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GROUP STABILITY:
A SOCIO-COGNITIVE APPROACH

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ABSTRACT

This paper uses a socio-cognitive model of the interface between self and society, based on constructural theory, to predict changes in interaction patterns among workers in a tailor shop in Zambia. Within this model all individuals in the society can simultaneously interact, exchange information, and alter with whom they interact. The parallel behavior of individuals can result in either social change or stability. General predictions of the model for group stability are examined. The model is then used to predict the changes in interaction patterns among workers in a tailor shop that was observed by Kapferer. The proposed model has higher predictive capability than do alternate models of changing interaction, such as Heiderian balance and the exchange model used by Kapferer. Finally, when the model is augmented with basic measures of friendship and antagonism it provides an explanation for the ability of the workers to engage in a successful strike after an aborted first strike that is consistent with Kapferer's observations.

The stability of groups is reflected in the change and stability of the relations between the group members. We observe change and stability in the group as changes occur in the pattern of interaction (who interacts with whom) and in the frequency with which individuals interact, and the consequent formation and dissolution of friendships, eruption and subsidence of hostilities, . . . , emer-

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gence and submergence of leaders. Such internal group changes may have far reaching systemic implications. For example, Kapferer (1972) found that the changing patterns of interaction among workers in a clothing factory in Kabwe, Zambia enabled the group to engage in a successful strike. If we could explain and predict changes in the relationships between individuals we would be better equipped to explain and predict the change and stability of the group.

This paper presents a socio-cognitive model of the interface between self and society, based on constructural theory (Carley 1986a; Carley 1986b) and then uses this model to predict changes in interaction patterns among workers in a tailor shop in Kabwe, Zambia (then Northern Rhodesia) (Kapferer, 1972). This model is also presented in (Carley, 1989) where its long run predictions for group stability are explored. The data, collected by Kapferer (1972) as part of a very rich and detailed field study of urban life, is on the changing patterns of interaction between African workers in an Indian owned clothing factory over a 10-month period during which the workers were engaged in negotiations for higher wages. Kapferer divided his record of these interactions into two periods: time 1—after which an abortive strike occurred, and time 2—after which a successful strike occurred. After initial analysis, the base model is augmented to look for changes in the potential for friendship and antagonism as a result of changes in interaction. Then the augmented model is used to reconstruct the change in worker-management relations that preceded the successful strike and to provide an explanation for the success of the second strike and the failure of the first strike that goes beyond Kapferer's explanation that increased unification among the workers made it possible to engage in a successful strike.

RELATING SELF AND SOCIETY

Recent advances in both cognitive science and network theory have engendered the belief that it should be possible to develop analytical models of the relationships between individuals that would enable quantitative predictions of changes in interaction and that take into account both the self and the society, the individual and the group, the cognitive and the social. These advances have rekindled the dream, originally seen in social comparison theory (Festinger, 1954), cognitive dissonance theory (Festinger, 1957), and balance theory (Heider, 1958), that it is possible to build a mathematics of group change as a function of individual change. Yet there is still a gap between the more cognitive and individual perspective in which changes in relationships between individuals result from independent dyadic encounters and the more social and structural perspective in which changes in relationships between individuals result from gross changes to the group. Currently a great deal of research is directed at bridging this gap.

On the individual side the linking of symbolic interactionism and role theory can be viewed as a move to incorporate social or group factors into an otherwise predominantly cognitive and individual theory (Turner 1978, 1984; Stryker 1980; Stryker and Statham 1985; Burke and Reitzes 1981; Stryker and Serpe 1982; Serpe 1987, 1988). Similarly, affect control theory is a move to incorporate the social, in terms of task constraints and social knowledge, into a cognitive and affective model of the individual's evaluation of (and hence determination of) future action (Heise 1977, 1979, 1987; Smith-Lovin 1987, 1988). In these cases, the models focus on the change in the individual or his or her relationships to an actual (or a generalized) other, treats the group or social world as present but relatively "fixed", and implicitly assumes that social or group behavior is "somehow" the aggregate of the results of *independent* encounters between pairs of individuals. This last assumption is not exclusive to those who propose more cognitively rich models of behavior. For example, we also see it in the work on status and dominance where hierarchies are viewed to result from independent dyadic encounters (Berger, Conner, and Fisek 1974; Rosa and Mazur 1979; Lamb 1986).

On the group side, evidence is being amassed that group behavior can not be accounted for by aggregating independent dyadic encounters (Chase 1974, 1980; Ridgeway and Diekema 1989) but is rather an emergent property of the simultaneous actions of all group members (Bales 1950; Homans 1950; Chase 1974, 1980; Fararo and Skvoretz 1986). The mechanism by which such group behavior emerges remains elusive. As a step toward locating this mechanism research in the structural and network traditions has been moving toward providing explanations, and hence predictions, of individual cognitive change in terms of the individual's social position. This can be seen in Burt's model of action (1982) where perceived similarity and hence norms, attitudes, likelihood of adopting innovations, and so on is a function of social position and in Krackardt's notion (1985, 1986, 1987) that the individual's social cognition (which he defines as the individual's perception of who interacts with whom) is a function of social position. These works reveal a more cognitive actor (than that revealed by classic structuralists) whose behavior is nonetheless socially situated. Yet, like the more cognitive individual models, these social models of individual change, still focus on the change in the individual while maintaining a relatively fixed social world.

Thus, both the individual and the social perspectives treat the social world as fundamentally stable. Consequently, neither perspective provides a mechanism by which such individual changes can produce social change. Neither approach is sufficient to explain, let alone quantitatively predict, changes in the interaction patterns for all members of the society at once. Rather, the explanations of social change are highly contextual relying on situation specific factors, forces, and constraints (such as goals, coercion, bureaucratization, change in group size, and membership rituals). To use a rough analogy, the loop between individual change and social change has not been closed. Nevertheless these individual and social approaches are complementary in their explanations of change in individuals and their relationships: where the individual models tend to exhibit richer cognitive detail and remind us of the limits of individual cognition the social models exhibit richer demographic and historical detail and remind us that the actions of individuals are contextually based. This paper presents a model combining both approaches, which closes the loop between individual and social change. This model should be thought of as simply a first step in combining these individual and social perspectives. It abstracts away from much of the richness we see in the alternate individual and social perspectives, but what is gained by this abstraction is the ability to mathematically represent a mechanism for self and social change and the ability to make quantitative predictions.

BASIC MODEL: KNOWLEDGE BASED INTERACTION

Every group has a population, that is a certain number of individuals, denoted by I.[1] In every group there is a set of information or facts[2] that is potentially "learnable" by the members of the group. This set of information contains each piece of information that is known by at least one group member. The number of such facts will be denoted by K. At a particular point in time, say time period t, the individual i for any piece of information, such as k, either knows that fact or does not. This is denoted by $F_{ik}(t) = 1$ if the fact is known by individual i at time period t and 0 otherwise. Every society has a culture, which can be thought of as the distribution of information across the population. At a particular point in time, say time period t, the individual i has a certain probability to interact with each other member of the society, such as j. This is denoted by $P_{ij}(t)$. Every society has a social structure, which can be thought of as the distribution of interaction probabilities across the population.

The first part of the model posits that interaction leads to shared knowledge. It is generally demonstrable that individuals acquire information (and hence will come to share knowledge) during interactions. In order to represent this process a variety of simplifying assumptions are made. All pieces of information are entirely unstructured and undifferentiated. Thus, the individual may know conflicting information such as *the sky is blue* and *the sky is green*. Consequently, the overlap in what two individuals' know is just the sum of the pieces of information that they both know. When two individuals interact each communicates one fact to the other. Individuals always learn the piece of information that is communicated to them. Consequently, if individual i knows that *the sky is blue* and individual j knows that *the sky is green* and individual j communicates to individual i that *the sky is green* the overlap in their knowledge increases. Hence, they have more shared knowledge. All facts known by the individual are equally likely to be communicated.

A specific piece of information is communicated from one individual to another if the two individuals interact and if that is the fact the communicator chooses to communicate. Whether individuals i and j interact at time period t is denoted by $INT_{ij}(t)$ where $INT_{ij}(t) = 1$ if they interact and 0 otherwise. Whether individual j chooses to communicate fact k at time period t is denoted by $u_{jk}(t)$ where $u_{jk}(t) = 1$ if k is chosen and 0 otherwise. Whether individual j communicates the piece of information k to individual i at time period t is denoted by $C_{jik}(t)$. Thus,

$$C_{jik}(t) = INT_{ij}(t)\, u_{jk}(t) = \begin{cases} 0 & \text{if } j \text{ does not communicate } k \text{ to } i. \\ 1 & \text{if } j \text{ does communicate } k \text{ to } i \end{cases} \tag{1}$$

The function $u_{jk}(t)$ represents the random choice of a fact k by individual j from the set of facts known by j, such that all facts known by j are equally likely to be chosen. There are many ways in which this could be implemented. (See Appendix 2 for details.)

An individual will know a fact the next time period if he already knows the fact or if anyone in the society communicates it to him. This is represented as:[3]

$$F_{ik}(t+1) = F_{ik}(t) \vee C_{1ik}(t) \vee C_{2ik}(t) \vee \ldots \vee C_{Iik}(t). \tag{2}$$

In this model there is no forgetting; that is, once an individual knows a fact he always knows it. And, in this model there is no discovery; that is, if the individual interacts with himself no change occurs in what he knows.

The second part of the model posits that the more similar two individuals are in terms of what they know, relative to everyone else, the more likely they are to interact. What this amounts to is the suggestion that individuals are more "comfortable" interacting with someone with whom they have more in common, and that individuals "determine" how much they have in common with another on the basis of the social similarity the individual perceives between himself or herself and every other individual in the group. This can be represented as:[4]

$$P_{ij}(t) = \frac{\sum_{k=1}^{K} F_{ik}(t) \wedge F_{jk}(t)}{\sum_{h=1}^{I} \sum_{k=1}^{K} F_{ik}(t) \wedge F_{hk}(t)}. \tag{3}$$

Thus, the probability that one individual interacts with another, denoted by $P_{ij}(t)$, is a function of how much information he or she shares with the other and how much information he or she shares with everyone else including himself or herself.

