (average status of alter and stability of ties over time), while others are not statistically relevant (density and size). This approach to social capital has also proved fruitful in the inclusions of previous research on strong and weak ties in a unique theoretical perspective, as well as other research fields such as social support, ethnic communities and migration studies. As strong ties tend to be reciprocal and clustered, the term 'bonding social capital' has been proposed, which is related to common identity, feelings of belonging and sometimes promotion of equality, while weak ties, that are typical of 'bridging social capital', are mainly instrumental for the fulfillment of one's goals, not aimed at the relationships themselves (Woolcock and Narayan 2000).

3. Analytical concepts and techniques

Social network measures are based on the representation of a set of points (actors) and a set of lines (relations between actors), so that many concepts and theorems of graph

theory can be meaningfully applied. Table 1 illustrates a panoply of different kinds of relations that can be translated into graph theoretical concepts and depicted in a specific matrix form, whose rows and columns represent the points and cells the relation between them. A matrix is a powerful and controlled way to organize information on a network rather than to rely on subjective and less clear means like the sociogram reported in figure 1.

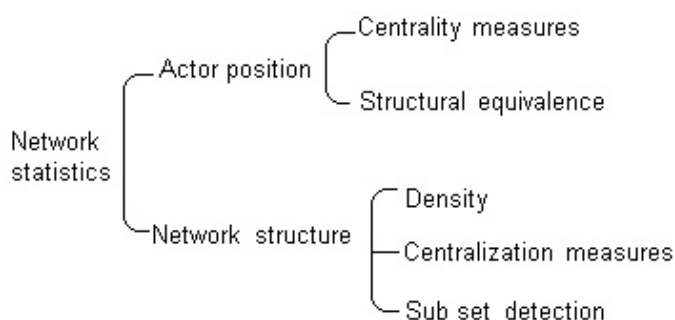
Table 1: *Types of ties and corresponding graphs and matrices*

Type of tie	Type of graph	Type of matrix
Presence/absence	Simple graph	Adjacency matrix: binary symmetric
Directed	Direct graph	Adjacency matrix: binary asymmetric
Positive/negative	Signed graph	Adjacency matrix: – + signs in cells
Weighted	Valued graph	Adjacency matrix: values in cells
Multiplex	Multigraph	Several matrices according to level of multiplicity
Membership	Ipergraph	Affiliation matrix: asymmetric

Simple graphs can be depicted in a binary symmetric adjacency matrix. Direct graphs take into account the direction of the arcs and use binary asymmetric adjacency matrices. Signed graphs are used to depict like/dislike relations and use matrices with positive or negative signs in cells. To study weighted relations data sets lose the algebraic properties of binary matrices but gain substantial information on the intensity of ties. To represent multiplex ties with multigraphs stacked matrices are used, while the representation of ipergraphs through asymmetric affiliation matrices allows the study of membership relations.

For each of these ties different networks can be studied with families of descriptive statistics illustrated in figure 2.

Figure 2: *A scheme of different types of descriptive statistics*



Available statistics can be related to the relative position of the actor in the network and to the structure of the network itself. As far as the actor's position is concerned two sub categories have been developed. The first one is devoted to a rich choice of centrality indexes, according to the range of the centrality, to the kind of network and to the type of graph. The theoretical hypothesis underlying is that central actors may have higher opportunities to fulfil their goals than peripheral ones. Table 2 reports a list of the indexes presented extensively in Wasserman and Faust (1994). Measures based upon the degree indicate the direct contacts of a point. This is a local centrality measure because the overall structure of the network is not taken into account. In directed

