Fundamentals of Network Analysis: Five Principles and Measurements

FUNDAMENTALS OF NETWORK ANALYSIS:
FIVE PRINCIPLES AND MEASUREMENTS

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Introduction

Structural sociology takes social structure defining the situation as principal determinant of behaviors and beliefs of actors within the structure. Network analysis describes, operationalizes, and analyzes the substance of social structure. The ambiguity of idea of social structure is notorious, but network analysis conceptualizes social structure as a persisting pattern of social relations. Social relations then are represented as a form of network which consists of actors and their relations. Relations are measured in terms of strength of connections between actors and aggregate indirect connections through other actors. Sociogram is often used to visualize the relation in which nodes are actors and links or arrows express their relations. Precisely, data are relationship measures in one or more matrices. Variable Z_{ij} measures the relations from actor i to actor j.

Modern network analysis has five principles: cohesion, structural equivalence, prominence, range and brokerage. The first two serve to define social boundaries and bonds of inter-actor influence and the latter three define components' ability, freedom or power to act within a system. These five principles are used to determine the network boundary (i.e. where one system ends and another begins), specify types of relations, identify and characterize the position each actor occupies in a network.

My purpose here is two fold; one is to introduce these five principles and their measurements; the other is to provide evaluation of strength and weakness of each principle with respect to empirical studies.

Cohesion

Cohesion is one of the two criteria which aggregate types of actors into subgroups thus define boundaries of social systems. Actors are cohesive when they have intense mutual relations. Actors have direct ties among them are cohesive, thus are apt to be similar in terms of their behavior and beliefs. What hold cohesive actors together as a clique are socializing bonds of interaction. The ties are causal forces which make cohesive actors share beliefs and show similar pattern of behavior. They are similar to the extent their communication ties are strong in the system. They constitute a network where same kinds of access, information and resources are available.
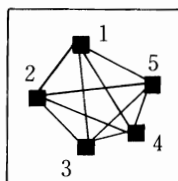
Figure 1-A
COHESION

Figure 1-A shows a network of 5 actors based on cohesion. The cohesive actors in the network forms a clique, since they all have direct ties to each other. A clique based on cohesion is one type of the network subgroups. Since cohesion concerns the intensity of specific relations rather than its form, the aspect of form of clique has been often ignored, but cliques can be regarded as positions jointly occupied by actors characterized by their cohesive bonds. Thus cohesion is used as one of the criteria to identify network subgroups, subgroups of people who hold the same position in a system of relations.

Cohesion of a network is often measured as density. In a symmetric network of N actors with t ties among them, the most simple formulation of density is as follows;

$$\text{Density} = 2t/N(N-1)$$

In terms of quality the more closely actors are related, the higher the

density, yet specifying the closeness involves conundrum.

The concept of cohesion has long been used to explain the homogeneity of behavior of group of actors. Actors within a cohesive subgroup are expected to reveal similar behaviors and attitudes. In Blau's investigation of the degree to which macro-level characteristics of collectives exert influence on social relations independent of personal preferences and ingroup bias, cohesion is employed as one of the most basic assumptions. (Blau, 1977) (Blau and Schwartz, 1984)

He defines ingroup cohesion as the density of (nonexclusive) ingroup associations. (Blau et al., 1984) He assumes that; (1) social associations are more prevalent among persons in proximate positions than between those in distant social positions; (2) ingroup associations are more prevalent than outgroup associations. Then he argues social associations (i.e., personal preference) are affected by opportunities for social contacts given that individuals prefer to interact with those who are similar to themselves in social characteristics.

Blau tests his propositions employing the rate of intergroup marriage as the dependent variable and macrostructural characteristics as variables explaining constraints from macrostructure on individuals marriage choices. His argument is evidenced with the result that people tend to marry those who are similar to themselves yet that there exist constraints on personal preferences by probabilities of aggregated collectives.

In Blau's study individuals are differentiated into subgroups on the basis of similarity of social characteristics (attributes and status) salient for interaction. Thus subgroups boundaries are defined not by observed relational ties among people but by attribute homophily. He beautifully formulates system of deductive theory and results of the study supports his theory that intergroup relations are constrained by the concomitant variation of emergent properties of population distribution. Underlying this study is the assumption of cohesion as causal force for the similarity of pattern of behavior among cohesive groups, but causal relation is not clearly stated.

