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Integrating individual, relational and structural analysis *

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The first part of this paper presents a statistical model which integrates individual, relational and network data, despite their different units of analysis. The model uses a stepwise approach to find the least number of parameters which adequately fit the data. The second part of this paper uses this model to analyze how the marital status of Torontonians is related to the kinship composition and social density of their intimate networks. It shows that kinship and friendship usually comprise independent social circles within these networks. The larger networks of married respondents tend to contain a higher proportion of kin, and consequently, to be more densely-knit. Yet single respondents tend to have more densely-knit clusters of intimates within their friendship-based networks. This is because marriage rarely joins the intimates of spouses.

The problem

This paper proposes and demonstrates an approach to linking individual, relational and structural analyses in quantitative sociology. In so doing, it offers a way to transcend the problem of different units of

* Ove Frank devised the model that is at the heart of our analysis, and Staffan Lundquist performed the key model testing. Barry Wellman prepared the data for the case study, organized the analytic enterprise, and wrote the final drafts. Craig Wilson did the programming for the statistical counts on which the analysis is based and wrote a draft discussion of the models. Vicente Espinoza wrote a draft discussion of the findings and analyzed Tables 3-5.

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analysis which has done so much to keep individual, relational and structural analyses separate in all but the most metaphorical sense.

Individual analyses – the prevalent approach in American practice if not in theory or ideology – co-relate the attributes of persons or larger social units. They want to know if individuals who have one or more attributes in common tend to share other attributes: "blondes have more fun"; "developed countries have happier populations".

Relational analyses – common in social and community psychology – co-relate the attributes of dyads. They want to know which attributes of relationships tend to occur together: "weak ties provide more information"; "branch plants do less research than headquarters" (a corporate dependency relationship even though commonly stated in individual attribute form).

Structural analyses – common in unAmerican sociology and in world systems and network analysis – focus on characteristics of sets of relationships. They want to know which attributes of networks tend to occur together: "persons in densely-knit networks have more fun"; "interlocked industries have higher profits".

Technical incompatibilities have largely led individual, relational and structural analyses to develop separately. Prevalent statistical techniques which routinely deal with the characteristics of individuals assume independence between individual units of analysis. They cannot address many of the issues raised by focusing simultaneously on different units of analysis. Yet this inherently happens when analysts in addition to studying individuals, also look at relations between two individuals – the essence of relational analysis – or networks of relationships among a population of individuals – the essence of structural analysis. [1]

Until now, quantitative analysts have often handled such matters by treating relationships and networks as if they were individuals. Thus some analysts have studied a sample of relationships – co-relating such phenomena as frequency of contact in a relationship with its supportiveness (e.g. Wellman 1979; Tsai and Sigelman 1982; Wellman and Wortley 1989, 1990; see also Homans 1961) – while others have studied

[1] For other efforts to deal with these issues, see Berkowitz 1988; Burt 1980; Coleman 1958; Fararo and Skvortez 1984, 1987; Fienberg and Wasserman 1981; Galaskiewicz *et al.* 1985; Levine and Mullins 1978; Marsden 1980, 1986, 1987; McPherson and Smith-Lovin 1987; Skvoretz 1983, 1985; Wasserman and Galaskiewicz 1984; Wasserman and Faust 1992, chap. 15.

a sample of networks – co-relating such phenomena as network homogeneity with the network's supportiveness (Wellman *et al.* 1987).

Some analyses have linked the attributes of individuals and the attributes of ties. For instance, some relational analyses have gathered information about the individual attributes of two network partners and the relationships between them. Thus Wellman and Wortley (1990) show that women are more likely to provide emotional aid in relationships. In such analyses, the effective unit of analysis is the relationship. Information about the attributes of the two individuals has been incorporated into the information about the relationship: e.g., woman–woman, man–woman ties, etc.

Several structural analyses have related the attributes of social networks to the aggregated attributes of the members of these networks. When they thus relate network structure to composition, the effective unit of analysis is the network. Thus Wellman *et al.* (1987) show that low-density networks have high rates of companionship.

When such structural analyses deal with the special case of ego-centric networks (networks defined Ptolemaically from the standpoints of defined focal individuals), they treat the focal individual and his/her networks as the same unit of analysis. They can then relate the attributes of the focal individuals to the attributes of their networks. For example, Fischer (1982) reports that the networks of northern California urbanites are more dominated by friends and sparsely-knit than the networks of rural Californians, and Wellman (1985) reports that Toronto women who do both paid and house work have fewer friends and neighbors in their networks than those who only do house work.

Such studies avoid dealing simultaneously with different units of analysis. Hence their approach inherently cannot integrate analyses which deal simultaneously with the attributes of focal individuals, their networks and the ties in their networks. The units of analysis are incommensurable. If the analyses focus on network attributes, they lose information about the attributes of the ties which comprise these networks. If the analyses focus on tie attributes, they lose information about the structures of these networks.

Hence there is a use for statistical models which link information about the attributes of individuals, ties and networks. Such models would explain how the attributes of individuals affect their likelihood of being linked or how such attributes are affected by existing ties.

These models would relate this interaction to the kinds of network patterns which are prevalent in a social system. For example, such models not only would enable us to relate individual attributes to the likelihood of cross-sexual friendship ties, they would also enable us to discover if networks predominantly composed of such cross-sexual ties are more likely to be densely-knit and egalitarian in resource distribution.