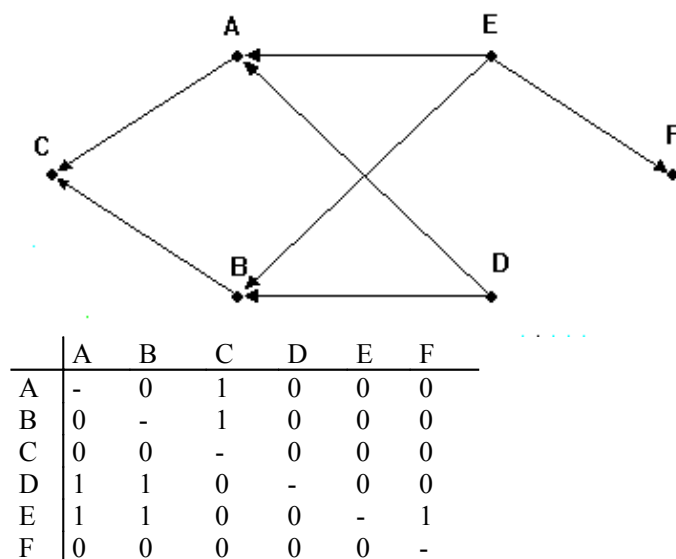
graphs, centrality in terms of outdegree can be interpreted as a measure of influence, while in terms of indegree it means prestige or popularity. The concept of neighborhood and its application to centrality measures allows the researcher to choose a given range of distance from the actor, according to the substantive meaning that can be given to the structure of relations. Distance based measures take into account the relative position of the actor to all other points in the network. For information networks specific centrality measures have been devised that take into account how a point is important for the transmission of information between any other couple of points.

Table 2: *Network position: a typology of centrality indexes*³

Type of centrality	Analytical concept	Symbol: simple graphs	directed graphs
Short range centrality	degree	C_D	C_{ID}
Variable range centrality	neighbourhood	C_N	
Global centrality	geodesic distance	C_C	C_{IR}
Information networks	rush, betweenness	C_B	
Local prestige	indegree		P_P
Global prestige	rank		P_R

The second category of actor's centrality measures has been developed around the above mentioned concept of structural equivalence that is focused on the detection of similar positions of points in the network. The underlying hypothesis is that actors with similar positions have the same constraints and opportunities structure. As exact structural equivalence is rare in empirical networks, algorithms have been devised to detect equivalent sets based on correlation between columns – columns and rows in case of directed graphs – in matrices. In figure 3, for instance, points A and B are structurally equivalent and correlation between their columns and rows is 1.

Figure 3: *Structural equivalence of A and B and corresponding adjacency matrix*



³ There are no shared conventional symbols in the international literature. I adopt the symbols proposed by Wasserman and Faust (1994), whose manual is diffused and well known.

Network structure measures can be subdivided into three categories (Stokman 2001): density, centralization measures and sub set detection. Density – the likelihood that a random pair of points in a network be joint with a line – is the most common measure. Research has shown that dense networks are more effective in controlling and sanctioning than in spreading information. In general they generate strong ties, redundant information and constraints, therefore are not suitable for innovation development and diffusion (Burt 1992). Network centralization statistics deal with the distribution of ties in the overall network and are mostly based on the analysis of variance of point centrality measures. The more the structure of a connected network is hierarchical, the higher the variance in the distribution of any kind of measure presented in table 2. Unlike density, whose values are not directly comparable for networks of different size, centralization measures have been standardized through the study of expected variance for different null models, given the number of points and lines (Snijders 1981). Sub set detection is an area where a lot of *ad hoc* criteria have been developed, according to the substantial meaning attributed to networks. The standard concepts are component (the maximal connected simple subgraph), strong and weak components (in directed graphs respectively maximal strongly or weakly connected subgraph), *n*-clique (the maximal complete subgraph at distance *n*) and blocks (the subset of points with similar structural equivalence⁴). If multiplicity of ties is involved, the technique of nested graphs (Stokman et al. 1985) can detect denser clusters in a network.

4. Merits, limits, and perspectives of the approach

NA techniques allow to specify empirical indicators of relational concepts, to control field hypotheses through the definition and measurement of traditional catch all, undefined concepts, like those of social structure and cohesion and others more recent like social capital. The development of analytical tools has helped in detecting structures underlying the apparently inextricable complexity of relations between actors in everyday life. From this point of view NA approach shares the same analytical purpose of other techniques, such those developed in social mobility studies, whose main goal is simplifying descriptions and devising standardized measures to be used for comparison. Nevertheless NA enjoys a larger range of potential applications, comparable to that one of traditional surveys, because it is hardly conceivable a social phenomenon that cannot be analyzed as a set of relations between individual or corporate actors. Moreover, research problems can be confronted both at micro and macro levels, without changing research design and techniques, because corporate actors can be simply interpreted as networks of networks.