During a particular time period whether two individuals actually do interact is determined by each of their probabilities to interact with the other, and whether or not either of them is already interacting with someone else or spending the time alone. The choice of an interaction partner, or spending time alone, occurs serially. In the model, an individual is chosen at random to start off the selection of interaction partners. Initially, all individuals are equally likely to be selected. Let us assume that i is the selected individual. Let $A_j(t)$ denote whether individual j is available for interaction such that $A_j(t) = 0$ if j is already interacting and 1 otherwise. Then, whether individuals i and j interact during time period t is represented as:

$$INT_{ij}(t) = v_{ij}(P_{ij}(t), A_j(t)) = \begin{cases} 0 & \text{if } i \text{ does not select } j \text{ to interact with.} \\ 1 & \text{if } i \text{ selects } j \text{ to interact with} \end{cases} \quad (4)$$

The v function represents the random selection of an interaction partner j by individual i from the set of individuals in the society who are available for interacting as weighted by his or her probability of interacting with those individuals. There are many ways of implementing this selection of an interaction partner. (See Appendix 2 for details.)

This model has several noteworthy features. During a particular time period, individuals (i) can never be more likely to interact with someone else (j) other than themselves as they can not share more knowledge with others than with themselves. Interaction probabilities are not necessarily symmetric between a pair of potential interaction partners because the probability that individual i interacts with j is a function not only of his likelihood to interact with j but his likelihood to interact with all other individuals in the society. And interestingly, the interaction/knowledge cycle does not necessarily lead to positive feedback, since it is possible for i and j to interact, increase their shared knowledge, and yet be less likely to interact in the future. For example, if Aaron and Zebadiah interact, and at the same time period Deety and Hilda interact, then Deety and Hilda may exchange information that is already known by Aaron thus increasing not only how much information they share with each other but how much information they share with Aaron. Thus both the amount of information that Aaron shares with Zebadiah and the amount of information that Aaron shares with everyone else increases. And, if the amount of information that Aaron shares with everyone else increases more in proportion to the increase in the amount of information that Aaron and Zebadiah share then the probability that Aaron and Zebadiah will interact in the future goes down. This is more likely to happen if Aaron and Zebadiah exchange information that they both already know. These contingencies—according to this vary spare model—are quite random: sets of knowledge are, after all, unstructured and the interactors' choice of a piece of information to exchange is random.

The Knowledge/Interaction Cycle

The proposed model, which will hereafter be referred to as CONSTRUCT, is based on three empirical generalizations: (1) interaction leads to knowledge acquisition, (2) homophilly, the tendency of frequent interactors (such as friends) to be similar, and (3) social relativity, the tendency of individuals to evaluate and determine their actions on the basis of their own characteristics and their perceived similarity to others.

That individuals acquire information during interactions is generally taken as axiomatic. It is generally demonstrable that individuals acquire information (and hence will come to share knowledge) during interactions (Festinger et al. 1950; Festinger 1950; Granovetter 1974; Garfinkel 1981, for example). In addition Carley (1986a, 1988 in press) demonstrated that higher levels of interaction led in general to higher levels of shared knowledge. In CONSTRUCT both interaction and knowledge are undifferentiated, and all interaction leads to the exchange of information, although not necessarily to the acquisition of new information.

Homophilly has been demonstrated on such dimensions as age, sex, race (Lazarsfeld and Merton 1954; Verbrugge 1979; McPherson and Smith-Lovin 1987) education, prestige, social class and occupation (Lipset, Trow, and Coleman 1956; Coleman 1957; Laumann 1966; Verbrugge 1979; McPherson and Smith-Lovin 1987). In CONSTRUCT knowledge is viewed as mediating between these dimensions and interaction. These various dimensions can be viewed as both part of what the individual knows and as determinants of what the individual knows. Thus, in the same culture, individuals of the same age, sex, race, educational level, social class, etc. can be said to know more of the same things and hence are more likely to interact. Similarly, individuals with the same attitudes and norms share at least some of the same knowledge (such as that the norm exists) and thus are more likely to interact.

Social relativity, referred to by Burt (1982, pp. 1–16) as a "normative" tendency, has received empirical support (Merton and Rossi 1968; Merton 1968; McGuire 1969) both when experimental (Sherif 1935; Asch 1951) and survey (Festinger, Schachter, and Back 1950; Festinger 1954) methodologies are used. This body of research demonstrates that the social context affects behavior. What behavior the individual engages in, what attitudes the individual evinces, appear to be a function of how the individual evaluates himself or herself relative to others. And often, positive evaluation of self as a group member leads to increased conformity with, or accordance with the group. In CONSTRUCT, individuals base their behavior (interacting with others) on a continual re-evaluation of their similarity to all others in the society, and not just members of a prespecified group.

CONSTRUCT combines these three forces—interaction driven knowledge acquisition, homophilly, and social relativity—into a single mechanism. There is nothing in the model that says that the individual is actively seeking information, is consciously evaluating his or her position, or is actively aware of each tie that the individual has with each other individual. What the model does say, is that the three processes are at work (whether consciously or not) and that there are not systematic biases within an individual's judgement of his or her similarity to others or across all individuals' judgements such that there is more accuracy in the relative similarity judgements for one group than another.

The question that arises is "If all three of these forces are going on at once, what does that mean for the individual and for society?" The first force, interaction driven knowledge acquisition, provides a basis for individual change and hence social change. The second force, homophilly (as reflected by the more we share the more we interact) when coupled with the first, provides an overall tendency toward solidarity and conformity (more interaction, more shared knowledge, more consensus). Thus one gets the tendency that the more individuals interact the more similar they become. This tendency was described by Homans (1950) as the production of friendship through interaction, by Durkheim (1912) as the production of moral solidarity through interaction, by symbolic interactionists as the production of the self and the generalized other through experience (Mead 1962; Blumer 1969; Stryker 1980), and so on. The third force, social relativity, modulates the movement toward overall solidarity by creating a local drive in the individual to view one's self as at one time more like one group and less like another, and yet later for the opposite to be true.

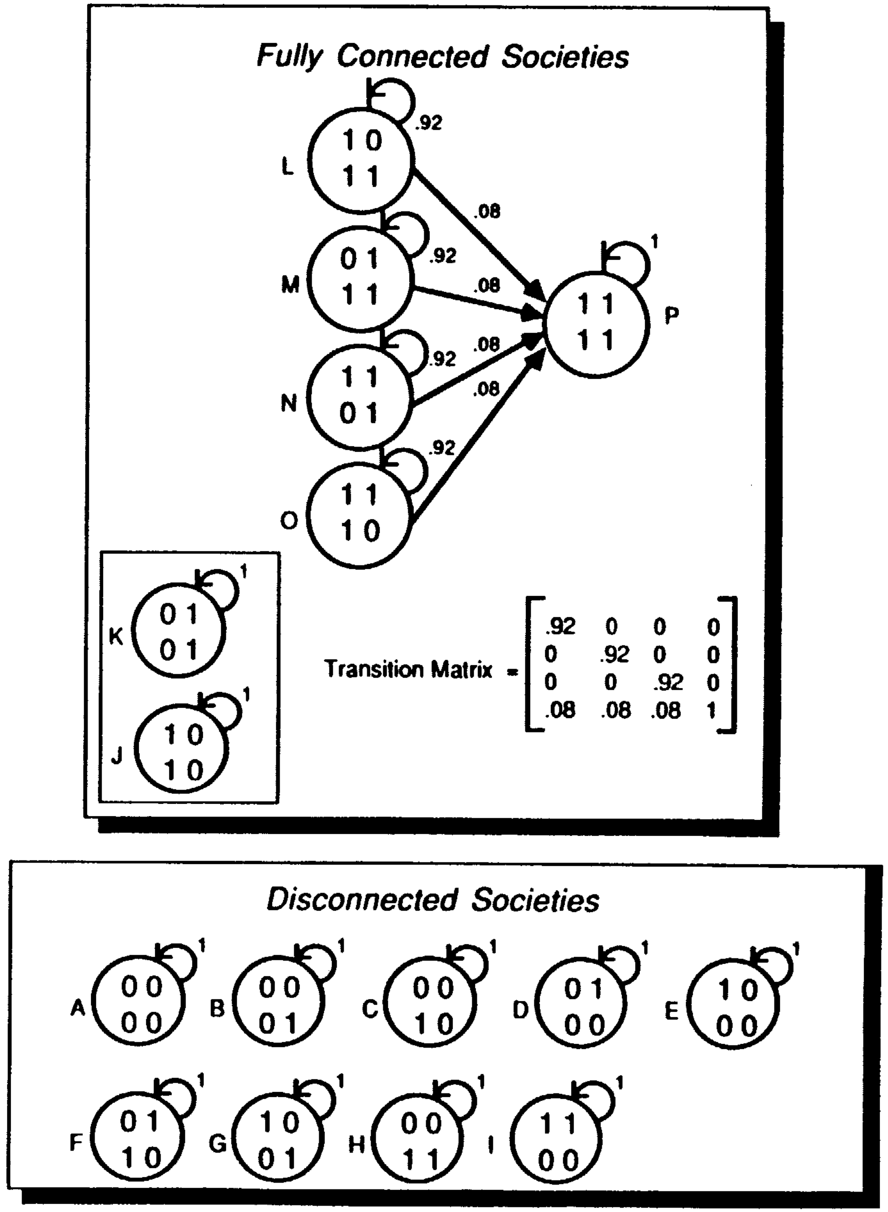
Collectively, these three forces give you a kind of short term chaos, where in the absence of restrictions on who can interact with whom and who knows what, that is in the absence of structural and cultural restrictions, any pattern of individual relationships can exist, any social behavior is possible, any configuration of groups is possible, any pattern of group cohesion and dissolution is possible, and so on. In the long term, these three forces, in the absence of forgetting, differentiation in information, or demographic changes, lead to social and cultural homogeneity whose prevalence is dependent on the initial distribution of information. The proposed model (CONSTRUCT) takes as its initial starting condition a description of a society in terms of its structural and cultural differentiation, and applies these three forces in order to predict what will happen in this society if factors such as population changes and new discoveries do not intervene.