We introduce a model which integrates individual, relational and network data when there is information about a large sample of networks. The model is described in the next section (see also Frank *et al.* 1986 for further information). To illustrate the use of this model, we analyze data from a study of the intimate networks of the residents of a central area of Toronto: East York. Our substantive inquiry is into the kinship structure of these networks. We investigate first the extent to which the marital status of the respondents – the egos at the centers of these intimate networks – affects the size and kinship composition of these networks. We investigate second if the aforementioned variables – egos' marital status, size of intimate network, and the kinship composition of these networks – affect the density of links between kin, friends, and "mixed" links between kin and friends. [2]

Although the case study we present deals with interpersonal relations, we believe that this approach can also be extended to macroscopic analysis. For example, studies of organizational environments might analyze the attributes of individual firms (industrial, financial), their kinds of intercorporate relations (exchanging boards of directors), and the kinds of links these corporate partners have among each other (see Galaskiewicz *et al.* 1985; Mintz and Schwartz 1985; Richardson 1985). Or, at a multinational scale, analysts might investigate the implications of trade relations between pairs of industrial, resource and service exporters for the structure of world systems (see Friedmann 1988).

[2] "Friends" in our usage here includes all those we have described in previous papers (e.g., Wellman 1979) as "friends", "neighbors", "co-workers" and other non-kin relations. Because all of these network members are intimate, they are almost always friends even if they live or work near one another.

The procedure

Development of a test

In this section we develop a generalized likelihood ratio test for assessing how significant the attributes of individuals are to the tendency of such individuals to have certain kinds of ties; i.e., to be dyad partners. In so doing, the test takes into account the different attributes and sample sizes of the individuals and the ties in the networks under investigation.

Consider the binomial distribution as a model for ties between members of a network, with the initial assumption that one cannot distinguish between the attributes of either the members of the network or the ties between members. In this model (1), p is the probability of a tie and R is the number of ties in N intimate pairs.

$$\binom{N}{R} p^R (1-p)^{N-R} \tag{1}$$

This baseline model must be made more complex to take into account the attributes of focal individuals, ties and networks. In order to distinguish between the attributes of the network members, consideration must be given to the relative frequency of the attributes, p_i, and the effects of the relative frequency of these attributes on the probability of a tie between two network members. For example, the probability of a network member having a tie with a kin is dependent on the proportion of kin in the network. If there are c attribute-categories of network members, then the model for the categorical composition $(N_1, \ldots, N_c)$ and the matrix (R_{ij}) of tie frequencies can be written as (2):

$$\binom{N}{N_1 \ldots N_c} p_1^{N_1} \cdots p_c^{N_c} \prod_{1 \le i \le j \le c} \binom{N_{ij}}{R_{ij}}$$

$$\times P_{ij}(N_1, \ldots, N_c)^{R_{ij}} \left[1 - P_{ij}(N_1, \ldots, N_c)\right]^{N_{ij}-R_{ij}} \tag{2}$$

where $N = N_1 + \ldots + N_c$ is the network size and $N_{ij} = N_i N_j$ for $i \neq j$ and $N_{ii} = N_i(N_i - 1)/2$.

Network size is a further consideration. No network is infinite, and the size of many networks studied is substantially small enough that the development of the model must consider how the number of members in these networks affects the distribution of network member attributes and the probability of ties between two network members. A modified Poisson distribution can be used to take into account network size, which is treated in the model as a condition on p_i: the probability of having a network member who possesses an attribute of type i. Thus the model becomes (3):

$$\frac{\lambda^N e^{-\lambda}}{N!}\binom{N}{N_1,\ldots,N_c} p_1(N)^{N_1}\cdots p_c(N)^{N_c}\prod_{1\le i\le j\le c}\binom{N_{ij}}{R_{ij}}$$
$$\times P_{ij}(N_1,\ldots,N_c)^{R_{ij}}\left[1-P_{ij}(N_1,\ldots,N_c)\right]^{N_{ij}-R_{ij}} \tag{3}$$

The outcome of this model has a probability depending on λ, the expected number of members of the network, $[p_1(N),\ldots,p_c(N)]$, the expected proportions of network member attribute-types in the network conditional on network size, and $P_{ij}(N_1,\ldots,N_c)$, the expected number of ties between the combinations of network members. In order to test the model, it is necessary to determine which values of these parameters provide the greatest likelihood of a fit with the sampled data. Formula (3) considered as a function L of these parameters is the likelihood function that has to be maximized in order to derive the Maximum Likelihood Estimators (MLEs) of the parameters.

The log likelihood is given by (4):

$$\log L = -\lambda + N\log\lambda - \sum_{i=1}^{c}\log N_i! + \sum_{i=1}^{c} N_i \log p_i(N)$$
$$+\sum_{1\le i\le j\le c}\log\binom{N_{ij}}{R_{ij}} + \sum_{1\le i\le j\le c} R_{ij}\log P_{ij}(N_1,\ldots,N_c)$$
$$+\sum_{1\le i\le j\le c}(N_{ij}-R_{ij})\log\left[1-P_{ij}(N_1,\ldots,N_c)\right]. \tag{4}$$

The modification on the Poisson distribution for a limited, non-zero number of specified network members (e.g., in the case of the example used in this paper, network size is between 1 and 6), modifies a factor in (3) to (5). In this example, a special form of the equation is needed for $j = 6$ because the sample data treats those networks with more than 6 members as having 6 members. If there were no size restriction imposed by the data collection procedure, then (5b) would not be needed and (5a) should hold true for all $j \geq 1$. Note that the factor $e^{\lambda} - 1$ in the denominator comes from the requirement that the network should have at least one member. (In our application, this means that there should be at least one intimate of the respondent.)

$$P(N=j) = \begin{cases} \dfrac{\lambda^j}{j!(e^{\lambda}-1)} & \text{for } j = 1, 2, 3, 4, 5 \quad (5a) \\ \displaystyle\sum_{i=6}^{\infty} \dfrac{\lambda^i}{i!(e^{\lambda}-1)} & \text{for } j = 6 \quad (5b) \end{cases}$$

The MLE of λ cannot be derived from conventional calculus methods because the equation has no explicit solution. Hence the MLE of λ, $\hat{\lambda}$, is found by a convergent iterative procedure (Andersen 1980: 115–116). The MLE for $p_i(N)$ is taken from the relative frequency of i type members in all nets of size N. The MLE for the ties between members with attributes i and j, $P_{ij}(N_1, \ldots, N_c)$, is taken from the relative frequencies of ties between network members of type i and j among i and j attribute types in networks with composition $(N_i, \ldots, N_c)$.

