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SOME PROBLEMS OF INFERENCE FROM CHAIN DATA

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Researchers studying rumor transmission are often interested in tracing the rumor to its source by asking each person who first told him. The end product of such a tracing may be a chain of acquaintances. In another kind of chain method, the researcher could ask a respondent to name the person with most influence on him; then, in turn, ask this reported influencer to name the person with most influence on him; and so on. Whatever the details of procedure, all the methods of obtaining chain data trace paths from one person to another on the basis of the relationships between them. Naturally occurring chains, like

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rumor chains, are social phenomena of interest in their own right; and chain data shed light on network structure and the ways people utilize this structure. Chains reflect aspects of network structure because such structures limit the possible paths for chains to take. Of all possible paths, the ones actually traced by a sample of respondents depend in part on their decisions about sending chains onward—for example, their decisions to pass rumors to certain acquaintances but not to others.

Since these topics are not easily studied with conventional techniques, chain methods have a good deal of appeal. Sociologists may be unaware of the recent development of chain methods because the available literature is widely scattered and not always fully explicit about the major issues involved in using chain data. This chapter attempts to provide orderly guidance to the literature and an explication of the key procedures and problems of chain methods. Chain methods will be briefly contrasted to others; an example will be used to illustrate some of the basic concepts and distinguish chain methods from network sampling, which has partially overlapping goals; and the major uses of chain data will be described. We then turn to four major methods of gathering chain data.

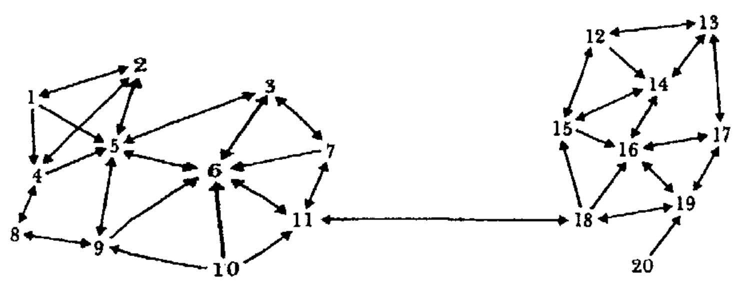
PERSPECTIVE ON CHAIN METHODS

Chain methods are obviously distinct from methods like survey sampling that are designed to provide information about attributes of aggregated individual units. Unless the usual survey procedures are much modified, they can yield only limited information about aspects of respondents' egocentric networks (as in Laumann, 1973). Among methods designed for the analysis of networks, some differ from chain methods in requiring complete observation of small bounded networks (White and others, 1976; Boorman and White, 1976). There is a more subtle difference between chain methods and network sampling, since both are primarily intended for the study of large networks. To clarify the difference between these two approaches, and also to clarify some of the basic concepts such as chain and network, I shall briefly discuss how these tools might be used in the study of social movements.

Several of the frequently suggested preconditions for a social movement concern the pattern of relationships between potential members of such a movement. Simmel (1964) argues that the sheer extent of such relationships affects the degree to which people interact with each other and become aware of common interests; hence the greater the density, the more likely that a self-aware group with a distinctive political ideology will emerge. Density, or the proportion of all possible ties that actually exist, can be studied through network sampling (see Granovetter, 1976). As a quick example, consider the hypothetical network in Figure 1, ignoring the direction of the arrows. I drew a sample of four points: 4, 8, 13, 15. In a network study I would make up a list of these names and show it to each of the four people, asking them to check off the people they knew. I would find that one of the six possible ties exists, so density in the sample is 0.17 as opposed to a density of 35/190 = 0.18 in the whole network. Although there may be some practical limits to the use of network sampling (Morgan and Rytina, 1977), this method promises a clear-cut approach to density in large networks—and (as we shall see below) chain methods generally do not.

Chain methods are likely to be more useful for answering different questions that bear on the genesis of social movements.

Figure 1. A hypothetical network.



Consider ties that are rare but crucial as communication bridges—for example, the tie between 11 and 18 linking two otherwise unconnected groups in Figure 1. Bridges may link potential movement members to necessary outside sources of information or help (Sheingold, 1973), or they may link different clusters of potential members together in an overall communication structure (Freeman, 1973). Now in Figure 1, unless 11 and 18 both happen to be included in a network sample, this tie between them will be missed and the two groups will seem completely disconnected. But this crucial link could be revealed by chain methods in several ways. We might trace chains of communication and find one in which information passed from 6 to 11 to 18 to 16; or the potential for such a communication chain might be revealed when we asked 6 to get in touch with 16 via interpersonal channels (see the small-world section below). Important indirect connections within a network can be explored with chain methods, while network sampling deals with overall density only.

USES OF CHAIN DATA

Before entering the crux of this discussion, I wish to distinguish four broad goals of inference from chain data. The four goals are described here in the same order in which they are discussed in more detail below for specific chain methods.

First, inferences may be made about individual social actors. All the chain methods described here begin chain tracing from an initial set of individuals, and this initial set can be used in the usual ways if it is a random sample. However, many of the chain methods tend to yield biased initial samples because the procedures are demanding and only the more cooperative subjects complete them.