Ultimate Behavior

The proposed model (CONSTRUCT) can also be represented as a Markov model where each state is a complete specification of who knows which facts. The number of states in such a model is 2^{IK} since there are IK individual-fact pairs and each can take on two values (0 or 1). For extremely small numbers of people and facts (e.g., two people and two facts) it is possible to analytically determine the configuration of the perfectly stable society and the rate at which the "society" converges to such perfect stability. The perfectly stable society is defined as one in which there will be no change in either the probabilities of interaction or in who knows what. Formulating the model as a Markov model is instructive as it illustrates the ultimate relationship between interaction, social structure, and knowledge.

Let us consider the case when there are only two people in the society and two facts, hence 16 states (Figure 1). In the two-person two-fact case, you will always end up with a perfectly stable society. Which stable social configuration emerges, however, is determined by the initial distribution of information across

Figure 1. In a Fully-Connected Society Everyone Ends Up Knowing Everything that Anyone Knows



Note: This is a Markov representation of a society with two people and two facts. Each possible social configuration (that is a state) is represented by a circle. The numbers within the circle indicate who knows what; that is, the rows are the people and the columns the facts. Thus state L is the society where the first person knows the first fact and the second person knows both facts. The corresponding transition matrix for the connected states is shown in the lower right corner. Individuals are connected if they share at least one fact. In those societies where the individuals are connected (top box) both individuals end up knowing everything that either of them know.

individuals.[5] For example, if the individuals share even one fact they will end up sharing all the facts that either knows; whereas, if they share no facts, they will never interact and never share facts.

In order to generalize the findings from the two-person two-fact society it is necessary to consider groups. Regardless of the way in which groups are defined, each group will have both intra- and inter-group interaction probabilities. We define the intragroup interaction probability to be the average probability of interaction across all pairs of individuals in the group, not counting self interaction. Similarly we define the intergroup interaction probability to be the average probability of interaction across all pairs of individuals, such that one individual is in one group and the other individual is in the other group. Within the boundary of CONSTRUCT, two groups are recognizable as distinct groups only if the distribution of information in the groups is not identical. Two groups will be said to be disconnected if no two members, one in each group, share even one fact. In this case, and only in this case, the intergroup interaction probability is zero. In contrast, I will refer to any two individuals or groups that have a non-zero likelihood of interacting as being connected. We can imagine a society in which there are no disconnected groups (regardless of size). Such a society will be referred to as a fully-connected society. A fully-connected society (or group) exists, just in case, for any two people in that society (or group): (a) they share at least one fact, or (b) they are connected by a chain of individuals such that each dyad along the chain shares at least one fact.

CONSTRUCT is essentially a model of increasing social and cultural solidarity. This follows from the fact that since for any two individuals who share even one fact they both come to share all facts that either knows (as was seen in the two-person two-fact case), within the fully-connected group all individuals will share everything that anyone knows. Thus, given the assumptions of this very spare model, eventually, every society will become, not only stable, but static. Further, this limiting stable configuration will be characterized by; (a) one or more groups—that will endure indefinitely; (b) segmented social structures—if there is more than one group all groups will be disconnected; (c) local social homogeneity—all individuals within a group are equally likely to interact with all other group members; (d) local cultural homogeneity—all group members will know exactly the same information; and (e) pockets of expertise (cultural specialization)—each group will have a distinct culture to the extent that no facts are shared between groups.

Simulation

The applicability of the ensuing analysis is increased if we can examine realistically sized groups and produce quantitative predictions. A Markov analysis, such as that done for the two-person two-fact case, can not be done with current matrix techniques for more complex societies given the size and degenerate nature of the transition matrix and current computational limits.[6] In addition, this model can not be solved analytically in its difference equation form. One reason for this is that the model contains discontinuous functions. Another, is that the model is a first order non-linear difference equation. In general only a few select first order non-linear difference equations can be solved—those in which a transformation of variables can convert the non-linear equation into a linear equation (Mickens 1987). For the model presented in this paper, no such transformation of variables is apparent. Therefore, in order to investigate the behavior of reasonable size groups it is necessary to turn to simulation.

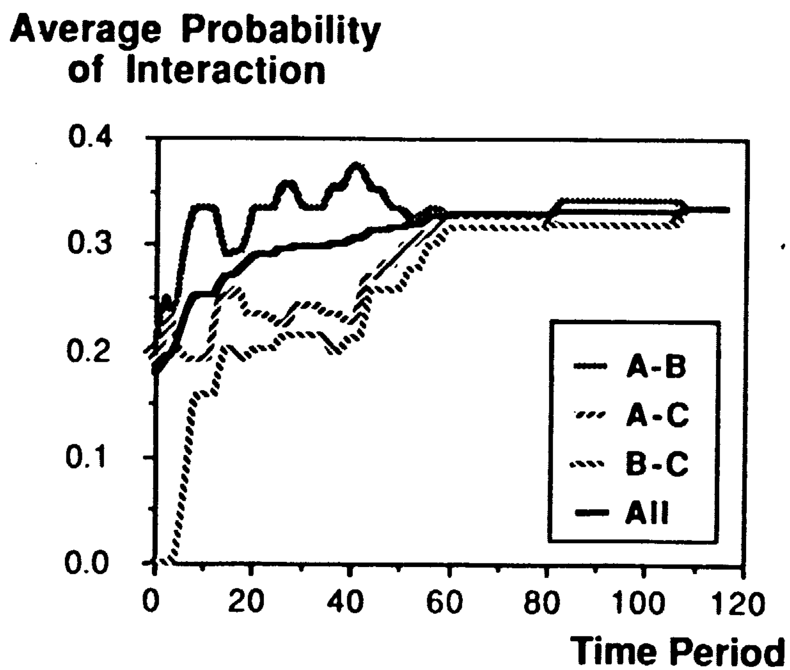
Simulation does offer a number of advantages to the researcher. First, we can use simulation to emulate the behavior of individuals and predict over time behavior. For example, when analyzing over time data (as in this paper) the simulation program can be given as its starting value the actual real world data at time 1 and can be used to predict data at time 2. Second, to the extent that such predictions are accurate, we can use the simulation to do hypothetical "what if" analyses. For example, we can use the simulation program to examine alternate hypothetical societies to see what differences in such societies might be necessary to get a different outcome than that perceived in the real data. The value of such an exercise, is not that it proves why the group or society changed as it did, but that such an exercise provides a way of reasoning about the situation, and enables the researcher to create more informed hypotheses that can then be empirically tested. In sociology, as we move to dynamic models with feedback we will find that they capture more of the social situation, but that it is incredibly difficult for the researcher to think through, without mistakes, the implications of such models. Simulation becomes a tool for increasing the specificity of theory, thinking through the theoretical implications, and generating testable predictions.

SOCIAL CHANGE AND STABILITY: GENERAL CONSIDERATIONS

Perfect stability, where social structure and culture are completely homogeneous, according to the proposed model occurs eventually in any society that is fully connected. Of course, if we think in terms of the histories of real societies this "eventual perfect homogeneity" becomes an ideal that may never be reached. Thus, we will now explore the implications of the model for the histories of individuals and groups within the society as the society progresses to this eventual perfect social and cultural homogeneity.

Let us consider a society in which there is a single fully-connected group. Some examples of such "societies" might be small religious sects or project groups in companies or research groups in science. In such societies the individuals are fully-connected as they at least share the information that they are members of the group. In such a society (see Figure 2) the average interaction probability within the group will monotonically increase to its equilibrium value—1/*I* (in which case, all individuals will be equally likely to interact with each other). The trend toward solidarity is an "average" trend that at a particular point in time may not be observable if we look at particular individuals. The probability that any two individuals will interact may oscillate making the individuals much more

Figure 2. Despite Overall Trend to Solidarity, Pairs of Individuals May Overtime Be More Likely, then Less Likely, then More Likely to Interact



Note: The history of a one-group society is portrayed by charting over time the intragroup interaction probability (bold solid line) for that group. The history of each dyad within that group is portrayed by charting over time their average proability of interaction (dashed lines). Notice that the group, as a collective, is monotonically approaching perfect stability (bold solid line) even though for each dyad (dashed lines) the approach is not monotonic. At perfect stability, interaction equilibrates and so each individual spends a third of his or her time interacting with each other individual.

This picture portrays the history of a single illustrative society. The behavior of this society is not unique. When 1000 other one-group societies were simulated all exhibited similar patterns. These alternate societies differed from the society illustrated, in the number of peaks and valleys per dyad, the location of these over time, and the time it took to reach perfect stability. The particular society portrayed is composed of 3 people (A,B and C). For this society there was a total of 15 facts. These facts are distributed such that each individual has 3 facts that he or she alone knows, AB share 3 additional facts, and AC share 3 additional facts. This distribution of facts means that initially, as in an imbalanced Heiderian triad, A interacts with B and A interacts with C but B and C do not interact. Through the gradual exchange of information, the triad balances; but, in this process AC and/or AB may move somewhat apart.

likely to interact with each other or much less likely to interact with each other than they will be once the society reaches perfect stability. Despite such oscillation in the individuals' behaviors the overall trend toward solidarity is maintained in part because the population is constant (that is, people do not enter and leave the society).