This is the most general model, incorporating all possible parameters. The key to the procedure is to find a more restricted model which retains adequate explanatory power. To do so, the researcher tests alternative models in which parameters have been removed.

The adequacy of these more restricted alternative models (with fewer parameters) is tested by a generalized likelihood ratio test (6). This test is asymptotically chi-square distributed with $d - d_0$ degrees of freedom as the number of networks, n, approaches infinity, and where $\hat{L}$ is the maximum value of the likelihood under the general model (i.e., no restrictions). If a removed parameter is not significantly related to the observed joint distribution of sample attributes, then the test statistic does not change significantly. Note that the model assumes independence between the n networks.

$$2 \log \frac{\hat{L}}{\hat{L}_0} \quad (6)$$

Thus in order to fit the model to data, we must first specify what categories of egos, network members and ties we want to separate, i.e., what attributes we want to include. Then we have to specify a model, estimate its parameters, and test its fit to data. We discuss estimation and fitting from an exploratory viewpoint in both composition and structural analysis. By using a stepwise procedure, we can reach a fairly good fit without having to include too many parameters.

The East York Survey

The data we use for our case study were collected in 1968 as part of a random sample survey of 824 adults (aged 18 and over) living in the Toronto Borough of East York. [3] East York (1971 population = 104,785) is an urban residential area near the center of Toronto, heavily working-class and lower middle-class, and predominantly British-Canadian in ethnicity (Gillies and Wellman 1968; Coates *et al.* 1970; Wellman 1979; Wellman *et al.* 1988).

The survey collected information about the intimate (socially close) members of these East Yorkers' ego-centric networks. The respondents were asked to describe these intimate ties (up to a maximum of 6) and to tell which of their intimates had close, intimate links with each other. This information was not restricted by any criterion other than intimacy: intimates could live anywhere in the world and have any sort of informal role relationship with the East Yorker respondents (e.g.,kin, friend, neighbor, co-worker) [4].

Not all respondent/egos reported having 6 intimate network members. In total, the 824 egos reported having 3,930 intimates, a mean of 4.8 intimates per ego. This mean underestimates somewhat the ex-

[3] Wellman (1979) gives the sample size as 845, but this includes 21 isolated respondents who are without intimate network members. These isolates have been excluded from the current analysis.

[4] The survey specifically asked: "I'd like to ask you a few questions about the people outside your home that you feel closest to. These could be friends, neighbours or relatives. Please write in their initials,...with the one you feel closest to on the first line, the next closest on the second line, and so on.

"Will you now tell me the relationship to you of each person you have written down?... Now, for the first person listed,...where does he/she live?

[After 6 intimates or less have been described], "I'd like to know which of the people...are close to another. Tell me about the first one, please. Which of the others are close to that person? Which are close to Person 2?" (etc.)

The data were originally collected in a study directed by Donald Coates, with Barry Wellman as co-director.

pected number of intimates per ego since no one could report more than 6 intimates (see Equation (5) above). The intimates, in turn, have 2,609 intimate "links" between themselves. [5]

To simplify understanding of the model, we chose all of our variables from the domain of kinship. Moreover, prior experience with these and related data sets have shown that kinship relations play important roles in shaping the composition, structure and socially supportive dynamics of these networks (Wellman 1979, 1985, 1988, 1990; Wellman *et al.* 1987; Wellman and Wortley 1989, 1990).

We chose marital status (married/not married) as the individual attribute to analyze, both because it is itself a kinship phenomenon and because observers have often wondered if unmarried members of Western industrial social systems tend to maintain more fragmented, friendship-dominated, intimate networks than those who are married (e.g., Allan 1979; Bulmer 1987; Willmott 1986, 1987). We chose network size and kinship composition as the relational variables to analyze because of their strong relationship to the provision of social support (Wellman *et al.* 1987). Our structural variables analyze links between intimate kin and friends, since the density of kinship relationships are often thought to be an important basis for network solidarity, sociability and support (e.g., Adams 1968; Gans 1962; Klatzky 1971; Wellman 1979, 1990; Willmott 1986; Young and Willmott 1957).

The analysis involved the merger of three data sets, respectively containing information on the respondents, their intimate ties, and the links between these intimate network members (Wellman and Baker (1985) discuss procedures). Simple counting procedures in SAS generated cell frequencies for all combinations of ego marital status, network member kinship status, and the links between network members. Frank *et al.* (1986) presents detailed frequencies of all combinations of attributes in the data set used in this case study.

[5] For the sake of clarity, we distinguish in this paper between "ties" – relations between egos at the centers of networks and their network members – and "links" – relations between network members (neither of whom are egos). Although the East York survey originally defined kinship status in terms of ego-intimate ties, we easily adapted these data to study intimate–intimate links. Two intimates who each have kinship ties with the same ego will also have some sort of kinship link with each other, if we accept in-laws as kin. We simplified our task by assuming symmetry in the relationships; an intimate link between two network members was defined to run in both directions. This is the only feasible way to treat such respondent-reported data and quite tenable in this case.