Second, inferences may be made about chains. Chain length, for example, can be estimated in various ways—with various difficulties—depending on the method used to trace the chains observed. Chain length is of interest because it is often related to important variables, such as the quality of jobs found through contacts (Granovetter, 1974), access to elected representatives (Erickson and Kringas, 1975), and the modification of information by word of mouth transmission (DeFleur, 1962; Buckner, 1965).

Third, inferences may be made about chaining processes; chaining processes occur whenever people have some choice in generating the traced chains so that these chains are not fully determined by network structure. Chain methods differ in the number of such choices allowed. If allowed, the pattern of choices can suggest ideas about a number of topics, such as how people think that networks are structured and can be most effectively used.

And fourth, inferences may be made about networks. A brief illustration was given in the previous section on social movements. Network connections, network density, prevalence of symmetric relationships, and related topics may be addressed.

An important problem that arises for all chain methods ought to be clarified at the start. Suppose information has been diffused through the network represented by Figure 1, information chains have been traced, and we are now trying to make inferences from the observed chain lengths. The chains may be long for structural reasons; for example, the shortest possible chain between 5 and 16 has three intermediaries (6, 11, 18), and in general the chains between these two groups will be long because the groups are so poorly connected. But one could also get long chains because of chaining processes. Suppose, for example, people pass the information to the highest-status person available—that is, to the most frequently chosen persons to whom they are connected. A chain from 18 to 17 could then have three intermediaries (16, 14, 13), like the chain between 5 and 16, even though a much shorter chain via 19 is available. The same problem arises for other chain features besides length: How can we tell, given the chains alone, whether their features arise from network structure or from the ways that people draw on that structure?

The inherent ambiguity between effects of network structure and effects of chaining processes is one of the most persistent and intractable problems in using chain data. Therefore the discussion of particular methods of collecting chain data is ordered in terms of this problem—from methods less affected to those more affected. Four methods will be discussed: snowball sampling, the small-world technique, and two ways of tracing chains that occur naturally. Each method has a separate section with a similar order of discussion: a short description of the method followed by procedures and problems of inference to individuals, to chains, to chaining processes, and to network structure. Since this is a somewhat intricate set of problems, the reader may find it useful to refer, when necessary, to the summary in Table 1. Finally, I note that many of the problems discussed here arise for chains among different sorts of units—for example, intergroup or international linkages. For convenience, however, I refer to individuals throughout.

SNOWBALL SAMPLING

A snowball sample begins with an initial sample of individuals who are asked to name people to whom they are related in a specified way. The people named form a second wave that can be interviewed in the same way to yield a third wave and so on. For example, say Figure 1 represents choices for "three best friends" and we begin a snowball with 7 and 12. A few stages of the snowball are diagrammed in Figure 2: 7 names 3, 6, 11, while 12 names 13, 14, 15, forming the second wave. We proceed to 3, who names 5, 6, 7; 6, who names 3, 5, 11; and so on to form the third wave. The number of waves, number of nominations per person, and type of relationship can all be varied by the researcher.

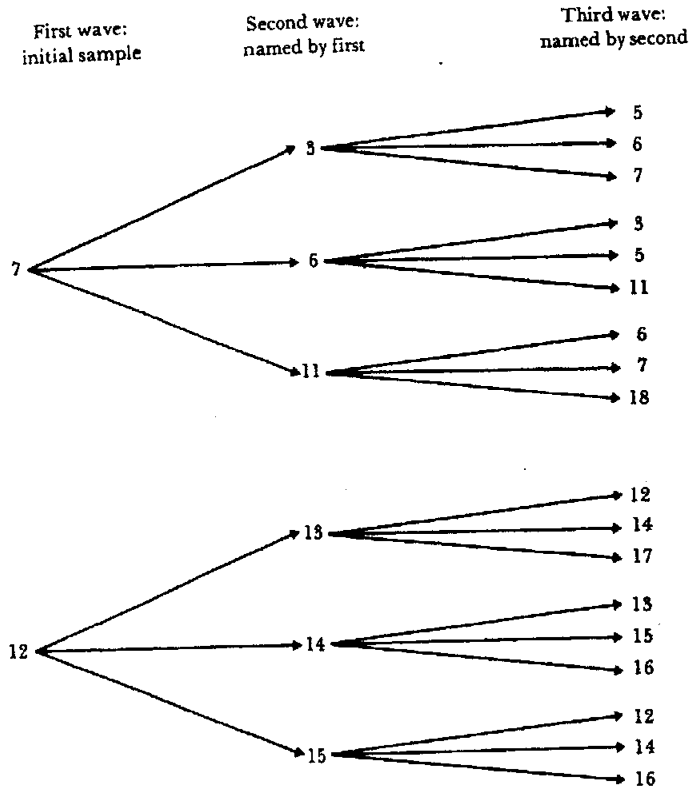
The obvious basis for inferences to individuals is the initial sample, which ideally is a random sample of individuals and can be analyzed in the usual ways. In practice, however, bias may be introduced through the demands that the snowball procedure makes on the respondents. Relational questions may be seen as a threat to the privacy of the respondent or the people he names, especially if the respondent knows the latter will be interviewed in their turn. The questions may also be hard to answer if they involve relationships not previously conceptualized by the respondent; for example, Katz and Lazarsfeld (1955) found that their Decatur housewives often claimed they had not engaged in influence relationships recently (and if they did report such a relation, the reported partner often failed to confirm it). The perceived