Real explanatory power of concept of cohesion can be clarified only

when it is re-formulated as a special case of jointly occupied position in which actors are tied together by cohesive bonds. In order to examine the causal relationship between homogeneous beliefs/ behaviors and cohesiveness of actors, we have to see the nature of "form" of cohesive relations exploring beyond the assumptions of clique of actors who are proximate in social characteristics. For that purpose I should discuss the second principle, concept of structural equivalence.

Structural Equivalence

Structural equivalence is another principle that defines boundaries of social systems. Boundaries of social systems are defined by the similarity of patterns of relationship around reference groups. Actors are aggregated into a jointly occupied position to the extent they are structurally equivalent to one another. The similar pattern of behavior/ attitudes of structurally equivalent actors are causally explained by their homogeneous norms and beliefs created by their role-playing within shared frame of reference which guides and socializes actors homogeneously.

Frequently structural equivalence is measured as Euclidean distance which Burt proposes as follows;
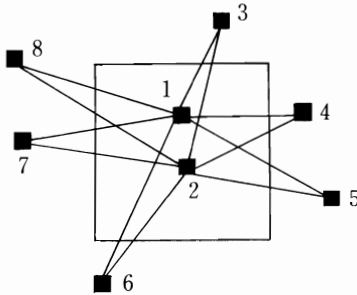
$$Dab = Dba = [\sum q(Oaq - Obq)^2 + \sum q(Iqa - Iqb)^2]^{\frac{1}{2}}, \cdot a \neq q \neq b$$

where Oaq is the proportion of measured strength of relations from actor a to q (i.e., $zaq/\sum kZak$) and Iqa is the proportion of measured strength of relations from actor q to a (i.e., $zqa/\sum kZka$). Two actors are structurally equivalent $(Dab = 0)$ to the extent that they receive identical proportion of relations from each other actors as object of relations $(Iqa = Iqb)$ and send identical proportion of relations to each other as subject of relations $(Oaq = Obq)$. (Burt, 1982)

Network subgroups are differentiated by the criteria of cohesion and/ or structural equivalence. Actors of a cohesive clique can be structurally equivalent, but structurally equivalent actors do not have to form a cohesive group. Figure 1-B shows a network of eight actors. Actors 3, 4, 5, 6, 7 and 8 are structurally equivalent. Since they have same relational patterns to actors 1 and 2. Structural equivalence

predicts similarity of behavior and attitude among actors 3, 4, 5, 6, 7 and 8 in spite that they do not possess direct ties among themselves while cohesion does not predict similarities of actors 3, 4, 5, 6, 7, and 8. Notice in Figure 1-A, five actors are cohesive and also structurally equivalent. Thus, both cohesion and structural equivalence predict similarity of five actors' behavior and attitude in the network of Figure 1-A.

Figure 1-B
STRUCTURAL
EQUIVALENCE

The contrast of cohesion and structural equivalence is highlighted by Burt's study of innovation adoption. Burt (Burt, 1980) (Burt, 1987) makes extensive use of the concept and argues the superiority of structural equivalence to cohesion in explaining contagion observed in the process of diffusion of medical innovation. The classic study of diffusion process of "tetracycline" among medical doctors by Coleman (Coleman et al., 1966) explains the transmission process by contagion. Using the same data, however, Burt argues the dominant factor was not contagion but physicians' personal preferences and that within the realm where contagion found, it was by structural equivalence rather than cohesion. By speculating the patterns of each physician's ego-alters network, he found adoption occurred not because of socializing bonds of direct interaction but awareness of norms among structurally equivalent physicians.

Contagion by cohesion focuses on interpersonal communication; how innovation spreads through direct ties, while structural equivalence explains imaginative role taking to make actors similar; how contagion occurs among those who have no direct contact. Here the concept of structural equivalence generates testable propositions on what kinds of physicians accept innovation, when and why adoption–time lag occurs, which could not be explained by cohesion.