Application of the procedure

Let the number of categories, $c = 2$ and index the 2 categories by 0 and 1. Then the general model has parameters (7):

$$\lambda,\ P_0(N),\ P_1(N),\ P_{00}(N_0,\ N_1),\ P_{01}(N_0,\ N_1),\ P_{11}(N_0,\ N_1). \qquad (7)$$

Here (8):

$$\begin{aligned} &P_0(N) + P_1(N) = 1 && \text{for } N \geq 1,\\ &P_{00}(N_0,\ N_1) = 0 && \text{for } N_0 < 2,\\ &P_{11}(N_0,\ N_1) = 0 && \text{for } N_1 < 2,\\ &P_{01}(N_0,\ N_1) = 0 && \text{for } N_0 N_1 = 0. \end{aligned} \qquad (8)$$

Let the data consist of n independently sampled ego-centric networks. Assume that the number N of intimates of ego is bounded according to $1 \leq N \leq 6$, by not allowing any sampled networks to have no members (i.e., an isolated ego with an "empty" network) and by disregarding any information about more than 6 network members.

There is one parameter, λ, denoting the expected number of intimates in a network. There are 6 parameters $P_1(N)$: the probability of a network member being a kin of ego if there are $N = 1, \ldots, 6$ intimates. There are 15 parameters $P_{00}(N_0,\ N_1)$: the probability of a link between two network members not being a kinship link (with each other, as well as with ego), if there are N_0 friend (i.e., non-kin) and N_1 kin intimates satisfying $N_0 \geq 2$ and $1 \leq N_0 + N_1 \leq 6$. (Note that there have to be at least two friend intimates in the network for such a link.) Analogously, we have 15 parameters $P_{11}(N_0,\ N_1)$ for $N_1 \geq 2$ and $1 \leq N_0 + N_1 \leq 6$: the probability of a link between two kin in the network. Finally, there are 15 parameters $P_{01}(N_0,\ N_1)$ for $N_0 \geq 1$, $N_1 \geq 1$ and $1 \leq N_0 + N_1 \leq 6$: the probability of a link between a kin and a friend intimate.

So far we have $1 + 6 + 15 + 15 + 15 = 52$ parameters. Now we distinguish between married ($M = 1$) and unmarried ($M = 0$) egos, label all the previous parameters by M, and add a new parameter for the proportion of married egos. In total we then have in the general model: $d = (2 \times 52) + 1 = 105$ parameters.

The most general model for data should be a probability distribution on (9) possible outcomes (Frank *et al.* 1986) which takes into account (a) the frequencies of both kin and friend intimates, (b) links between kin intimates, (c) links between friend intimates, and (d) links between kin and friend intimates, i.e., $(N_0, N_1, R_{00}, R_{11}, R_{01})$.

$$\sum_{\substack{N_0=0 \\ 1 \le N_0+N_1 \le 6}}^{6} \sum_{N_1=0}^{6} (1+N_{00})(1+N_{01})(1+N_{11}) \tag{9}$$

Here $N_{00} = N_0(N_0-1)/2$, $N_{11} = N_1(N_1-1)/2$ and $N_{01} = N_0 N_1$ are the respective upper limits of R_{00}, R_{11}, and R_{01}.

In this case study (9) contains 27 terms with a total of 874 outcomes. With marital status of ego added, there will be a total of $2 \times 874 = 1{,}748$ outcomes. This is 1,747 degrees of freedom which is far too much for a sample of 824 networks. By restricting our general model to $d = 105$ degrees of freedom, there seems to be a reasonable balance between sufficient generality and sufficient accuracy for the asymptotic chi-square distributions to be applicable. Thus our general model seems to represent a reasonable start for the stepwise testing procedure.

Findings

Model testing to find the minimum number of useful explanatory variables

All of the models analyzed here provide information about three types of variables:

- an individual attribute: marital status (M);
- network composition: the number of intimates in a network (N), the number of intimate friends $(N_0 = \text{J})$; the number of intimate kin in a network $(N_1 = \text{K})$;
- network structure: number of links between two friends (R_{00}), number of links between two kin (R_{11}), number of "mixed" links between a friend and a kin (R_{01}).

The model parameters include the expected number of intimates (λ_{M}), the proportion of kin (κ_{MN}), the density of friendship links

(α_{MJK}), the density of kinship links (β_{MJK}), and the density of mixed friend–kin links (γ_{MJK}).

Our task is to find out which parameters we need – and in what combinations of indices – in order to describe with fidelity to the data the density of friendship, kinship and mixed links. This will tell us which of the available parameters describing marital status, network size, and the percentage of kin in a network are necessary to fit the observed distributions of network structures.

The tests

Table 1, the key analytic table in this paper, presents the results of testing various reduced models against the most general model (Model 1). Model 1 contains all 105 parameters described above, while in the reduced models specific parameters have been systematically removed. For example, Model 2 is reduced from Model 1 by assuming that the percentage of links in a network between kin and friends (denoted as γ) is independent of the number of friends (J) and the number of kin (K) in the network (column 2 of Table 1).

Since the test statistic indicates Model 2 is not significantly different from Model 1 (column 6 of Table 1), Model 2 is a satisfactory reduction of Model 1. The lack of a significant difference between Model 2 and Model 1 suggests that the percentage of mixed kin–friend links in these networks is independent of the number of kin and friends in these networks. This is indicated by the absence of the J and K indices of γ in Model 2. The continued presence of the M index of γ means that Model 2 still retains information about the effect of the marital status of the egos on the proportion of the mixed kinship–friendship ties in these networks. In other words, a single parameter, γ_M, is as useful as a set of 15 parameters, γ_{MJK}, in estimating the composition and structure of these networks. In this simpler model, we gain 14 parameters for married and 14 parameters for unmarried egos corresponding to the 28 degrees of freedom for testing Model 2 (column 7).