TABLE 1

Summary of Problems by Method

Chain Method	Individuals: Is the Initial Sample Likely to Be Random?	Chains: Main Sources of Bias in Length of Observed Chains	Limits on Chaining Processes	Confounding of Chaining Process and Network Structure Effects
Snowball	Some bias toward cooperative *S*'s	Masking, nonresponse; no formal corrections; Goodman (1961) gives loop estimates	Strong	Some
Small world	Strong bias toward cooperative *S*'s	Nonresponse biases toward shorter chains; corrections in White (1970a) or Hunter and Shotland (1974) may not always be calculable or effective	Slight	Considerable
Natural chains sampled at an endpoint	Task is easier and more comprehensible than for snowball and small-world methods; hence less bias toward cooperative *S*'s; may be difficult to get good sampling frame for endpoints	Nonresponse biases much less than for snowball and small-world methods; if there is more than one chain associated with an endpoint, corrective weights are needed	None	Extensive
Natural chains sampled via individuals who may be in any position on chain	Routine sampling frames can be used and task is easy; hence good samples are attainable	If chains are fully traced, longer ones are over-sampled (see White, 1970b); if traced to source only, length of incomplete chains is underrecorded (write to author)	None	Extensive

Figure 2. A miniature snowball from Figure 1.



intrusiveness and the inherent difficulty of the task lead to lower response rates and a bias toward more cooperative subjects (often the better off and better educated).

Sometimes the researcher wants to make inferences to individuals from all the people studied, not just from the initial sample. This is most likely when snowballing has been used to get adequate numbers of individuals from a relatively inaccessible population; for example, Useem (1973) did a snowball sample of draft resisters. If the population is difficult to sample, then the initial sample is not likely to be random; and, even if it is, the individuals found by snowballing will certainly not be a random sample. Popular people (like 5 in Figure 1) will be overrepresented and less popular people (like 20) will be underrepresented. If one is able to begin with randomly sampled individuals, one might try to supplement them with snowball-generated people after weighting the latter to approximate the former in their distribution on the major independent variables.

When making inferences to chains, one of the most important and often considered matters is chain length. For snowball studies, chain length must be treated somewhat differently from other chain methods. The length of snowball chains without looping—that is, chains that continue for as many distinct individuals as there are waves in the study—is not of much interest since the length (the number of waves) is set by the study design. But snowball sampling, unlike the other methods to be considered here, permits loops in which a person, named in a later wave, in turn names someone from an earlier wave. In Figure 2, for example, 7 names 3, who in turn names 7, because 7 and 3 have a reciprocal tie in Figure 1. The extent of looping of various lengths is often of substantive interest; for example, one might often want to know the frequencies of reciprocated choices in various friendship networks. Estimates using loops of various lengths have been developed by Goodman (1961), who points out that a snowball sample is a more efficient way of making such estimates than a simple random sample that includes the same number of individuals.

Nonresponse may pose problems for inferences to chains as well as individuals. Suppose, for example, that asymmetric ties are weaker and people are thus less likely to report them; symmetric ties, or short loops, would then be overrepresented in our observed chains. To date, there has been little investigation of possible relationships between nonresponse and chain characteristics in snowball sampling.

Masking, another sort of problem, occurs when respondents are willing enough to report their relationships but are unable to do so accurately because they have more, or fewer, relationships than they are asked to report. Suppose that Figure 1 represents information flows and each person is asked to name three people to whom he or she gives information. Person 5 actually gives to four people, and must decide which one not to report;

20 gives information to only one person and must somehow choose two more. The effect of masking on loop length depends on (1) how such respondents decide to add or drop names and (2) the respondent's position in the network. The combined effect can get complicated. Consider 20 again. Since his network position is virtually that of an isolate, any two nominations (besides 19) that he makes will inflate the estimate of asymmetric ties on the first two waves. On further waves this estimate will also be affected by the ways he makes his choices. If he chooses on the basis of status, he will choose 16, all of whose choices are reciprocated; if he chooses on the basis of shared marginality, he will choose 18, who has one choice in three reciprocated. The former sort of choice bias will lead to overestimating reciprocity; the latter, to underestimating it. The net effects in real networks have not been explored, although Holland and Leinhardt (1973) have used some simulated examples to argue that masking may well lead to a pattern with a less clear-cut structure than in the original network.

Despite the masking problem, the use of a fixed number of nominations is probably desirable. Goodman's estimates are designed for a fixed number.[1] If respondents are allowed to choose their own number of nominations, one gets a new set of problems; for example, some people may name only very strong ties while others name weaker ones as well. One can design checks on the extent of masking and its possible correlates. Laumann (1973), for example, first asked how many people the respondent thought of as especially close friends; then he asked the respondent to name his three best friends.