I should point out that one limitation here is that structural equivalence model requires ego's awareness of existence of structurally equivalent others in his network. The mechanism does not yield homophily to the occupants of same status who do not recognize the presence of the other. The structural equivalence thus stands only on the assumption of mutual recognition.

Prominence

Prominence is a feature that defines an actor's status within a system. An actor is prominent to the extent that his relations make him particularly visible relative to other actors in the system. Therefore prominence of an actor in a social system is a trait of his relational pattern which defines his position in the system. An actor is prominent when he is being the object of prominent contacts to the degree that an actor is involved in relationship that makes him very visible member of a social network.

More precisely it is conceptualized as centrality in a system of symmetric relations, and as prestige in a system of asymmetric relations. The central actors are those who are extensively involved in relationships. Centrality focuses on actor's connectedness in relations, regardless of the actor's status as source/object in his relationship. The more extensively an actor is involved with relationships, the more prominent he is in terms of centrality.

On the other hand, prestigious actors are those who are extensively the objects of relations. The more an actor receives relations from others, the more he is prominent in terms of prestige. Being an object of relations determines the degree of prominence of an actor in terms

of prestige. Thus an actor's prominence is a function of absolute volume of both direct and indirect relational ties for centrality and of degree of receiving relations from others for prestige.
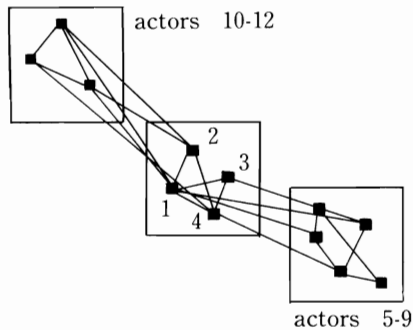
Figure 1-C
PROMINENCE

Figure 1-C shows the system of network of twelve actors. Given their relations are symmetric, actor 1 has the highest centrality. Let the relations be asymmetric and that all the ties actor 1 holds be directed at him, he is most prestigious.

For operationalization, a variety of prominence measures are presented, yet they can be categorized into two; one relates to volume of relations, (i.e., the number of relational ties an actor has); another is concerned with quality of relations, (i.e., the number of unreciprocated relational ties). Nieminen proposes a measure of centrality as the count of degree or number of adjacencies for a point as follows (Nieminen, 1974);

$$CD(pk) = \sum_{i-1}^{n} a(pi,pk)$$

where a $(pi,pk) = 1$ if pi and pk are connected by a line

$= 0$ otherwise

Prestige measure proposed by Burt takes following form:

$$Pj = \sum_{i-1}^{n} PiZij$$

where prestige of actor j, (Pj) is the sum of each actor i's prestige (Pi) weighted by the strength of his relation to j (Zij). (Burt, 1982)

The advantage of prominence concept captured by network analysis is that the concepts such as centrality and prestige of an actor are defined and operationalized precisely as relational property of the external social structure and the actor without referring actor's internal attribute. Therefore once a group of actors is given, the concept of prominence is especially useful to detect hierarchy of actors and stratification of subgroups.

Crane presents an empirical test of the "invisible college" hypothesis within the field of diffusion of agricultural innovation and detects subgroups among scientists. It has been argued that growth of scientific knowledge is say not all, but at least to some extent contingent on the patterns of social relations among actors who engage in scientific activities. Her analysis supports that there exist informal collectives of closely interacting elite scientists which advance research front of science. (Crane, 1972)
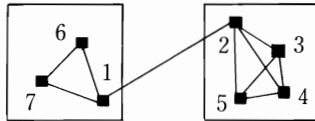
It should be noted for such analyses as to describe the intranetwork stratification, boundary specification is vital. Since an actor's promi-nence is determined by the volume and quality of relations he has within the system, addition of an extra actor to the system or deletion of an actor from the system may change prominence of all the actors in the system. The argument of prominence requires an assumption that the boundary of network discussed is systematically defined. Crane's analysis has its weakness in defining the boundary rather vaguely. The field she chooses has inter-disciplinary character thus she necessarily finds difficulty in specifying network boundary.