Other reductions are presented in the remainder of Table 1. Column 1 states the model being tested and column 4 states the model it is being tested against. We present for all models the comparison with the general model, Model 1. We also present comparisons with models which although they are reduced are somewhat more general than the model being tested (e.g., line 4 of Table 1 compares Model 3 with

Table 1
Likelihood-ratio testing of various network models

1 Model	2 Parameters of composition, structure	3 d	4 Test vs. model	5 Test statistic	6 [a]	7 df	
1	$\lambda_M \kappa_{MI}\ \alpha_{MJK} \beta_{MJK} \gamma_{MJK}$	105					General model
2	$\lambda_M \kappa_{MI}\ \alpha_{MJK} \beta_{MJK} \gamma_M$	77	1	−15.35		28	
3	$\lambda_M \kappa_{MI}\ \alpha_{MJK} \beta_{MJK} \gamma_M$	57	1	15.63		48	
3	$\lambda_M \kappa_{MI}\ \alpha_{MJK} \beta_{MJK} \gamma_M$		2	30.98		20	
4	$\lambda_M \kappa_{MI}\ \alpha_{MJ} \beta_{MJK} \gamma_M$	57	1	21.11		48	
4	$\lambda_M \kappa_{MI}\ \alpha_{MJ} \beta_{MJK} \gamma_M$		2	36.46	*	20	
5	$\lambda_M \kappa_{MI}\ \alpha_{MJ} \beta_{MK} \gamma_M$	37	1	52.09		68	Final model
5	$\lambda_M \kappa_{MI}\ \alpha_{MJ} \beta_{MK} \gamma_M$		3	36.46	*	20	
5	$\lambda_M \kappa_{MI}\ \alpha_{MJ} \beta_{MK} \gamma_M$		4	30.98		20	
6	$\lambda_M \kappa_{MI}\ \alpha_{MJ} \beta_M \gamma_M$	29	1	108.6	**	76	
6	$\lambda_M \kappa_{MI}\ \alpha_{MJ} \beta_M \gamma_M$		5	56.53	***	8	
7	$\lambda_M \kappa_{MI}\ \alpha_M \beta_{MK} \gamma_M$	29	1	78.14		76	Alternative model
7	$\lambda_M \kappa_{MI}\ \alpha_M \beta_{MK} \gamma_M$		5	26.05	**	8	
8	$\lambda_M \kappa_{MI}\ \alpha_M \beta_M \gamma_M$	21	1	134.7	***	84	
8	$\lambda_M \kappa_{MI}\ \alpha_M \beta_M \gamma_M$		6	26.05	**	8	
8	$\lambda_M \kappa_{MI}\ \alpha_M \beta_M \gamma_M$		7	56.53	***	8	
9	$\lambda_M \kappa_{MI}\ \alpha \beta \gamma$	18	1	198.6	***	87	
9	$\lambda_M \kappa_{MI}\ \alpha \beta \gamma$		8	63.95	***	3	
9	$\lambda_M \kappa_{MI}\ \alpha \beta \gamma$		13	98.03	***	18	
10	$\lambda_M \kappa_M\ \alpha_{MJK} \beta_{MJK} \gamma_{MJK}$	95	1	24.86	**	10	
11	$\lambda_M \kappa_M\ \alpha_{MJ} \beta_{MK} \gamma_M$	27	1	76.95		78	
11	$\lambda_M \kappa_M\ \alpha_{MJ} \beta_{MK} \gamma_M$		5	24.86	**	10	
11	$\lambda_M \kappa_M\ \alpha_{MJ} \beta_{MK} \gamma_M$		10	52.09		68	
12	$\lambda_M \kappa_M\ \alpha_M \beta_M \gamma_M$	11	1	159.5	***	94	
12	$\lambda_M \kappa_M\ \alpha_M \beta_M \gamma_M$		8	24.86	***	10	
12	$\lambda_M \kappa_M\ \alpha_M \beta_M \gamma_M$		11	82.57	***	16	
13	$\lambda_M \kappa_{MI}\ \alpha_{MJ} \beta_{MK} \gamma$	36	1	100.6	**	69	
13	$\lambda_M \kappa_{MI}\ \alpha_{MJ} \beta_{MK} \gamma$		5	48.50	***	1	

[a] Significance level: * 0.01 to 0.05; ** 0.001 to 0.01; *** below 0.001

Model 2). Column 3 presents the degrees of freedom in the model being tested, while column 7 presents the degrees of freedom for the test statistic, that is the difference between the models in columns 1 and 4.

The best models

Model 5 and its even more reduced form, Model 7, are clearly the best models found in Table 1. They achieve the largest reductions in degrees of freedom (column 7) while still retaining the lack of significance in the test statistic which indicates that their parameters are as good predictors as the general model of the kinds of links between kin and friends in these networks. In contrast, although Model 6's reduction in degrees of freedom of 76 is equal to Model 7 and greater than Model 5's reduction of 68 degrees of freedom, the significant test statistic of Model 6 indicates it fits the data badly.

Model 5 differs from the general Model 1 in the following ways:

- α, the percentage of links in these networks that are between two friends, is independent of the number of kin. (Subscript K is absent from α.) As in the general model, the percentage of links in these networks that are between two friends remains conditional on the number of friends (J) and the marital status (M) of the egos who are at the centers of these networks.
- β, the percentage of links in these networks that are between two kin, is independent of the number of friends. (Subscript J is absent from β.) As in the general model, the percentage of links in these networks that are between two kin remains conditional on the number of kin (K) and the marital status (M) of the egos who are at the centers of these networks.
- γ, the percentage of "mixed" links in these networks that are between a friend and a kin, is independent of both the number of friends and the number of kin. (Subscripts J and K are absent from γ.) Hence the percentage of mixed friend–kin links is independent of the size of the network. As in the general model, the percentage of mixed links remains conditional on the marital status (M) of the egos who are at the centers of these networks.