Chaining processes are at work whenever respondents have some choice in how the chains are constructed. Ideally, no chaining processes occur in a snowball study because each respondent makes nominations according to criteria specified by the investigator. We have already seen one kind of qualification to this ideal picture: The effects of masking depend in part on how people choose to add or drop nominations to produce a fixed number of them, and their choice processes are chaining processes. Chaining processes may also be at work when the relational questions

[1] Goodman remarks that his estimates can be extended to studies without a fixed number of choices; but he does not give such estimates nor is it clear how complex and unwieldy such estimates might be.

are unclear or threatening in the eyes of the respondents, so that they make some choices about interpreting or deflecting the questions. Kadushin and Abrams (1973) asked members of a sample of Yugoslav elites to make a set of influence nominations. Such questions are somewhat ambiguous in that influence is not a clearly defined relationship (recall the difficulties the Decatur housewives had with it); and the questions are potentially threatening for such an elite sample whose members might want to be cautious in declaring ties with political overtones. It is thus not surprising that many respondents claimed to have been influenced by prominent and unimpeachable figures with whom they could have had but little contact.

There are no formal procedures for making inferences to chaining processes, perhaps because snowball users have been more concerned with minimizing chaining processes than with studying them. Chaining processes might be suggested by examination of transition probabilities. Suppose we classify our respondents on a status measure that divides the universe of individuals into even quarters and then find a chooser–chosen matrix like Table 2. Of all the highest-level people who made choices, 0.8 chose other first-level people and 0.2 chose people in the second level. These are transition probabilities with respect to status. Table 2 shows more upward than downward choosing, which suggests that people may be using whatever leeway is available to them (via masking or ambiguity) to favor ties with higher-status people, who are generally preferred interaction partners (Laumann and Senter, 1976). We cannot make such an inference with much confidence, however, because there is a very plausible rival interpretation—namely, people direct more interaction upward than downward.

Snowball data can be used for inferences about many aspects of network structure. For example, the cliques in Figure 1 have a dense pattern of largely reciprocal ties. In Figure 2, this clique structure is reflected in the inbreeding of nominations: Of the 12 distinct individuals in the third wave, 8 also belong to the first or second wave. The separation between cliques in Figure 1 is also reflected in Figure 2, where we see only one nomination crossing between cliques. In a practical application of this strategy, Useem (1973, pp. 250–251) found the ratio between new and old nominations for each wave of his snowball study of draft re-

TABLE 2
Hypothetical Matrix of Transition Probabilities

		Status Level of Person Nominated			
		1	2	3	4
Status level of person making nomination	1	0.8	0.2	0.0	0.0
	2	0.3	0.6	0.1	0.0
	3	0.1	0.3	0.6	0.0
	4	0.0	0.1	0.3	0.6

sisters and then compared these figures to ones for a baseline random net, or one similar to the observed data except that choices were randomly allocated.

Transition probabilities can also be used to make structural inferences. Table 2, for example, might simply reflect the actual pattern of relationships between people of different status levels, with a good deal of status homogamy in interaction and more interaction oriented upward than downward. Now in the previous section this same table was used as an illustration of how transition probabilities can suggest chaining processes. How can one tell whether chaining processes, structural patterns, or some combination of the two are the source of an observed set of transition probabilities? One cannot, unless one has additional information that is usually not available. If we knew the actual pattern of ties among status levels, we could use Table 2 to examine chaining processes and vice versa. This ambiguity is inherent in all the chain methods. Potentially, at least, the ambiguity is least marked for snowball sampling because this procedure includes a planned attempt to control chaining processes so that structural inferences can be more clear-cut.

More subtle inferences can be attempted if the transition probabilities are found separately for successive pairs of waves (the first to the second, second to third, and so on). If a network has a centralized structure, then successive waves tend to move from less central to more central people since the latter are more likely to be chosen; this is the typical pattern of nominations in reputational studies of community power structures.[2] Choices

[2]Bonjean (1963) had informants nominate leaders; then he identified top leaders from those often named. Nominators not among the top leaders gave 53 percent of their first three leadership choices to the top leaders; the top leaders themselves gave 80 percent of their top three choices to one another.

among the more central people on later waves may be systematically different from choices on earlier waves, leading to different transition probabilities for different pairs of waves. A more diffuse structure might yield a more constant set of probabilities. Goodman (1962) has developed some useful tests for comparing transition rates. If the rates do differ, one still faces a basic ambiguity: Do people on different waves have different patterns of relationships or different biases in choosing which relationships to report?

The pragmatic applicability of snowball sampling is limited by the need for fairly cooperative subjects, the advisability of unambiguous relational questions, and the possible confusion between chaining processes and structural effects. In addition, the method is hard to apply to relationships of which the respondent may have a great many, for example, weak ties. Finally, it is impractical to use more than a handful of waves lest nonresponse (cost aside) get severe, so that the overall structure of large networks is difficult to assess.