In such a society, the complexity of the culture (number of facts) and the cultural homogeneity (percentage of shared facts) and not the size of the population will affect the rate at which they reach perfect stability and hence social and cultural homogeneity (see Table 1). A set of such fully-connected one-group societies were examined which differed in their cultural homogeneity (percent of facts shared was 6.3%, 25%, or 56.3%),[7] cultural complexity (number of facts was 40, 60, or 80), and size of population (number of people was 10, 20, or 40).

Table 1. Societies Reach Stability Sooner, Regardless of Size, If Their Cultures are Less Complex and More Homogeneous

Number of People	10	20	40
Cultural Complexity			
Number of Facts = 40			
Cultural Homogeneity			
6.3% shared	372	341	335
25.0% shared	313	298	317
56.3% shared	248	262	285
Number of Facts = 60			
Cultural Homogeneity			
6.3% shared	593	540	541
25.0% shared	475	491	494
56.3% shared	415	423	459
Number of Facts = 80			
Cultural Homogeneity			
6.3% shared	785	721	727
25.0% shared	690	653	679
56.3% shared	589	589	629

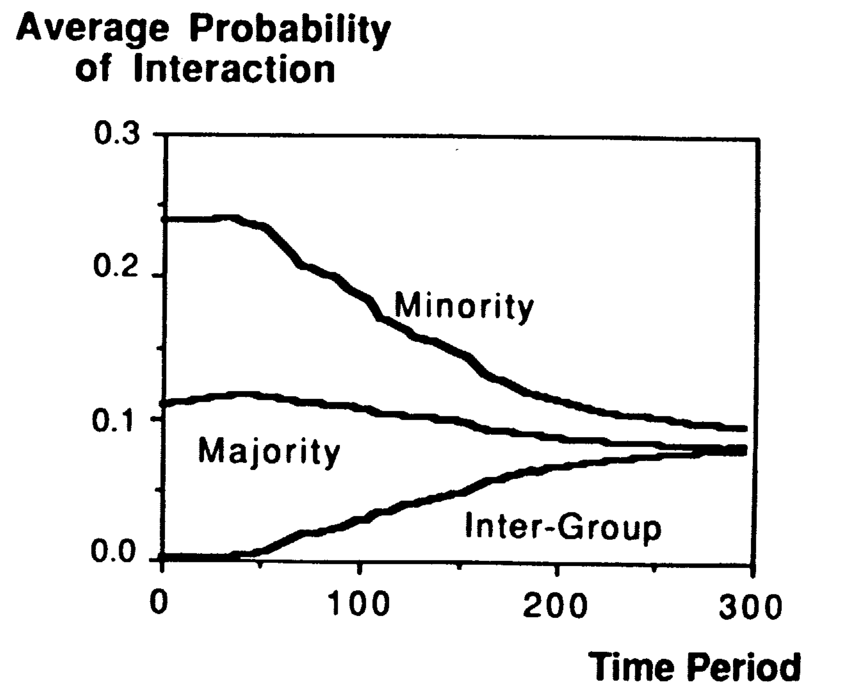
Note:
These numbers are the average number of time periods until perfect stability is reached based on 100 societies with these characteristics. Lower numbers indicate that the society reaches perfect stability sooner. The difference in times for societies of the same size, but different numbers of facts are significant at the .95 level. The difference in times for societies with the same number of facts, but different numbers of people are often not significant at the .95 level. When the number of facts is 40 the standard deviation ranges from 5 to 7. When the number of facts is 60 the standard deviation ranges from 8 to 12. When the number of facts is 80 the standard deviation ranges from 9 to 15.

Using a Monte Carlo approach each society was simulated 100 times.[8] The behavior of the individuals in these societies was simulated until within a society everyone knew everything that anyone did. The number of time periods until such perfect stability was reached was recorded and averaged across the 100 simulations. Results are presented in Table 1. The stability of these societies does not vary systematically with population. Irrespective of size, the less complex the culture, the greater the level of cultural homogeneity, the faster the society approaches this state of perfect stability.

Now let us consider a fully-connected society in which there are two groups. Let us consider the case where the minority has an area of specialization that makes it unique from the majority. Some examples of such societies might be laity and clergy in a religion, the general public and politicians, and workers and managers in a factory. The model predicts an overall trend in which such cultural specialization and group differences eventually disappear if even one member of one group shares even one fact with a member of the other group. In such a two-group society, eventually, everyone will know everything that anyone knows, all individuals regardless of group affiliation will be equally likely to interact, and the groups will no longer be specialized in terms of knowledge (see Figure 3). The eventual merger of all groups is an "average" trend, that at a particular point in time may not be observable. For example, at a particular time the level of intra-group interaction may be increasing and the level of inter-group interaction may be decreasing thus "hiding" the overall trend toward solidarity and cohesion. As with the one-group society the overall trend toward solidarity is in this model due, at least in part, to the assumption that the population is constant.

In such a society, the cultural homogeneity of the minority (percentage of shared facts) and and it's size relative to the majority will determine how long the minority is able to endure as a distinct group and maintain its cultural specialization (see Table 2). A set of societies was examined, with societies varying in the cultural homogeneity of the minority (percent of facts shared), and the size of the minority (and hence overall size). These differentials in knowledge and size, effected initial differentials in inter- and intra-group interaction levels. Initially, the intragroup interaction probability for both groups was greater than the intergroup interaction probability. The majority was composed of 40 people, and the minority of either 3, 10 or 20 people. Each member of the majority initially knew 20% of the 40 "majority" facts. In addition, the minority had an extra 10 facts that were special to them of which each member of the minority initially knew 50%, 75%, or 100% of the 10 facts, and each member of the minority initially knew 10% of the "majority" facts. We will say that the groups stop being distinct when the minority's intragroup interaction probability equals its intergroup interaction probability; that is, the groups are no longer distinct if members of the minority are as likely to interact with a member of the majority as with another member of the minority. Using a Monte Carlo approach each society was simulated 100 times. The behavior of the individual's in these societies was simulated

Figure 3. Two Groups May Grow Apart Before Merging Into A Single Group



Note: The history of a two-group society is portrayed by charting over time the intragroup interaction probability for the minority (top line) and majority (middle line) and the intergroup interaction probability (bottom line). In this example, both groups initially become more cohesive (that is, the intra-group interaction probabilities increase). Later, and only gradually, as the level of inter-group interaction increases the intra-group interaction decreases. Despite the gradual move to overall solidarity the two groups maintain their distinct identities (lines do not cross). Prior to their merger the groups grow apart (peak in intra-) and together (valley in intra-) multiple times. Although, for this society, such shifts are minor compared to the overall trend.

This picture portrays the history of a single illustrative society. The behavior of this society is not unique. When 1000 other societies were simulated all exhibited an oscillatory approach to stability; although, the degree of oscillation differed by society. These other societies differed from the society illustrated, in the number of peaks and valleys, the location of these over time, and the rate of convergence to a single group. The particular society portrayed is composed of 12 people with 8 people the majority and 4 in the minority. For this society there was a total of 150 facts. Members of the minority knew 90% of the first 75 facts and 1.5% of the second 75 facts. Members of the majority knew 50% of the second 75 facts and none of the first 75 facts. Thus, in this society there is a highly homogeneous minority, a relatively heterogeneous minority, with little initial cultural overlap.

until the groups stopped being distinct. The number of time periods until group distinction was lost was recorded and averaged across the 100 simulations. Results are presented in Table 2. The greater the difference in the size of the groups (the smaller the minority relative to the majority) and the more culturally homogeneous the minority relative to the majority the more stable the distinctiveness of the two groups.

Table 2. Smaller More Homogeneous Minorities Endure Longer

Minority's Homogeneity	25%	56%	81%	100%
Ratio of Group Size				
40 : 3	140.49	291.53	354.62	358.75
	(11.09)	(11.01)	(9.32)	(12.62)
40 : 6	158.94	254.10	295.21	291.14
	(9.34)	(8.69)	(9.95)	(8.48)
40 : 10	172.47	233.15	246.49	244.88
	(8.36)	(8.44)	(8.73)	(8.53)

Note:
These numbers are the average number of time periods until the members of the minority are as likely to interact with members of the majority as with each other for 100 societies with these characteristics (standard deviation of the means are given in parenthesis). Lower numbers indicate that the society, as a whole, is more stable, i.e. that it reaches perfect stability sooner. Higher numbers indicate that the minority endures as a distinct entity longer and hence is more stable. All numbers are significantly different at the .95 level except for those in column 1.

In the foregoing discussion we explored the implications of the model for long term group stability. Real societies, however, rarely if ever achieve such stability before factors such as population change or new discoveries are made. Therefore, let us now turn our attention to determining how well the proposed model can predict short term change in a *real society*.

A TAILOR SHOP IN ZAMBIA

Between May 1965 and March 1966 Kapferer carried out extensive fieldwork on the social relationships between African workers at Narayan Bros. a clothing factory in Kabwe, Zambia. This study resulted in a rich and highly detailed account of African urban and work life during a historical period in which there was great political and social upheaval. As noted by Kapferer,

> Zambia had just thrown off the shackles of colonial rule. It had its first independent African government and numerous reforms beneficial to African interests were either in progress or were being mooted. All sections of the population, African, European, and Indian, were in the process of re-defining their relationships with each other and amongst themselves. Europeans, no longer in control of the government, had to establish new relationships and modify their behavior accordingly. African workers full of high expectations now felt their position as regards their employer sufficiently strengthened to press all the harder for wage increases, improved working conditions, and jobs previously the preserve of Europeans. But African political party leaders in ministerial and civil service posts were now often required to act in a manner contrary to the high expectations of those with whom they were united in pre-independence days.