Model 7 is a further reduction of Model 5 with respect to the α parameter. The absence of any J subscripts of α in Model 7 suggests that the percentage of links in these networks that are between two friends is independent of the number of friends in these networks as well as being independent (as in Model 5) of the number of kin in these networks.

Although Table 1, line 12, shows that Model 7 is an adequate reduction from the general Model 1 (large reduction in degrees of freedom coupled with a non-significant test statistic), line 13 suggests that the reduction from Model 5 to Model 7 – removing information about the number of friends in the networks – appreciably distorts Model 7's ability to describe what proportions of links between two friends actually occur in these networks. We discuss this ambiguity below when we explore in greater detail the parameters present in Models 5 and 7.

Ego's marital status

Being married has important positive effects on the number of all intimates in a network (λ_M) and the proportion of kin intimates conditional on the number of all intimates (κ_{MN}). Not only are these key terms in Models 5 and 7, they are present in all of the models tested for Table 1. Indeed, in any tests we did for this study (including many not published here), ignoring the impact of marital status on these links significantly affected the test statistics.

Although we caution that we have not analyzed any other individual attributes, our findings suggest the importance of marital status in affecting the composition and structure of the network. Marriage is a change in the life cycle position that has a key importance in the type of network set up by an ego. Marital status shows up in all parameters and by itself significantly predicts the size of the network – married egos have larger ones with greater proportions of kin – as well as the density of mixed friend–kin links. Marital status interacts with the number of friend or kin intimates to affect the distribution of friendship and kinship links respectively. The following subsections analyzes each of these parameters separately.

Network size–number of intimates in a network

Both singles and marrieds tend to have large networks, with a model concentration at the maximum allowable of 6 (Table 2). However, a higher proportion of singles than marrieds have small-size networks with 1 or 2 members. Thus 14.8 percent of the singles and 7.3 percent of the marrieds have intimate networks with only 1 or 2 members. Conversely, a greater proportion of marrieds have large networks. While 57.1 percent of the singles' networks contain 5 or 6 members, 64.9 percent of the married's networks are this large.

Because the respondent/egos were limited to reporting about a maximum of six intimates, a truncated Poisson distribution was used to avoid underestimation when calculating the expected size of the networks. The parameter λ_M is the expected number of intimates in a network (i.e., network size) for singles and marrieds. Andersen's (1980)

Table 2
Percent distribution of network sizes according to marital status

Network size	Singles	Marrieds	Expected
1	3.7	2.0	2.4
2	11.1	5.3	6.8
3	12.4	14.3	13.8
4	15.7	13.5	14.1
5	12.9	14.5	14.1
6	44.2	50.4	48.8
Mean size	4.6	4.8	
Number of networks	217	607	

iterative procedure provides λ estimates for networks ranging in size form 1 to 6. This procedure yields estimated expected network sizes of 5.1 for singles and 5.6 for marrieds. The truncated Poisson distributions show a good fit to the data, and the distributions of singles and married egos are different at the 0.5 significance level (Table 2).

Although the differences are not large, the consequence of these findings is that network size must be conditioned on marital status when testing our models. Singles tend to have slightly smaller intimate networks than marrieds. In-depth interviews with a subset of 33 of our respondent/egos suggested several reasons for this (Wellman 1985; Wellman *et al.* 1987, 1988; Wellman and Wellman 1992). Upon marriage, spouses may merge all or part of their networks, making each other's friends and kin available for interaction. Married couples have bigger networks because they are more likely to interact as couple-to-couple or within groups, while singles are more likely to interact one-on-one with their network members.

A subset of marrieds – married men – gain the additional spousal benefit of living with a wife, when wives are the preeminent arranges of kinship, friendship and other forms of community life (see also Bott 1971; Willmott 1987). As one of our interview respondents put it:

> My wife is the birthday rememberer, also 'phone numbers and dates. I wouldn't even go out and buy a birthday card. She signs both our names.

It is also probable that large networks may also "cause" marriages. Gregarious individuals may be more likely to get married and to

Table 3
Percentage of kin intimates by egos' marital status and network size

Network size	Singles	Marrieds
1	88	50
2	35	50
3	40	58
4	42	55
5	34	48
6	32	55
Total	35	54

maintain large networks. Larger networks can provide more help in finding mates, just as they are better at providing other services (Wellman *et al.* 1987).

Percentage of kin intimates in a network

The proportion of kin in these intimate networks, κ, is an important descriptive term in Models 5 and 7. The analytic chain has been continued one step. Where γ_M, discussed above, showed that network size is related to egos' marital status, the exact term here is κ_{MN}, which means that the proportion of kin is related to both egos' marital status (M) as well as to network size (N).

Table 3 shows in more detail how the percentage of kin varies complexly according to egos' marital status and network size. The influence of network size can only be seen when marital status is controlled. Marrieds have higher percentages of kin intimates than do singles, in general and for all but the smallest, one-intimate networks. Indeed, the percentage of kin intimates for married's networks does not vary much by network size: the mean proportion for all married's networks is 54 percent, with a maximum of 58 percent in networks of size 3 and a minimum of 48 percent in networks of size 5.

By contrast, the majority of singles who have comparatively large networks of 5 and 6 intimates tend to have lower percentages of kin in these networks than do those singles with smaller networks (Table 3). Except in the smallest one-intimate networks, friends form the majority of singles' networks. Like marrieds, singles tend to maintain a core set of kin with whom they are especially intimate: these are quite likely to be ties with aged parents, adult children or siblings (Wellman 1979, 1990; Wellman and Wortley 1989). Unlike marrieds, singles have few kin intimates outside their most intimate core set.