THE SMALL-WORLD METHOD

In a small-world study (Milgram, 1967) the researcher gets an initial set of "starters" and asks each starter to try to reach a specified target person whose name, address, and occupation are provided. The target must be reached through a chain between people who know each other on a first-name basis. If the starter does not know the target on a first-name basis himself, he passes the chain along to someone he thinks may know the target or have an indirect link to the target. Say Figure 1 represents first-naming and 6 is asked to reach 16. Starter 6 cannot do so directly but can begin the chain 6–11–18–16. People in real networks do not have a map like Figure 1 to help them and may well generate longer chains than necessary—for example, 6–3–7–11–18–16. When a respondent chooses another intermediary, he gives the latter a description of the study, a roster of previous members of the chain, and a set of postcards. Each chain member sends a postcard to the researcher so that the latter can keep track of chains in progress and has a record of incompleted chains.

The initial set of starters could be used to make inferences to individuals if this set were a random sample. Unfortunately the starters are often a nonrepresentative set of highly cooperative people, because the small-world task is unfamiliar and exceptionally difficult. Shotland (1976, p. 71) obtained an exceptional response rate of 94 percent, but he drew on an unusually cooperative universe: members of a university. Studies of broader universes have had nearly equal rates of cooperation from initially chosen people (85 percent in Korte and Milgram, 1970, p. 103)—but only when these starters were volunteers, which restriction itself introduces a bias toward better-educated respondents of higher status. Studies starting with samples of broad universes have had to cope with initial response rates that are quite low (15 percent in Erickson and Kringas, 1975). Response rates might be improved by paying respondents (entailing a modest increase in cost) or by interviewing sequences of people instead of having the respondents conduct chains through the mail (with a large increase in cost).

Since getting a completed chain requires the cooperation of several people, completion rates for chains are much lower than response rates for individuals. With a response rate as high as 94 percent, Shotland (1976, p. 70) got a chain completion rate of 69 percent. Most others, with lower response rates, have had quite low completion rates for chains (22 percent in Korte and Milgram, 1970). Longer chains require more cooperating individuals, so the net effect is a bias toward shorter observed chains than one would get if everyone cooperated.

Although the direction of the bias is clear, there is some difficulty in making exact corrections for it. It is not always possible to calculate a direct solution (White, 1970a). Hunter and Shotland (1974) suggest a Markov modeling approach: Find transition probabilities for some relevant set of categories and then calculate how long chains would be if all chains went to completion governed by these transition rates. The transition probabilities are not in fact constant for different kinds of chains (Hunter and Shotland have separate sets of rates for different kinds of targets); nor are the rates constant over different stages of chains. Hunter and Shotland (1974, p. 325) acknowledge that "the model will be false in almost any situation where the small-world technique would be employed," but they argue that the fit of the model is adequate for parameters most relevant to estimating chain lengths. Adequacy is argued from a reasonably close prediction of (1) the actual (known) length of completed chains only and (2) multiple-step transitions, using the complete data set in which data from completed chains are more than twice as extensive as data from incompleted chains. Neither procedure fully demonstrates that the overall transition matrix is adequate in either sense for incomplete chains, which are just the ones whose length must be estimated.

In considering the possible effects of response rates on chains, it may be useful to know whether or not these rates remain constant at different removes from the starters. Fienberg and Lee (1975) provide maximum-likelihood estimates and a test procedure.

Small-world respondents are asked to send the chain toward the target by the shortest route. If the target is only one intermediary away, then the shortest route may be easy to find; but if the target is any further off, then the respondent can have little knowledge of what the best route is. When asked how far from the target they are, respondents one or two intermediaries away make accurate estimates while all others make wildly varying ones (Shotland, 1976, p. 110; Erickson and Kringas, 1975, p. 587). Thus the more distant respondents, lacking sure knowledge of the shortest path, must use strategies, or chaining processes. Detailed analysis of the chains can suggest the conceptions of social structure that underlie respondent choices about sending the chain onward. Chains often converge on the target's geographical or occupational area; one infers that respondents think of neighborhoods and occupational areas as fairly densely connected. Chains often move upward in status at first; probably respondents think of higher-status people as having better information and connections (Travers and Milgram, 1969; Korte and Milgram, 1970).

To make such inferences formally, one would naturally turn to transition probabilities; but their use in more than a loose and suggestive manner is faced with several obstacles. First, as noted above, transition rates are not usually the same at different distances from the target. Second, inferences could not be made to any clearly specifiable universe. Initial starters are often a biased selection, and the people to whom the chains later pass are nonrandomly selected (which is why chaining processes are of interest here, after all). Third, once again it is difficult to tell whether observed chain results arise from chaining processes or from network structures. Do chains tend to move upward in status at first because respondents think that higher-status people are better connected, or because higher-status people really are better connected and hence more likely to be chain intermediaries since they have more ties? Despite these obstacles, the data are of great value because there are so few ways to get any data on conceptions of social structure. (DeSoto, 1960, is an example of a different approach.)

All other things being equal, chain length directly indicates an important network feature: the relative distance between pairs of groups along relational paths. But things other than network structure affect observed chain lengths and may not be equal. First, response rates may be different for different starter-target combinations. This possibility is easily checked and seems to vary more with study design than with starter-target combinations (White, 1970a). Second, respondents in different starter-target combinations may use unequally efficient chaining processes. Korte and Milgram (1970, p. 107) conjecture that white starters know more about white social structure than about black social structure and therefore move chains more efficiently toward white targets, which would lead to chain differences even if the network paths from whites to whites or blacks were similar. Since we lack direct evidence on respondent efficiency and on the length of available paths, we cannot disentangle their possible effects on chain data.