Narayan Bros. is an Indian owned clothing factory Kabwe, Zambia employing African workers. The workers are highly heterogeneous, and are for the most part migrants to the city from different tribes. Whereas, the owners form a highly homogeneous group consisting of 4 Indians, all Hindu, all born in India, all living in the city center, and all part of the socio-economic elite. One of the owners, Patel, served as the factory manager.

Kapferer observed interactions among workers in the tailor shop over a ten month period June 1965 through January 1966 during which the workers were engaged in extended discussions for higher wages. After Kapferer's time 1 (June 1965 through August 1965) an abortive strike (a walkout by senior workers) occurred and after his time 2 (September 1965 through January 1966) a successful strike (in which all workers were united) occurred. Two types of interactions were recorded "instrumental" (lending or giving money or assistance) and "sociational" (general conversation, gossip, and sharing a drink). All interactions required for work purposes were not recorded. Although Kapferer recorded all "voluntary" interactions he presents this data in a collapsed form such that for each time period an interaction of each type is either "present" (if the dyad frequently interacted) or "not present". The "instrumental" ties can be asymmetric, whereas the "sociational" ties are symmetric. This tie data for the 39 workers who were present during both periods of observation is available through UCINET (MacEvoy and Freeman 1988). Turnover was relatively high. Kapferer lists 60 employees in Appendix 1, of which only 39 are listed in his "interaction" matricies (ch. 5) as present in both time periods. In the following analysis we will consider only these 39 people.

Modeling the Tailor Shop

According to CONSTRUCT, the future histories of groups can be projected by tracing simultaneously the changes that occur in the cognitions (knowledge) of all the individuals in the society (and hence their cultural and social position) from their initial position. The initial position of all individuals can be determined from either the social structure or the culture. Although, predictions from the culture should be more accurate as there are multiple distributions of information across the population that will give the same distribution of interaction probabilities. Kapferer's interaction data is representative of the social structure. Thus, his first set of observations can be used to define the individuals' initial positions. This data is not ideal for the purpose at hand as Kapferer did not denote the frequency of interaction, nor did he include all exchanges outside of the workplace and non-voluntary exchanges, and he only included those interaction that were in his opinion frequent. Nevertheless, Kapferer's data is representative of the social structure within the clothing factory and the data from his first set of observations can be recoded and given to CONSTRUCT as the initial conditions. CONSTRUCT can then be used to simulate the behavior of these workers.

In order to examine the change in interaction among the workers using CONSTRUCT it was necessary to recode the data. A single interaction matrix for each time period was created using the following procedure. First, since, according to the constructural theory each individual during an interaction has the opportunity to learn a fact from the other, all actual interactions are treated as symmetric. To reflect this the "instrumental" matricies were symmetricized such that for each dyad there was a tie between them just in case either of them had a tie with the other. Second, for each time period, the "instrumental" and "sociational" matricies were added. This was done as the constructural theory does not differentiate between types of interactions, but instead focuses on the overall frequency of interaction. Further, since there is no reason to assume that "sociational" or "instrumental" ties represent more frequent interactions, a simple addition model was used. Third, it was necessary to construct a value for self interaction as the constructural theory argues that behavior is a function of position relative to everyone, including one's self. The assumption made here, that there is a fixed limit on how much the individual can interact (that is the same for all individuals), seems most in keeping with the data collected by Kapferer (as it retains individuals with few interactions as being "loners" and individuals with many interactions as being "socially active") and most in keeping with reality (there are after all a fixed number of hours to interact and the more individuals there are the lower the "random chance" of interacting with any one individual). This fixed limit was set to 78—the number of possible interaction ties between dyads 2, times the number of people, 39. This limit enabled each individual to have both an instrumental and a sociational tie with each other individual (including self). Thus, the initial probability of interaction between each dyad was set equal to the number of interaction ties between them divided by 78, and the probability of interaction with self was set to $1 - \sum_{j=1, i \neq j}^{39} P_{ij}(t)$. And finally, since in the proposed model interaction changes as a function of changes in knowledge it was necessary to construct a knowledge matrix that corresponded to the observed interaction data (see Appendix 3 for details). The procedure used reproduced exactly for each dyad the interaction ties observed by Kapferer at time 1 (as recoded) and the additional interaction ties with self (as defined above). There are several procedures that could have been used to generate the knowledge base. The procedure chosen modeled the society as maximally culturally heterogeneous by essentially giving each dyad a shared fact for each interaction tie at time 1. The maximally heterogeneous assumption was made because Kapferer in describing the workers described them as highly heterogeneous, coming as they did from different tribes, and differing in their skills, ages, marital status, political status, educational level, length of time on the job, etc.

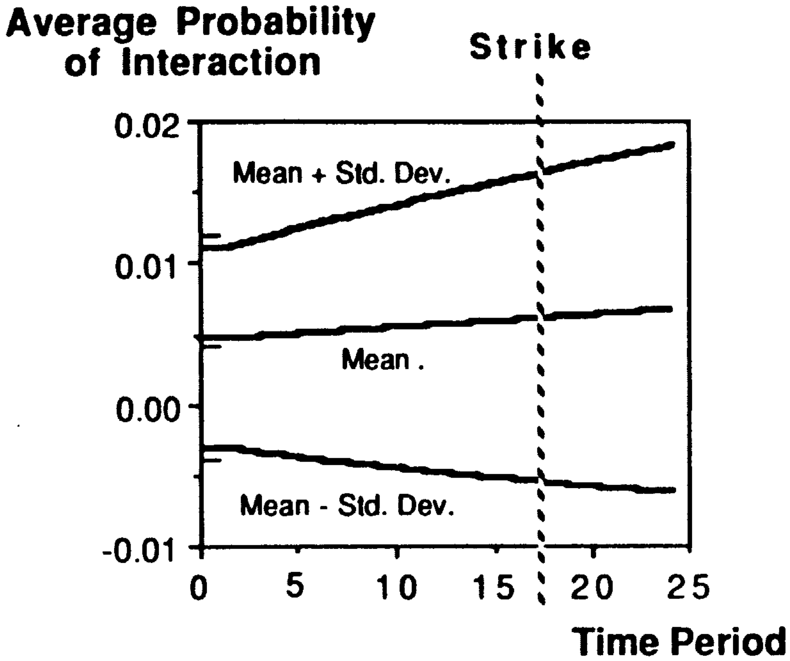
Expectations for Future Interaction

Given Kapferer's time 1 interaction data as its starting condition CONSTRUCT was used to simulate the workers' behavior. A single simulation ran for 25 time periods. This length of run was chosen as sample runs indicated that this number of time periods was sufficient to include that time period at which the simulated average interaction probability exceeded the observed average probability of interaction at time 2 (0.005502). Recall that the average probability of interaction increases monotonically to the equilibrium value of $1/I$. Thus, this point occurs only once. The strike is defined as occurring immediately before that time period at which the predicted average probability of interaction first exceeds the actual average probability of interaction at the time of the strike. Taking a Monte Carlo approach 30 different simulations were run. That is, the interaction and exchange of information among Kapferer's workers over the 7 month period was emulated 30 different times. This approach was taken in order to provide better estimates of who was likely to actually interact with whom. The results from these runs, per time period, were averaged to produce a single composite probability of interaction between each dyad (directed). The average behavior at each time period across all 39 workers based on these composite values is displayed in Figure 4.

The average probability of interaction is predicted to first exceed that observed by Kapferer at the time of the strike at time period 18. Thus the strike is marked at occurring at time period 17. No claim is being made that a certain number of simulated time periods correspond to a certain number of actual time periods. For example, marking the strike at time period 17 should not be interpreted as saying that in every society simulated, 1 simulation time period equals 7/17th's of a month. Rather, it should simply be interpreted as saying that the data at this time period are those that will be used to predict the data observed by Kapferer at time 2.

Constructural theory, as embodied in the proposed model, given Kapferer's interaction data as a starting condition, predicts an increase in interaction overall (increase in average probability of interaction), and a decrease in homogeneity (decrease in standard deviation in the interaction probabilities) (Figure 4). Kapferer observed an increase in interaction and a corresponding decrease in homogeneity (see Table 3). The number of "interactions" (measured as either an instrumental or a sociational tie) rose from 350 to 496 which is a percentage increase of 42%. Looked at in terms of the recoded interaction probabilities there is an increase from an average interaction probability of .004048 to .005502 (which is a mean difference of .001403 wi h a standard deviation of .000230).[9] The decrease in homogeneity is seen in the standard deviation of the average interaction probabilities increasing from .007 to .008. Thus, CONSTRUCT is able to predict the general overall trends that Kapferer observed.

Figure 4. In the Tailor Shop Interaction Should Increase but Homogeneity Decrease



Note: CONSTRUCT predicts that the average probability of interaction among workers in the tailor shop (bold line) should increase over time. And, the homogeneity of the society should decrease (that is, the standard deviation should increase). These predictions are derived by taking Kapferer's observed interaction data at time 1, using it as the starting condition for the simulation program, and then using the simulation program to predict what changes will occur among these workers over time. All lines represent the average value across 30 simulation runs and the 39 workers. On the horizontal axis (time period) the time 0 is the end of Kapferer's time 1. The time of the strike (end of time period 2) is marked on this axis as the last time period in which the predicted average probability of interaction was less than that observed by Kapferer at time 2 (0.005502). This occurs at time period 17. Since the average probability of interaction increases monotonically to its equilibrium value the strike point occurs only once.

Alternate Models

Now let us examine how well the proposed model (CONSTRUCT) fits the observed data on a dyad by dyad basis. This will be done by contrasting the "fit" of the constructural model with competing models. The competing models are the "no-change" model, the "random" model, Kapferer's exchange model (Kapferer 1972), and the Heiderian balance model (Heider 1958). How well these various models fit the data will be examined in two ways—correlating the predicted interaction probabilities with the actual, and calculating the percentage of "interactions" at time 2 that are correctly predicted.