The reasons that marrieds have significantly greater percentages and absolute numbers of kin than do singles are largely similar to those discussed above for the larger networks that marrieds have. Marriage brings an additional set of kinship ties – in-laws – and such ties tend to persist. Norms require interaction with intimate in-laws (Farber 1981) and "kinkeeping" women relatives see to it that kinfolk stay in contact (Rosenthal 1985; Wellman 1985, 1990; Wellman and Wortley 1989). Thus the big advantage of kin remaining in networks is that they are there – organized into social systems with individuals to maintain role obligations and make social arrangements. As one married woman told our interviewer:

> I'm connected with a very wonderful family: my in-laws. We have a lot of activities together. They're a family that likes to get together. They enjoy one another's company. We have a big bang-up day at Christmas time, and once or twice during the summer we have a weekend away, and this includes all our children as well as the adults. Usually there's about 20 or 22 of us.

Links between intimates in networks

The payoffs come in the integration of the analysis of an individual attribute (ego's marital status), a tie attribute (ego-network member kinship) with structural attributes: the percentage in these networks of links between pairs of friends, pairs of kin, and mixed pairs of friend and kin. Our analysis of the structure of these networks asks: how do marital status and the kinship status of intimates affect the density of different types of links between intimate network members? One of our concerns is with the density of links within these networks: are network members densely connected in order to facilitate the communication of an ego's needs and the maintenance of social solidarity and social control? Our other concern is with the cohesiveness of these intimate networks: are kin and friends segregated in separate components of an ego's network?

Table 4
Percentage of links between friends by egos' marital status and number of friends in networks

Number of friends	Singles	Marrieds
2	20	27
3	23	15
4	28	21
5	16	15
6	19	15
Total	21	18

Links between friends

To what extent do an ego's intimate friends – his/her close friends, neighbors and coworkers – tend to have intimate links with one another? Table 4 shows that only about one-fifth of all possible friendship links have actually been formed. The pertinent term in Model 5, α_{MJ}, suggests that the distribution of these links depends both on egos' marital status and on the number of friends in these intimate networks.

The intimate friends of singles are slightly more likely to be intimately linked themselves than are the intimate friends of marrieds. Actual links between friends represent 21 percent of all potential friendship links in networks of single egos and 18 percent in married egos' networks. Here is where marriage may bring its toll: although the joining of two marital partners has enlarged their networks, their friends have not been fully integrated. Thus our interviewed respondents report that in fully 65 percent of the ties they maintain with couples, the relationship is really to only one member of that couple (Wellman *et al.* 1988). Consequently, the intimate friends of married egos are somewhat less densely-connected than the intimate friends of singles.

Our findings go against an opportunity interpretation: It is not true that the greater the number of friends in the network the larger the percentage of friends who are linked with one other. However, one must bear in mind that these are not isolated, disconnected little networks which are worlds unto themselves: network members can – and do – look elsewhere for most of their intimate relationships.

Moreover, the patterns in singles and marrieds distributions are not the same. The singles' pattern is curvilinear, and the marrieds' percentage of friendship links decrease somewhat with larger network size (Table 4). These patterns suggest another meaning of "opportunity": It is somewhat less likely in larger, more fragmented, networks for friends to be in intimate contact with each other. In such larger networks, intimacy with egos is less apt to be associated with intimacy among egos' friends.

These weak associations with network size are reflected in the slight difference between Models 5 and 7. In Model 7, unlike Model 5, network size does not affect links between friends. The relevant parameter in Model 7 is α_M while in Model 5 it is α_{MJ}. Both models afford strong, interpretable, desirably-nonsignificant reductions in parameters from the general model, but the removal of the network size parameter significantly distorts Model 7 when compared to Model 5 (Table 1, line 13). Not only does Model 5 offer a more reliable fit to the data, but the parallelism in its α_{MJ} and β_{MK} parameters makes it easier to comprehend and more aesthetically pleasing to consider.

Links between kin

Intimate kinship is a more densely-knit social system in North America than intimate friendship. Fifty-nine percent of all possible intimate links between kin in these networks actually do exist, as compared with only 19 percent of the potential links between intimate friends. Kin intimates of egos, then, are likely to relate intimately to each other.

What determines the distribution of these links in our networks? The germane parameter in Model 5 for links among kin, β_{MK}, is analogous to the one just discussed for links among friends. Both egos' marital status and the number of kin in the networks affect the percentage of links between kin in these networks.

As is the case for friendship links, the kinships links among the intimates of married egos are somewhat less densely-knit (56%) than they are for singles (66%) (Table 5). Even though married people have the largest proportion of kin among their intimates, they have less densely-knit kinship links than do singles. The comparison holds for all network sizes. The interpretation is similar: in-laws are less likely to be linked than members of the same family of orientation.

The number of kin intimates in these networks is inversely related to the density of links between kin, with the exception of the very largest networks. As networks become arithmetically larger, the number of links between members must expand geometrically in order to maintain

Table 5
Percentage of links between kin by egos' marital status and number of kin in networks

Number of kin	Singles	Marrieds
2	80	70
3	67	61
4	61	57
5	50	45
6	71	60
Total	66	56

the same network density. Kin may find it more difficult to keep in contact with the larger number of kin, especially when they are in networks fragmented into "own family" and "in-laws".

Nevertheless, for singles and marrieds, at all network sizes, a majority of an ego's kinfolk (including in-laws) are intimately linked. Kin continue to be the important central, connected cores of most East Yorkers' networks (see also Wellman 1990; Wellman *et al.* 1987, 1988; Wellman and Wortley 1989).

Links between friends and kin

Kinship and friendship are highly segregated among these East Yorkers' intimate networks. Only 7 percent of possible intimate links between friends and kin actually exist.