Although there is no formal way to separate network and chaining process effects, one can get a good deal of informal guidance from the information provided on the postcards, including the kind of tie between adjoining chain members and the stated reasons for passing the chain on to a particular person. One can then make reasonable suggestions about a wide variety of topics: relative differences between groups, internal group structure, access to important kinds of targets, and so on. Such aspects of large-scale networks cannot feasibly be explored with any other method yet devised.

NATURALLY OCCURRING CHAINS

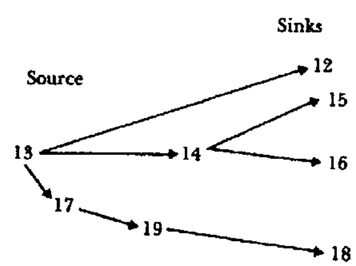
In small-world or snowball studies, chains are constructed at the instigation of the researcher. In the next two methods discussed, the researcher traces chains that occurred without any input from him. Natural chains are intrinsically interesting as ongoing social events; they are in some ways easier to study than constructed chains; but they are especially likely to have mingled effects of network structure and chaining processes, since the researcher does not have any control over the latter at all.

Suppose Figure 1 is a set of undirected relationships and 13 starts some chains (he is the *source*); he may tell people he is looking for a job or pass on something else. He tells 12, who tells no one else, thus ending this chain (12 is a *sink*); 13 also tells 14, who then in turn tells both 15 and 16, who tell no one else. We could get a set of natural chains like those in Figure 3. To study such chains, we first sample individuals and then trace chains in which these individuals are involved. On the one hand, we can sample just those individuals who are at the endpoints of chains (sources or sinks); this is the first of the two natural-chain approaches to be discussed. On the other hand, we can sample all individuals irrespective of chain position; this is the second method to be treated.

Natural Chains Sampled at Endpoints

The researcher finds a way of sampling a population of endpoints, samples them, and then traces chains from them. Granovetter (1974) began his study of chains leading to a new job

Figure 3. Possible chains from Figure 1.



by sampling men who had recently changed jobs, as revealed by comparing two successive issues of a city directory. Then he found out which respondents had obtained jobs through interpersonal contacts and traced the contacts involved.

The initially chosen endpoints (whether sources or sinks) can be used in the usual way if they are randomly sampled from a known universe. Granovetter began with a sample of recent job changers in Newton, Massachusetts, and hence could make inferences about such changers in general. The main difficulty is likely to be in finding a good sampling frame for endpoint. (City directories, for example, are often incomplete and outdated.) Response rates do not cause as much difficulty as for constructed chains because respondents can easily understand the task posed for them and generally find it interesting and valuable.

Although nonresponse tends to be less of a problem for natural chains, it is still important to keep nonresponse to a minimum because of the cumulative effect it has on completion rates for tracing of chains. The most complete and also the most accurate results can be obtained by asking respondents about specific, easily remembered events. In this context, that means it is helpful to trace the chain in the right direction: from those who receive something (often information) to those who give it. Tracing in the other direction is less accurate because people tend to overestimate their own importance as informers or influencers of others. DeFleur (1962) asked a sample of housewives: (1) whom they had heard from first and (2) whom they had first informed. On the whole, it would seem from his report that the former set of responses was more accurate than the latter.[3]

Thornier problems arise from the ways that chains are chosen for tracing. If the initially sampled endpoints are sinks, there is no problem since each sink is associated with exactly one chain. But if a sampled endpoint is a source (as in Granovetter's

[3]DeFleur (1962) tried tracing chains of information diffusion in both directions; he asked from whom a respondent *first* received the information and also asked whom the respondent informed. He argues that the latter was less accurate. For example, frequently several people laid claim to informing the same person. This could happen if one person discussed the information with several people, never making it clear that he had heard the information before from someone else. Yet a respondent should know when he is receiving the information for the first time himself.

study), then it may well be a source of *several* chains, as in Figure 3. In principle one could cope with this problem by tracing all the chains from each sampled source. Estimated parameters, like chain length, would then be unbiased although they would have higher variance than if the chain population had been sampled directly. (The problem is analogous to that of cluster sampling.) But tracing all the chains from sampled sources may be prohibitively expensive, particularly if the chains branch further as they are traced back (for example, if one person passes the news to three people who in turn tell ten more . . .).

Perforce the investigator falls back on studying just one chain per endpoint to keep research costs low and predictable. If the chains are all of the same type, so that there is no theoretical reason for choosing one chain from several associated with a source, then the researcher can randomly choose one for tracing. If so, correcting is important since uncorrected samples may have many built-in biases. Consider rumor chains, for example. Someone who starts passing the news very early, while most people do not know about it, has better chances of starting many chains—and long chains—than someone who gets going when most people already know the news. Thus the number of chains per source and the length of chains from a source are likely to be correlated. Since chains from sources with fewer chains are overrepresented, chain length is underestimated. Corrective weights should be directly proportional to the number of chains per source. But it is difficult to know how many chains started from a source without tracing all of them, which process is just what one would like to avoid. The source can be asked how many chains he started (for example, how many people he asked about a job), but this information is easily misremembered. Further along there may be further branching to consider, like 14 telling both 15 and 16 in Figure 3. The weighting is thus likely to be both complex and inaccurate, although necessary.