Table 3. Kapferer Observed an Increase in Interaction

	Time 1	*Time 2*	*Difference*
Number of Interactions	350	496	146
Percentage	23.62%	33.47%	41.71%*
Interaction Probability Mean	0.004048	0.005502	0.001453
Standard Deviation	0.007857	0.008448	0.000230**

Notes:
Only the 1482 non-diagonal cells are used.
*This is the percentage increase from time 1 to time 2.
**This standard deviation is an estimator of the difference in means for the population taking into account their covariance. The difference in means, $\bar{x} - \bar{y}$, is assumed to be distributed $N(\mu_x - \mu_y, \sigma_x^2/n + \sigma_y^2/n - 2\rho\sigma_x\sigma_y/n)$.

No-Change: According to this model individuals who were interacting keep interacting and those that were not interacting continue not interacting.

Calculating predicted interaction probabilities: The probability that one individual interacts with another at time 2 is predicted to be the probability of interaction as recoded from Kapferer's data at time 1.

Calculating predicted interactions: Under this model the expected "interactions" at time 2 are exactly those present at time 1. Therefore, the dyads are said to:

- continue interacting—If Kapferer observed them interacting at time 1.
- begin interacting—By definition this can not occur under this model.
- stop interacting—By definition this can not occur under this model.
- never interact—If Kapferer did not observe them interacting at time 1.

Random: According to this model all individuals are equally likely to interact and the proportion of individuals who do interact is determined by exogenous factors. Under this model the number of interactions will be defined to be the number observed by Kapferer—496.

Calculating predicted interaction probabilities: The probability that one individual interacts with another at time 2 is predicted to be the proportion of interactions observed by Kapferer at time 2; that is, 496/1482 or .3346828.

Calculating predicted interactions: At time 2 approximately one third of all dyads will be interacting irrespective of what Kapferer observed them doing at time 1.

Kapferer's Exchange Model: In explaining the observed change in interaction Kapferer (1972, see ch. 5) relied on social exchange theory largely as it was described by Blau (1967). To this he added the idea that individuals were risk averse in selecting interaction partners. And, that relationships that were imbalanced in power were more stable over time (p. 203). The workers were divided into 7 categories on the basis of the job that they performed and their senority: supervisors, line 1 tailors, line 2 tailors, line 3 tailors, buttoners, ironers, and cotton boys. These jobs differ in their associated power and status, with supervisors and line 1 tailors being the most powerful and ironers and cotton boys the least. According to Kapferer exchange theory predicts: (1) an increase in interaction between the senior (supervisors and line 1) and the junior or unskilled workers (ironers and cotton boys) (pp. 200–201), (2) an increase in interaction between the supervisors and everyone (p. 193) with the strongest increase in interaction between supervisors and line 1 tailors (pp. 193–198), (3) increased interaction among line 1 tailors (p. 200), (4) and a decrease in interaction between line 1 tailors and those others bidding for power (Lyashi) (p. 200). To this he adds that there will be a decrease in interaction between individuals engaged in balanced interactions (p. 203). Although never explicitly stated, it is implied that the exchange process is more powerful than the balance process, thus one would expect that this decrease in interaction is true only for non-senior personnel. Kapferer used these ideas to explain the general pattern that he observed and the interaction behavior of specific individuals. Although, he did not analytically implement these ideas and empirically test his predictions, it can be done. Herein, these ideas are implemented using the following conventions.

Calculating predicted interactions:

- continue interacting—If the individuals as recorded by Kapferer were interacting at time 1 and they had different jobs (imbalanced relation) or they were both senior (supervisors or line 1).[10] Continued interaction ties retained their original value (2 or 1).
- begin interacting—If the two individuals as recorded by Kapferer were not interacting at time 1, but one of the two was senior and the other junior, or one of the two was a supervisor. Beginning interaction ties were a 2 if between supervisors and line 1 tailors and 1 otherwise.
- stop interacting—If the two individuals as recorded by Kapferer were interacting at time 1 and had the same job (balanced relation) and neither was senior. Or, if the two individuals were interacting, one was bidding for power (Lyashi) and the other was a line 1 tailor.
- never interact—If the two individuals as recorded by Kapferer were not interacting with each other at time 1 and did not begin interacting.

Calculating predicted interaction probabilities: Interaction probabilities were calculated, based on the interaction data created in the foregoing procedure, using the same procedure that was applied to Kapferer's data.

Heiderian Balance: According to this model two individuals will interact at a later time if they are both, at time 1, interacting with the same third partner (the mutual friend). Kapferer recorded only interaction and not whether the interactions were "positive" or "negative". Consequently, without further assumptions, the full scope of Heiderian balance can not be incorporated, and we can only use balance theory to look at increases in interaction.

Calculating predicted interactions: The balance model was implemented by creating a prediction for who interacts with whom at time 2 as follows:

- continue interacting—If the individuals as recorded by Kapferer were interacting at time 1 they continued to interact. Continued interaction ties retain their original value, 2 or 1.
- begin interacting—If the two individuals as recorded by Kapferer both interacted with the same third person (either instrumental, sociational, or both) but not with each other at time 1 then they are said to be interacting at time 2. All beginning interaction ties are coded as a 1.
- stop interacting—By definition this can not occur under this model.
- never interact—If the two individuals as recorded by Kapferer were neither interacting with each other at time 1 nor with a mutual friend then at time 2 they are said to be not interacting.

Calculating predicted interaction probabilities: Interaction probabilities were calculated, based on the interaction data created in the foregoing procedure, using the same procedure that was applied to Kapferer's data.

CONSTRUCT (The Proposed Model): In contrast to these three models, under the proposed model (CONSTRUCT) the probability that two individuals interact increases or decreases gradually as they exchange information. In a sense, CONSTRUCT can be thought of as a kind of balance mechanism occurring at the micro level. Consider the following example with four individuals—Aaron, Zebadiah, Deety, and Hilda—such that Aaron and Deety both share Zebadiah and Hilda as mutual friends but don't interact with each other. Eventually, either Zebadiah or Hilda will tell either Aaron or Deety something that makes Aaron and Deety more similar to each other and to Zebadiah or Hilda. In the long run, this process will lead all four individuals to being equally likely to interact—as one would expect from balance theory. In the short run, however, an increase in the interaction probability between any two individuals may decrease their interaction probabilities with others. In order to generate predicted data on who interacts with whom the following procedure was used.

Calculating predicted interaction probabilities: The probability of interaction for each dyad for each time period was averaged across the 30 simulations to produce a single "probability" for that dyad for that time period. Next the time period was chosen where the average of these probabilities across the entire society was the closest to, but did not exceed, the average observed by Kapferer at time 2 (0.005502). The averaged interaction probabilities from this time period are the predicted interaction probabilities.

Calculating predicted interactions: Based on these probabilities, individuals are said to:

- continue interacting—If the individuals as recorded by Kapferer were interacting at time 1 and if their predicted probability of interaction increases or at least does not decrease by more than 0.0005.
- begin interacting—If the individuals as recorded by Kapferer were not interacting at time 1 and if their predicted probability of interaction is greater than 0.0005. This value represents 1/25 of the minimal interaction probability derivable from the Kapferer data.
- stop interacting—If the individuals as recorded by Kapferer were interacting at time 1 but their predicted probability of interaction is less than their time 1 probability of interaction minus 0.0005.
- never interact—If the individuals as recorded by Kapferer were not interacting at time 1 and their predicted probability of interaction is less than or equal to 0.0005.

Results: The results of these alternate models are shown in Table 4. The prediction generated by the random model predicts that 33% of the dyads will interact, this leads the model to correctly predict 56% of the dyads' behaviors. Unlike the other models, the random model is the best at predicting which pairs of individuals stop interacting. The no-change model correctly predicts the most interaction ties (73%); but, this is because most individuals do not change with whom they are or are not interacting. Thus, 73% of the behavior, although perhaps the least interesting part, is accounted for by the no-change model. In contrast, the Heiderian balance model best predicts which dyads start interacting; but, it does so at the cost of over-predicting interaction. Thus, although the balance model does the best at predicting those people who begin interacting it

Table 4. Ability of Different Models to Predict Interaction Ties

Interaction	*R*	*never*	*continue*	*begin*	*stop*	*Total*
MODEL						
Random	.000	**572**	**74**	**91**	**85**	**822**
		67%	33%	33%	67%	56%
Kapferer's Exchange	.225	**632**	**168**	**108**	**4**	**912**
		74%	76%	39%	3%	62%
Heiderian Balance	.339	**224**	**222**	**242**	**0**	**688**
		26%	100%	88%	0%	46%
No-Change	.413	**858**	**222**	**0**	**0**	**1080**
		100%	100%	0%	0%	73%
CONSTRUCT	.422	**662**	**215**	**140**	**1**	**1018**
		77%	97%	51%	1%	69%
Number of Observed Interaction Ties		**858**	**222**	**274**	**128**	**1482**

Note:
Each cell contains the number of interaction ties in that category correctly predicted using that model. Column percentages are indicated below each number. In calculating presence or absence of interaction ties no account is taken of their value (2 or 1). The tie value is only accounted for when looking at the overall correlation (R) between predicted and actual interaction. Interactions with self are not included in this analysis.

does the worst at predicting those people who never interact. Both Kapferer's exchange model and CONSTRUCT have the right "pattern" in their interaction predictions. Kapferer's exchange model, however, does only slightly better than the random model at predicting who starts to interact and like the random model it underpredicts who will continue to interact. CONSTRUCT, however, outperforms the exchange model except at predicting who stops interacting. In this case, Kapferer's model does only slightly better, accounting for 3% of the stop interaction ties. In contrast to all other models examined we see that CONSTRUCT does quite well: (1) the overall correlation is the highest (that is, it does the best at predicting where the 2's as opposed to 1's and 0's will be); (2) the pattern of predicted interactions is closer to "correct"; and (3) the 69% of all interactions are correctly predicted.