Prominence measured in network analysis, however, is much more reliable than prominence operationalized by attributes as explanatory variables. An actor's prominence or prestige is not determined nor explained independent of his surroundings. Such concept is less than an attribute of the actor but than relational feature of position in a network. Therefore I believe this is a principle which allows network analysis to perform accurate and reasonable operationalization with the cost of hard work for establishing plausible boundaries.

Range

Range is a concept which may be least pretentious among five principles. As in Figure 1-D, an actor's relations have range to the extent they connect actor with an extensive diversity of other actors. Redundancy of contacts either by structural equivalence or by cohesion decreases the range of an ego network. Naturally, depending on how we define "diversity" of actors in a network, range can be differently operationalized.

Figure 1-D
RANGE

Range measures can be categorized in two ways. First, given that each of ego's contact equally increases the range of his contacts, range is measured in terms of volume of contacts. One type of this measure counts the number of actors directly connected to ego, another counts the number of different status groups represented by the alters directly connected to ego. Second, range can be defined in terms of quality of contacts. A contact has quality to the extent that it increases the diversity of alters in ego's network.

Range is more specifically analyzed with the concept of weak ties as bridges by Granovetter. (Granovetter, 1973) In Figure 1-D, the tie between actors 1 and 2 is a bridge. A bridge is an only path in a network which connects two different kinds of actors, which could be a strong tie but often is a weak tie. Granovetter argues weak ties serve as social resources since they connect different kinds of actors and optimize nonredundant contacts and help actors to be informed of necessary information. Without weak ties, he argues ego is deprived of information from distant part of social systems and ego is unable to

receive information outside clique.

Above argument is evidenced by his analysis of men's job mobility (Granovetter, 1974). He employs the amount of time each man spent with alters in his network as a measure of strength of ties, and examines how information of job openings flow through weak and strong ties. He shows that men who received the best job offers were those who had more dispersed network of acquaintances. He claims the networks with weak ties had wider reach to different parts of social structure and provided those men the opportunities for appropriate job openings at right time.

Yasuda analyzes the 1985 U.S.-Japan Input-Output Table and reports that market performance of industries is negatively associated with wider range of cross-national trading. (Yasuda, 1990) The range of an industry's trading network is measured as the number of ties of selling and buying commodities. In this instance, wider range does not provide profits to holder.

The weakness I think with the concept of range comes from the fact that the concept allows many ways of operationalization. Existence of different kinds of range measurements logically implies the possibility of diversity of range for an ego network depending on the definition. Some measurements can pick up the change in network range, but other measurements may not, depending on the type of relation added. Ego may add an alter to his network. Unless the relation with the alter remains so candid that the tie serves as a communication channel, ego network can only increases its range in terms of volume of ties, not in terms of quality. Thus what dimension of diversity of network range matters should be explicitly specified.
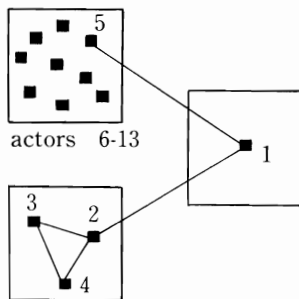
The strength of range concept we observe is the rejection of attributes of actors. In Granovetter's work, in stead of attributing receipt of better job offers to each man's characteristics such as age, race, or educational background, he specifies what differentiate these men are patterns of social ties each man has. Relational pattern often correlates with individual traits but it does cause the opportunity differentials. By avoiding the approximating attributes as causal force

but by specifying range of each man's network, he has succeeded to show true causal relation between the different degree of job offers among men and their relational patterns.

Brokerage

Brokerage is the fifth principle which embodies that "Fra i due litiganti, il terzo gode." By brokerage, intermediary actors can facilitate transactions between other actors lacking access to and influences the distribution of power in networks. (Marsden, 1982) If a transaction between actors or groups of actors can take place only with one particular intermediary actor (i.e., two dyadic exchanges should have one actor in common), the actor as a broker has power over other parties to the extent the others' need for the transaction. The lack of alternative brokers for the particular interaction increases power of the intermediary actor. This idea is closely related to one of the propositions of exchange theory; that dependency is the source of an actor's power over the others. Cook et al. (Cook et al., 1983) presents a theoretical analysis and laboratory experiments on the distribution of power in exchange networks. In Figure 1- E, actor 1 occupies the broker position.