Finally, most researchers can think of some theoretical or practical criterion for choosing a unique chain per source on a nonrandom basis. Granovetter (1974) traced that chain which resulted in a respondent's new job—a meaningful choice if one is interested in different processes involved in job finding. In this case, each source is associated with just one chain (of a special kind) so that a random sample of sources gives a random sample of chains of that special kind. If one wishes to make generalizations beyond that kind of chain—for example, to compare the characteristics of chains that do or do not result in getting a job—then the unique chains and randomly chosen chains must both be recorded (and the latter must be weighted for certain comparisons).

Chaining processes probably play a large part in the generation of natural chains, even when the people in the chains are not consciously choosing to pass chains onward in particular ways. To continue with the job search example, 24 percent of the people interviewed did not seem to be deliberately searching out a job; rather, they reported that information was passed "by the way" in conversations begun for unrelated reasons (Granovetter, 1974, p. 35). But much of this apparently incidental activity may have been based on patterned, if unselfconscious, ideas about who was worth trying. There was, after all, some pattern in what was tried; for example, younger men were more likely to have family or social ties rather than work ties in their job chains (Granovetter, 1974, p. 43).

The greater use of family and social ties by younger men might indicate a chaining process in which young men prefer to use such ties—perhaps because they think strong ties will be more effective than weak ones. But two problems must be dealt with before we can make such an inference. First, recall that Granovetter did not randomly select chains for tracing; only chains that actually resulted in a job were considered. Possibly the younger men used work ties as often as anyone else—but less often succeeded with them—because their weak ties are largely to other young, still low-ranking people with little leverage. Then the correlation between age and prevalence of work ties in job-producing chains would be an effect of network structure, not of chaining processes. Second, the younger men may not use any more family or social ties proportionately; that is, their shorter work histories imply they have fewer work ties to draw on, so availability rather than preference may structure their use of family and social ties. Again this is an effect of network composition rather than of chaining processes. To detect the latter more convincingly, one would like to know what kind of ties the job searcher drew on unsuccessfully and what kinds of ties were more or less frequent in his personal network.

Just as possible network effects make inferences about chaining processes more difficult, possible chaining processes make it harder to draw firm inferences about network structures. I have just suggested that younger men may have fewer strategic work ties than older men—a structural explanation of younger men's greater use of nonwork ties. But the correct explanation could be chaining processes (young men prefer nonwork ties) for all we can tell from the chains alone.

Granovetter shows his awareness of this difficulty by frequently regretting the absence of "baseline data" on the overall networks of the men he studied; and he attempts to cope with the problem by a set of plausible assumptions about data he does not have and careful working of the data he does have. It might be worthwhile to supplement thoughtful analysis with at least some rough data on baseline aspects of networks and of possible chaining processes as well. One might, for example, ask respondents to describe interactions over the last week (to get some idea of network composition) or administer a scale designed to measure their beliefs about the relative efficacy of different types of ties for a given purpose. These data would have some problems of their own, but they could still shed light on the inherent ambiguities of natural chains. Despite the ambiguities, such data are highly productive of interesting suggestions about large-scale networks and their bearing on individual life histories.

Natural Chains Sampled Anywhere

The fastest and easiest way to sample natural chains is to begin with a sample of individuals irrespective of chain position. From Figure 1 we might sample cases like 13 or 15, which are endpoints in the chains in Figure 3; or perhaps we might sample cases like 14 or 19, which are not endpoints. From these sampled individuals we can trace chains to their sources, to their sinks, or to both. For example, information diffusion chains were traced following a disaster (a large explosion taking several lives) in North Bay, Ontario.[4] The North Bay residents were sampled

[4]Joseph Scanlon, director of the study, provided background information and data. For a report see Erickson and others (1978).

through an up-to-date list of dwellings. All sampled individuals were asked how they had heard of the disaster, and, if they had heard from another person, from whom. Then people who were the first to inform members of the initial sample were asked who (if anyone) was first to inform them, and so on until the chains of information diffusion were traced back to their source (an eyewitness or someone informed by the media).

The initially sampled people can be used for inferences to individuals. In the North Bay case one can examine characteristics of people faster or slower in hearing the news. These inferences, like the others, are made much easier because the simplicity of the initial sampling means that a study can be fielded very quickly while the chains of interest are still recent and easily remembered. The North Bay study began the day after the disaster, when people still recalled their conversations vividly and were eager to talk about them. All the initially sampled people cooperated and chains were traced to sources for 160 of the 168 sampled.

Chain inferences proceed somewhat differently depending on whether chains encountered between endpoints are traced in one or both directions. White (1970b, app. B) gives sampling frames, biases, and corrective weights for chains traced in both directions. Since White deals with fully traced chains, let us consider the somewhat trickier case of chains traced one way only as in the North Bay example.