Like all models, except the random model, CONSTRUCT has difficulty predicting who stops interacting. When 30 simulations are averaged there are only a few dyads for whom the predicted probability of interaction decreases from its original value by more than 0.0005. On individual runs more dyads exhibited a decrease in their interaction probability greater than the 0.0005 cutoff. Nevertheless, for Kapferer's data we must conclude that CONSTRUCT has difficulty predicting who "stops" interacting with whom. There are several reasons for this. First, there may be "errors" in the actual data; that is, the individuals may actually be interacting but at a level lower than that recorded by Kapferer. Second, in using CONSTRUCT to make the prediction it was necessary to create a "knowledge base" for each individual. In the absence of actual knowledge data, each individual was given knowledge such that their knowledge structure exactly replicated their interaction data. Individual differences in knowledge that might not have affected the interaction probabilities at time 1 may have been responsible for the observed changes. Yet, without data on such knowledge differences it becomes difficult to predict the decreases in interaction.

A STRIKE IN A TAILOR SHOP

On September 1, 1965 a walkout occurred (Kapferer 1972, ch. 7). Senior workers (supervisors and line 1 tailors) were predominantly involved; whereas the less senior workers refused to strike (cotton boys, ironers, and some of the line 2 and 3 tailors) on the grounds that they had more to lose and would gain nothing. Some worker demands were met, in particular senior workers received a pay increase. As noted by Kapferer (p. 273):

> Although the junior workers had not supported the strike, their fears had been upheld, and the fact that it was only the senior and more skilled workers who received increments emphasized the status differences in the factory.

Yet, five and a half months later, February 15, 1966, a full fledged strike occurred in which all workers participated. The question is *what changed?*

Kapferer's explanation rests on three concepts: increased unification, change in power and status of particular employees, and the resultant increased militancy toward management. He notes that (p. 60) "although towards the end of the fieldwork period [end of time 2] there was the development of a more clearly expressed polarization between the interests of management and workers, for much of the early period [time 1] all workers could not be seen as opposed to management." For Kapferer this increased polarization was the result of structural change (that is, change in who interacts with whom) and was intensified by Patel's withdrawel of certain transactions from the employees (such as tightening up the indulgency system). According to Kapferer (p.330), "The factory workers through the competition of some among them for power and leadership became bound together in a set of relationships which cross-cut divisions noticeable at an earlier period of the observations." Thus, according to Kapferer, the success of the second strike derived from the fact that there was increased interaction, and that this increase included an increase in interaction between senior and junior personnel. Further, according to Kapferer, this increase in interaction results from an exchange process in which the quest for leadership by a few workers and the counter attempts by other workers to maintain their status engender interaction between senior personnel (who can provide services) and junior personnel (who can provide support) as those are the dyads where exchange is profitable.

There are several difficulties with this analysis. First, it assumes that the active

quest for power and leadership and the desire to maintain or improve social status controls the increase in interaction. Yet, as we have seen, the systematic application of this exchange principle over predicts the amount of interaction that actually occurs. Second, it follows from Kapferer's argument that although there should be a general increase in interaction between the supervisors and all others, there will be a greater increase in interaction between the senior and junior workers than there will be within or between other groups. Yet, most of the "new interaction ties" (that is, pairs of individuals who start interacting at time 2) are between the senior and middle level groups and within the middle level group (see Table 5). And finally, this analysis does not explain why Patel chose to withdraw certain services at this point in time; that is, why there should be a change in management/worker interaction. Nor does this account explain why the increased interaction between workers should result in conflict with management. These deficiencies suggests that a different explanation is called for.

Like Kapferer's explanation, a constructural explanation looking only at the workers would begin with the changing pattern of interaction and suggest that the ability of the workers to mount a successful strike at time 2, and not time 1, resulted in part from structural change, specifically the rise in interaction. This rise in interaction is seen as part of the natural move toward solidarity that arises between individuals as they interact and come to share more knowledge. This analysis, by looking only at workers and not management, suffers the same fate as Kapferer's. That is, although the rise in interaction, and the increase in shared knowledge, suggest that collective action is possible due to the increased cohesiveness and similarity of interests, it is not sufficient to explain why the strike occurred when it did nor why there should be a change in response to manage-

Table 5. Number of Dyads Who Begin to Interact at Time 2 by Sub-Groups

	SENIOR	*MIDDLE*	*JUNIOR*
SENIOR (supervisors and line 1)	**48** 26%	**51** 21%	**17** 15%
MIDDLE (line 2, line 3, buttoners)		**52** 19%	**17** 13%
JUNIOR (ironers and cotton boys)			**4** 7%

Note:
The top number in each cell is the number of dyads, such that one worker was in the "row" group and the other was in the "column" group, who began interacting during time 2. The bottom number in each cell indicates that percentage the top number is of the total number of dyads in that cell. There are 14 senior workers, 17 middle level worker, and 8 junior workers.

ment. We can use the constructural perspective, however, to look at the change in interaction among the workers while taking into account their changing pattern of interaction with management. Yet, as will be seen, even once management is considered it will be necesseary to expand the model to incorporate notions of friendship and enmity in order more fully explain why a strike should occur at all.

The Case of the Missing Management

Over the course of Kapferer's investigation changes occurred in not only which workers interacted with which other workers, but also in the workers with which the management interacted. The management consists of 4 Indians, one of whom—Patel—serves as the actual manager within the factory building. Most of the interaction between workers and management occurred between the workers and Patel. During time 1, Patel primarily interacted with the supervisors using them to control and moderate the behavior of the other workers. By time 2 this pattern of behavior had changed. The goal in this section is to determine if by taking into account the interaction between management and workers at time 1, and using the CONSTRUCT model to predict change in the within versus between interaction levels for workers and management the constructural perspective can provide insight into why there was a change in worker manager interaction.

Modeling Worker Management Interaction

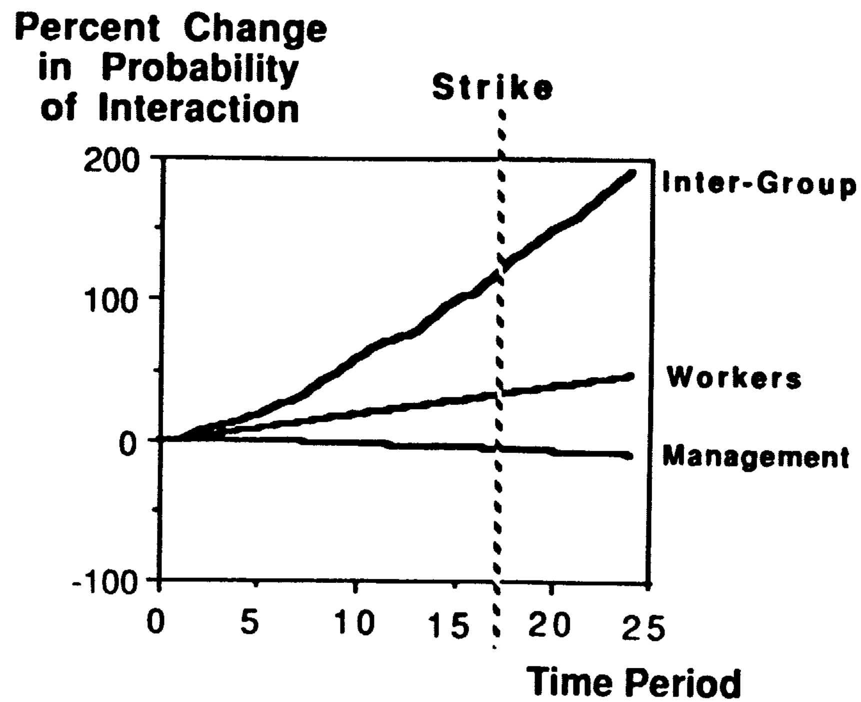
In coding interaction between management and workers I used only the events that occurred during time 1 as described by Kapferer in his Appendix 2. According to these events there was no direct interaction between workers and managers other than Patel, with the possible exception of an interchange during the discussions over the first aborted strike. Thus, only Patel is coded as interacting with the workers. Interaction between Patel and workers was defined as occurring if in Kapferer's appendix 2 it was mentioned that they interacted during time 1. The strength of the interaction is defined as the number of times that they interacted. (See Appendix 4 for details.) Based on Kapferer's description the management group was modeled as highly homogeneous (that is, sharing 20 facts). By adding this worker-manager and manager-manager interaction data to the worker-worker interaction data (used in the last section) we now have a starting state description for the entire factory and not just the workers.

Expectations for Future Interaction with Management

Given Kapferer's time 1 interaction data as its starting condition, CONSTRUCT was used to simulate the behavior of the workers. A single simulation ran for 25

time periods. Taking a Monte Carlo approach 30 different simulations were run. The average behavior within- and between-group behavior for workers and managers is displayed as a percentage change from the initial value in Figure 5. Constructural theory, as embodied in the proposed model, given the actual interaction data for both workers and managers as a starting condition, predicts an increase in interaction among workers, a decrease in interaction among management, and an increase in interaction between workers and managers. The greatest shift in interaction probabilities, as a percentage of the original, is between workers and managers.

Figure 5. The Greatest Shift in Interaction Should Occur Between Workers and Management



Note: CONSTRUCT predicts that the greatest shift in the average probability of interaction (measured as the percentage change in the average probability) should occur between workers and management. And that, while the average probability of interaction among workers, and between workers and management should increase; the average probability of interaction among managers should decrease. These predictions are derived by taking Kapferer's observed interaction data at time 1 for both the workers and the managers, using it as the starting condition for the simulation program, and then using the simulation program to predict what changes will occur among and between workers and managers by time 2. All lines represent the average value across 30 simulation runs. On the horizontal axis (time period) the time 0 is the end of Kapferer's time 1. The time of the strike (end of time period 2) is marked on this axis as the last time period in which the predicted average probability of interaction among the workers was less than that observed by Kapferer at time 2 (0.005502). This occurs at time period 17.