Important limits counterbalance the above mentioned advantages. It is often stressed that the copiousness of the analytical and technical apparatus has been for a long time in contrast with the poverty of theoretical and substantive results, which are mostly descriptive or even artifacts coming from simplified simulations. While the same critics is perhaps applicable to most surveys, the relative scarcity of empirical results in NA is

⁴ Here I refer to block model technique developed by Breiger *et al.* (1975), while the term block sometimes refers to different analytical concepts and procedures (see for instance Stokman and Sprenger 1989).

certainly affected by specific difficulties of field research. Unlike traditional surveys, based on standardized questionnaires concerning opinions of anonymous respondents, the collection of relational information implies sampling problems. Statistical models for social networks are difficult to compute because relationships between points cannot be treated as independent observations. Additional difficulties are related to the reliability of intrusive questions concerning personal contacts. This is why often network analysts have preferred collecting data from documents and repertoires rather than ask direct questions.

In spite of these difficulties some network data collection techniques have been devised to test specific hypotheses. Ego centered networks allow to insert network information in normal surveys, providing that for each interviewee his/her personal network at distance one is obtained through the name eliciting technique – name generator questions – and using the ‘who knows whom’ question. This procedure gives important insight to the structure of actor’s interpersonal relations, but cannot give an idea of the network as a whole. To test the more general societal network structure the so called ‘small world experiments’ have been devised since the mid 1960s that give the possibility to probe the connectedness of large networks and structural holes across age, gender, social class, and so on (Milgram 1967).

Scholars recognize that NA has contributed to the development of a number of middle range theories empirically grounded in different fields. These new perspectives have in turn encouraged emerging theoretical concepts based on relational assumptions. A promising one is social capital, whose definition has been controversial for a long time (Bourdieu 1980, Coleman 1988, Lin 2001). My opinion is that it can be better formalized in network terms and network analysis can contribute to a better understanding of its mechanisms, while its theoretical importance for a wide range of social phenomena can potentially give a general theory which NA has been lacking of since its methodological breakthrough of the 1970s (Scott 1991).

The availability of a complete set of structural indicators encourages network comparison, in order to explain differences in space and changes over time. In this perspective two tendencies are emerging. One is concerning the development of statistical models that permit to compare actual networks with models generated by probabilistic assumptions, to test goodness of fit hypothesis. The difficulties of these developments are evidenced by research on models of triad counts and mutual choices. The other is the opportunity of integrating static structural data with the collection of additional survey like information. This implies a systematic combination of relational information with individual attributes of nodes and ties and has evidenced promising results showing how NA and traditional surveys are not necessarily alternative techniques of research, as some ‘orthodox’ network analyst would sustain.

It has been recently stressed the fact that, in spite of the above mentioned developments, the available technicalities put an emphasis on the description of static network structures (Stokman 2001), while theoretical interests have now moved to evolution and network dynamics implied by social capital theory that puts an emphasis on actors’ strategies. In the 1970s and the 1980s structural deterministic approaches stressed the importance of networks in conditioning actors’ behavior, attitudes and wellbeing, so that static analysis was requested because the network was treated as the independent variable. Since the last two decades the most popular assumptions have been those in which actors actively contribute to the formation of their network, building, strengthening, maintaining and breaking up relationships.

In this perspective the cross fertilization of NA with social exchange theory seems potentially fruitful, as well as with game theory. In this direction of increasing interest, in spite of an old contribution by Harary (1959), who proposed a theory of structural balance in signed graphs, little has been still done. For instance, Cook *et al.* (1983) have studied the different structural outcome of actors' choices in the case of positively vs. negatively connected exchange networks. In the former, relations are not mutually excludible, so that each actor can maintain exchange relations with different partners at the same time. In the latter actors have to choose a partner and exclude others. Experimental results show that the network generated by choices is completely different in the two cases. In the former the distribution of power among actors can be measured through current measures of centrality, while it is not the case in the latter instance. These approaches have been developed at micro level on small groups, because of their complexity. Their natural development goes in the direction of the detection of structural consequences on the overall network at macro level. Since the 1980s Markov models of network change have been developed where the unit of analysis is the dyad with its four states of relation: no tie, reciprocal ties, tie from A to B and vice versa. The model gives estimations of the likelihood of transition from one state to the other, assuming that the parameters stay constant and the population is homogeneous over time. These rigidities of the model have prevented wide range applications, in spite of the need to study dynamic processes. For these reasons scholars are developing more recent models that give up these limiting assumptions and integrate standard Markov models with models of rational actors' choices (Snijders 1996).

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