The relevant parameter in Models 5 and 7 is γ_M, indicating that the percentage actually occurring of such "mixed" friend-kin links is only affected by marital status. Here, too, singles (8%) have slightly more densely-linked relationships than do marrieds (6%), and probably for much the same reasons as discussed above. Because the percentage of such mixed links is so low, the distribution of these rare relationships is not affected by the number of either friendship or kinship ties. The problem is not the presence in the network of sufficient mixed partners; the problem is one of getting potential links to be formed.

Conclusions

In addition to addressing the methodological problem of integrating individual, relational and structural analysis, our research has sought to address substantive questions about how marital status and kinship relations intersect to affect the size and density of intimate egocentric networks. This is of more than academic interest, as other research has shown that the size and density of such networks affect the amount of companionship, emotional aid and services they provide (Wellman *et al.* 1987).

The impact of marital status is pervasive. It is the only variable which appears in all terms of the final models, 5 and 7. Marital status is related both to the size of the intimate networks and to the proportion of kinship relationships in them. Moreover, egos' marital status is significantly related to the likelihood that other members of their networks will be intimately linked – be they kinship, friendship or mixed ties.

The correlates of marital status are complex. Married egos have slightly larger intimate networks than do singles. The marrieds' networks tend to contain higher proportions of kin, and because kin are much more apt to be linked with one another, the overall intimate networks of marrieds are denser. The kin so prevalent in the married networks are especially likely to provide supportive emotional aid and services. The friends proportionately more present in singles' networks are especially likely to be sociable companions (Wellman and Wortley 1990).

Although the overall density of marrieds' intimate networks is greater than the singles', singles tend to have denser clusters of intimates within their intimate networks. It is the greater number and proportion of kin in the marrieds' networks which causes the higher overall density of their networks. Yet if we consider separately sets of friendship and kinship ties within networks, the friendship and kinship networks of singles tend to be denser than those of marrieds. The friendship and kinship networks of marrieds are less dense because the networks of husbands and wives are incompletely integrated. Although the intimate kin or friends of one marital partner are often intimates of the spouse ("I consider my in-laws to be my family"), there is a low percentage of links between the kin (or friends) of one marital partner and the kin (or friends) of the spouse ("My parents and my wife's friends don't talk to each other").

The key elements are the characteristics of kinship in North-American society. Ties with kin continue to comprise about half of the ties in most networks, even when the criterion of intimacy is relaxed somewhat (see the reviews in Willmott 1987; Wellman 1988, 1990). Kin dominance is even stronger when their greater capacity for coordinated action is taken into account. In these data, about three-fifths of all possible intimate links actually occur between the egos' intimate kin. By contrast, only about one-fifth of all possible intimate links actually occur between the egos' intimate friends. If weaker links between network members are taken into account, it is most likely that kin dominance in these networks will be even greater (Wellman and Wortley 1989; Wellman *et al.* 1988).

Yet the higher proportion of kin and the lower densities in married egos' networks suggests that in-laws often do not develop links with each other. This lack of integration in kin ties of married egos is consistent with bilateral kinship systems of western industrial social systems (Gordon 1978). People stress links with kin who were fellow members of the same nuclear family (Willmott 1987). Although one may still speak of extended families, they are not densely-knit systems of kinship. Married egos who belonged to different nuclear families are more apt to link their in-laws than for their in-laws to have direct intimate links themselves.

Our findings show in several ways that kinship and friendship are largely independent social circles within egos' intimate networks. Most obviously, there is a low percentage of mixed kin–friend links in these networks. More subtly, the number of kin in these networks does not affect the density of links between friends (α does not have a L subscript in our final model). In parallel, the number of friends in these networks does not affect the density of links between kin (β does not have a J subscript in our final model).

The general tendency is for kin intimates to comprise a relatively stable, density-knit core – especially if they are parents, adult children or sibs – for friends to comprise a sizable, more sparsely-knit portion of these networks, and for hardly any bonds of intimacy to link friends and kin directly (see also Wellman 1979; Wellman *et al.* 1988). Thus kinship and friendship have different structures and dynamics: kinship operates as a system, friendship is one-on-one, and hardly ever the twain shall meet.

This paper has presented a newly-developed procedure for evaluating and comparing different network models. The final model selected was substantively analyzed taking account of literature on the topic. The results of this analysis show that the model offers interesting elements from a sociological viewpoint. The results are consistent with previous findings using different techniques and also furnish new clues for further analysis.

The need for multiparameter network models is evident from the fact that random graph models with few parameters, like the Bernoulli graph, are often not sufficient in social science applications. The way in which we have introduced relational and structural parameters complements the network models investigated by Holland and Leinhardt (1981), Fienberg and Wasserman (1981), Arabie and Boorman (1982), and others. If we focus on the exploratory use of the present approach, it can be seen as an alternative to the clustering approach discussed by Frank *et al.* (1985a, 1985b).

From a theoretical point of view, the "Markov graph" approach investigated by Frank (1985) and Frank and Strauss (1986) can be an alternative to our present model. Markov graphs have dependent dyads in contrast to the models of Holland and Leinhardt (1981) and Fienberg and Wasserman (1981). However, the inference problems for Markov graphs are prohibitive because available methods require extensive computer simulations (Frank and Strauss 1986). Therefore the present model is more useful for inference purposes (see the review in Frank 1988).

There are data limitations to our procedure. It requires a good deal of network data, and it can handle only a few attributes at one time. The researcher must bring prior knowledge and theory to bear in the choice of variables and models. Yet despite these limitations, the procedure has shown a way to integrate individual, relational and structural data, and it has yielded substantively interesting and reasonable findings in our case that illuminate the interplay between marriage, kinship and network structure.

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