Figure 1-E
BROKERAGE

Concept of structural autonomy explains the benefits of occupying broker positions in more detail. An actor's ability to pursue and realize

interest without constraints from other actors in the system depends on the patterns of connected actors and disconnected actors in a network. In Figure 1-E, actor 1 has the structural autonomy against disconnected actors 5-13, but actor 1 is not autonomous against cohesive actors 2, 3 and 4.

By operationalizing the concept of structural autonomy as the combination of oligopoly and group affiliations, Burt explains the relative industry profits as the function of structural autonomy of each industry in American market system. Furthermore, his analysis shows that firms' purchasing goods from other firms are constrained by the cooptive ties they hold. The result has shown the benefits gained by structurally autonomous actors as brokers are clearly reflected in their profits. (Burt, 1989) Structural autonomy in the context of purposive actions describes the mechanism for an actor to play others off against one another to win one's own interest. In such context disorganized others are the sources for gaining interest since by having contact with them the actor occupies the position to negotiate relations to his personal advantage. The more an actor has direct ties to others who are disconnected from each other, the more brokerage opportunities he has, thus the greater his power potential within the network.

I should add, however, applying the principle of brokerage to purposive actions requires an assumption: that actors prefer transaction which involves shorter routes to transaction that requires more intermediary ties in completing the transaction. A direct transaction is the best, an indirect transaction via one broker is preferable next, and an indirect transaction via multiple intermediaries is the worst. It is because of the different amount of brokerage cost each type of transaction requires. Naturally the less the cost, the better the transaction.

The assumption is regarded as that of rational action from the view of economists, yet it can also be thought as assumption of normative action among structurally equivalent actors. Therefore the utility of broker concept is applicable and mostly suited to explain the situation where actors are keenly aware of the costs and benefits their actions

trigger. The network perspective of market explains the mechanism why it is rational for a firm to transact with another particular firm, and why certain industry is almost maximizing its profits while others are not.

Conclusion

Five principles of network analysis and their measurements are introduced with evaluation of strength and weakness each principle bears. Summing up, network analysis is to capture the substance of social structure by the form of network which is composed of actors and their relations. Causal forces are not actors' attributes but the positions and roles actors occupy in their network. Network analysis asserts actors' norms, opinions and behavior are largely determined by the social structure surrounding them as the context for their action. As data required are relationship measures, network analysis can and actually has been applied to both macro and micro level analysis. Therefore I consider network analysis, inspite of its prematurity, as promising paradigm which subjugates the macro-micro controversy as a theory as well as a method.

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ネットワーク分析の基礎概念

〈要　約〉

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安　田　　　雪

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　「社会構造」という概念はその多義性のゆえに頻用されてはいるが，この概念の実質的な定義に関しての統一見解は確立していない。ネットワーク分析は，あえて社会構造を「行為者の間で比較的恒常的に存在する関係，または，繰り返される行為のパターン」と定義し，(1)行為者とその関係が構成するネットワークとして，社会構造を抽出・記述し，(2)社会構造がその構成要素である成員の行為・規範を規定・拘束するプロセスを解明する試みである。本稿の目的は，結合，構造同値，威信・中心性，範囲，仲介というネットワーク分析の基礎概念を中心に，社会構造としてのネットワークの記述・分析の方法を紹介し，実証研究の成果と対照しつつ，その問題点と可能性を論ずることである。

　研究対象となる集団の構造は，行為者間の関係をソシオグラムとして，有向または無向グラフで表される。行為者数Nで構成されるネットワークはN×N行列に抽象化され，分析の基本データとなる。N×N行列において変数 Z_{ij} は行為者 i から行為者 j への関係の強弱を示す。

　ネットワーク分析は，行為者が属するネットワーク構造の特徴及び，行為者がネットワーク内で占める位置こそが主体の行動・規範の主要な決定要素であると，主体の生得的属性に注目してきた従来の社会学に問題提起をする。主体の生得的・内的要因を否定する事により，構造と行為の因果律を分析対象のミクロ・マクロのレベルに関わらず導くことが可能になる。構造分析の手法として，理論として，注目すべきパラダイムである。