This procedure has two chain-length biases with opposite effects. On the one hand, longer chains are more likely to be sampled because they include more people; on the other hand, the observed length of a chain will often be shorter than the true length because of the one-way tracing that misses segments going beyond the person sampled. One can estimate the true distribution of chain lengths most simply by looking only at chains that happened to be sampled at their stopping points so that their true length is known. These estimates may not be unbiased; they use a restricted number of the chains (108 of the 168 sampled chains in the North Bay study); and they tend to have high variances. (For more technical information on two possible estimation procedures, write to the author.) However, such estimates are necessary to check on the possible biases in observed chain lengths and to suggest corrections if necessary.

The same ambiguities discussed above for other methods apply here: Chaining processes are not under the control of the researcher; they are likely to have an important effect on chains; and these effects may not be easily distinguished from effects of network structure. However, there is one new possibility suggested by the speed with which one can field a study of natural chains when a standard sampling frame is used: One can trace information that is of widespread interest just after it is diffused. If the diffusion is thorough and rapid, chaining processes may be relatively simple—for example, they may boil down to proximity.

The North Bay disaster was a very loud, centrally located explosion that took place during the normal working day, so that a large number of eyewitnesses began information chains that nearly saturated the population in a few hours. A variety of data strongly suggests that the news passed from person to person as they met in the context of their work. (Most people reported talking to others with whom they routinely interacted at that time on a working day.) Although there were a few exceptions when people heard the news from strangers or by eavesdropping, the dominant chaining process seemed to be speed of access at work.

Network inferences are once again made ambiguous by the possible role of chaining processes unless we can somehow establish that the latter are absent or very simple. If disaster information diffuses quickly to whomever is available, then the chain data would be clearly structured by frequencies of interaction. In the North Bay example, workers tended to pass the news to others of similar status; we might infer that workers tend to interact most frequently with coworkers at a similar level.

Studies of dramatic events may seem like an attractive option, then, because they do provoke relatively quick and unselfconscious communication. There is no guarantee, however, of fully simplified chaining processes. In North Bay, for example, workers were not so constrained by proximity that they told only coworkers; many got word to family members. Further, this option is not conducive to careful planning. One cannot count on a dramatic event happening when and where one would like; and when one happens, it may generate an accidentally partial view of networks. In the North Bay case the eyewitnesses who began most chains tended for idiosyncratic reasons to be students or lower-status workers, not a cross-section of the population, so the length of chains is most revealing of the social distance between these groups and others.

CONCLUSIONS

The various chain methods offer a complex set of problems and opportunities. The major problems are summarized by chain method and goal of inference in Table 1. Inferences about individuals must rely mainly on the initial sample, since additional individuals found by tracing chains are never found randomly or even with known biases. Chain methods are most likely to yield good initial samples when there is a standard sampling frame and an undemanding task, as in the case of natural chains sampled irrespective of chain position. Samples strongly biased toward cooperative subjects are most likely for demanding tasks such as those present in the small-world method.

Inferences to chains raise varying problems. Masking or nonresponse are more serious problems for constructed chains and sampling procedure biases are more serious for natural chains. Procedures for inferences about chain lengths have received a good deal of attention, and there is at least some preliminary material on chain length for each of the methods.

The problems in making inferences about individuals and about chains are often consequential, but they are at least in principle solvable: One can build in added incentives to increase an anticipated low response rate, or work out more of the theory for chain inferences, and so on. When we turn to inferences about chaining processes and network structures, however, we encounter an insoluble ambiguity—chain features are affected by chaining processes and by network structures, and the effects most often cannot be clearly distinguished. The chain methods do vary in the degree of ambiguity. The more narrowly limited the possible effects of chaining processes, the more unambiguously we can infer network structure from our chain data. Snowball samples put the most stringent limits on chaining processes, without being able to eliminate them entirely, and hence provide the most clear-cut inferences about networks that can be feasibly studied in this way or networks of strong ties with a moderate size. Natural chains include no controls by the researcher and hence typically include extensive confounding of network effects with chaining processes. The confounding could be reduced by further effort to limit the scope of chaining effects, but this strategy leaves out the intrinsically interesting natural chains while probably requiring ever more complex tasks and more frustrating response rates. One might also try to measure chaining processes both to observe them and to control their effects statistically so that network inferences would be more clear-cut. Here the major difficulty is that chaining processes are probably mostly unconscious and difficult to measure; certainly there is no well-developed measurement procedure at present. Finally, one might try to observe chains passing through a known network structure in order to infer chaining processes unambiguously. We seldom know small network structures, however, and rarely, if ever, do we know the large ones.

Despite the built-in difficulties, the inferences about chaining processes and network structures are frequently the most important parts of chain studies. Often a skillful analysis yields a persuasive, even if not cast-iron, set of results. Further, these results are quite often the only ones we have. No other method allows us to address problems of large-scale network structure and the ways in which people use such structures. The only major rival in this field is network sampling, whose feasibility has not been tested at the time of writing and which, as pointed out at the start of this discussion, does not attempt to deal with all the topics illuminated by chain methods. Field experience with chain methods is extensive and growing; problems with the methods are becoming better known; and solutions to some of the problems are available or underway.

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