This suggests that it was not just the change in the structure of worker interactions, but it was also the change in the worker-management structure that enabled a successful strike. That is, the overall trend toward solidarity, in this particular society, led to an increased unification among the workers (which can be seen in the rise in intra-group interaction) and a rise in interaction between workers and managers. These 39 workers, by staying in the factory, are coming to have not only more shared knowledge with (and hence greater interaction with) other workers, but also with the management. Indeed, worker-management interaction is increasing much more rapidly than worker-worker interaction. This suggests, that although the average probability of interaction between management and workers is still low compared with intra-group interaction, the rapid rise in inter-group interaction increases the affective presence of management. In a political environment that is already filled with strife, such a shift might be the necessary catalyst for a strike. Such a speculation, however, goes beyond the CONSTRUCT model which simply predicts that there will be a rise in intra- and inter-group interaction for the workers. We observe, however, that this rise in interaction in the case of worker-worker exchanges led to unification and in the case of worker-management exchanges led to conflict. Thus, while the model can explain the changing response of workers to managers as a function of the overall solidarity tendency, it does not explain why in one case interaction led to unification and in the other to conflict.

Unity and Conflict—Friendship and Animosity

In order to examine the rise of unity and conflict, and hence the ability of the group to sustain a successful strike, it is necessary to augment the CONSTRUCT model with notions of friendship and enmity. Thus far in presenting the model the concern has been with interaction, knowledge, social structure, and culture. Yet, we observe that interactions differ, for example, while friendliness is exhibited in some interactions antagonism is exhibited in others. In looking at a historical situation it often becomes necessary to look at the potential for conflict, antagonism, friendship, or cooperation inherent in a situation. Thus, if we could link the CONSTRUCT model to such concepts we would be able to historically reconstruct a situation and locate possible underlying explanations for observed behavior.

In 1950 Homans, after inspecting the pattern of interactions between workers in the Bank Wiring Room and in other groups, postulated that interaction leads to friendliness (pp. 133–136): "the more frequently persons interact with one another, the stronger their sentiments of friendship for one another are apt to be." Levine (1989), in a recent statistical re-analysis of the Bank Wiring Data, found an empirical relationship not only between interaction and friendliness but also between interaction and antagonism.[11] Levine argued that friendship and enmity depended, at least in part, on the interactive distance between individuals. What

Levine found was that: the more frequently two individuals interacted the more likely they were to be friends; if two individuals had a moderate level of interaction they were more likely to exhibit enmity than if they had either a high or low level of interaction; and individuals who interacted infrequently were generally neither friends nor enemies.[12]

Modeling Friendship and Animosity

What Levine's analysis suggests, within the confines of this study, is that the probability for two individuals to be friends or enemies can be determined from the probability that they will interact. Specifically, one has the greatest probability to be friends with those with whom one is most likely to interact, and the greatest probability to be enemies with those with whom one is moderately likely to interact. The relationship between friendship/enmity and interaction probabilities is viewed simply as an empirical regularity. By looking at friendship and enmity in this way we are saying that friendship and enmity are not in themselves factors affecting change in interaction but are the result of interaction, and that as the probability of interaction changes between two individuals the probability that they will be friends or enemies changes. This is not saying that as an individual's probability of interacting with another increases they become first enemies and then friends. Rather, it is saying that, for whatever reasons one chooses others as friends or enemies (reasons that may go well beyond the proposed model), one will be more likely to choose as friends, at a particular time, those with whom one has a high probability of interaction and one will be more likely to choose as enemies, at a particular time, those with whom one has a medium probability of interaction. Whether such individuals actually become friends or enemies is beyond the scope of this model.

Rather than specifying particular functional forms for friendship and enmity probabilities, in this paper, an individual is said to consider another individual as a potential friend (or enemy) if his or her probability of interacting with the other is in a particular pre-defined range. Thus, for individual i, another individual j is a potential friend if $P_{ij}(t) > 0.0133333$ and a potential enemy if $0.0005128 < P_{ij}(t) \leq 0.0133333$. The friendship cutoff, 0.0133333, was chosen as it is equal to the cutoff for an interaction tie of strength 2, and the enmity cutoff, 0.0005128, was chosen as it is equal to the cutoff for an interaction tie of strength 1. In other words, applying these notions of friendship and antagonism to Kapferer's data, suggests that the individuals who are friends are more likely to engage in both sociational and instrumental ties, where as those who are enemies are more likely to engage in either sociational or instrumental ties. At the social level, as the number of potential friends increases relative to the number of potential enemies we will say that there is an increased potential for cooperation and unity. Whereas, as the number of potential enemies increases relative to the number of potential friends we will say that there is an increased potential for conflict.

Expectations for Future Unity and Conflict

In order to determine the potential shift in friendship and enmity the number of potential friends and enemies for each individual (among management or workers) using the cutoffs defined above were counted for both time 1 and 2. Then these values were summed across all the members in that group. For time 1 the initial interaction probabilities, including management, were used. For time 2 the predicted interaction probabilities (as predicted by CONSTRUCT) were used. In this case the interaction probabilities are for period 17 (the predicted time of the strike). The resultant number of dyads who are potential friends and enemies at the two different time periods are listed in Table 6.

In table 6 we see that the increase in interaction among workers is leading to an increase in the number of potential friends and enemies among the workers. Similarly, the increase in interaction between workers and managers is leading to an increase in the number of potential inter-group friends and enemies. For the workers, the increase in intra-group interaction is leading to a greater increase in friendship than enmity; whereas, the increase in inter-group interaction is leading

Table 6. Animosity Between Workers and Management is Increasing Rapidly

	Time 1 Actual	*Time 2 Predicted*	*Difference*
AMONG WORKERS			
Number of Potential Friendship Ties	124	322	198
Percentage of 1482	8.37%	32.73%	159.68%*
Number of Potential Enmity Ties	236	359	123
Percentage of 1482	15.92%	24.22%	52.12%*
AMONG MANAGERS			
Number of Potential Friendship Ties	12	12	0
Percentage of 12	100.00%	100.00%	0.00%*
Number of Potential Enmity Ties	0	0	0
Percentage of 12	0.00%	0.00%	0.00%*
BETWEEN WORKERS AND MANAGERS			
Number of Potential Friendship Ties	4	11	7
Percentage of 312	1.28%	3.53%	175.00%*
Number of Potential Enmity Ties	14	111	97
Percentage of 312	4.49%	35.58%	692.86%*

Notes:
The number of times is summed across all dyads in the group, thus if for both individuals the other was a potential friend/enemy that tie is counted twice.
*These numbers are the percentage change between time 1 and 2.

to a greater increase in enmity than friendship. This is due, in part, to the increase in interaction between workers resulting in an increased multiplexity of interaction ties. As observed by Kapferer (ch. 5) those workers who had previously engaged in instrumental ties with other wrokers began to engage in sociational ties and vice versa. In other words, for workers, the increase in the average probability of interaction among workers is due not just to more workers starting to interact but in workers who had previously interacted continuing to interact but at a higher level. Whereas, the increase in the average probability of interaction between workers and managers is due to new worker-management dyads beginning to interact. This last is seen, in part, in the shift in Patel's behavior from time 1 where he relied on, and interacted predominantly with the supervisors, to time 2 where he began to rely on other workers such as Chipata and Meshak (ch. 8).

In summary, the constructural perspective suggests the following explanation for the strike. Over time, the increase in shared knowledge among workers and between workers and managers, as part of a general trend toward solidarity, led to an average increase in interaction among workers and between workers and managers. Correspondingly individuals began spending less time in isolation. In the two groups the change in interaction had different effects. Worker-worker interaction increased because of an increase in the level of interaction between specific workers thus increasing the number of other workers that any specific worker might consider a friend. Whereas, worker-management interaction increased because of an increase in the number of dyads who started interaction. Since workers interacted more with other workers than managers they were more likely to choose their enemies from the managers. Thus, on average, the expectation is that the level of friendship will increase among workers and the level of enmity will increase between workers and managers. This suggests that the strike at time 1 was aborted both because the level of interaction between workers had not risen sufficiently to produce internal unification and because the level of interaction between workers and managers was so low that the workers did not feel sufficient antagonism to management to support a strike. By time 2, however, a successful strike could be waged because the increase in interaction among workers had led to sufficient unification and the more moderate increase in interaction between workers and managers (which still remained lower than that between workers) has increased the potential for worker-management antagonism.

DISCUSSION

CONSTRUCT goes a little beyond both purely social models[13] and purely cognitive models[14] in that it incorporates elements of both into a single dynamic system. As a result, despite its limitations, CONSTRUCT has predictive capabilities and explanatory power. Despite the inadequacies of the data, the quantized form of interaction and the fact that knowledge data had to be constructed, the proposed model was able to predict observed change in interactions among Kapferer's workers better than alternative models including Heiderian balance and Kapferer's exchange model. The predictive capabilities of the model suggest that this approach to combining individual and social considerations, despite the severe level of abstraction, has merit. And it provides hope that our ability to predict changes in interaction patterns will improve as we move on and elaborate this model so that it more realistically captures the nuances of interaction and the exchange of information between individuals.

An example of such an elaboration would be to consider non-transferable information such as what sex or race or job one holds. In the proposed model, the state of perfect stability indicates a completely egalitarian structure for not only is there no differentiation between individuals in terms of frequency of interaction there is also no differentiation between individuals in terms of information. Let us contrast this with a hierarchical structure, such as workers and managers in a factory, where the elite interact as much with each other as with the non-elite (and vice versa). In such a hierarchy, although interaction may not be differentiated knowledge will be. That is, members of the management know the piece of information "I am a manager" which the workers do not, and so on. Such information, can be thought of as "fixed" or non-transferable for the communication of such self-attribute information can not change whether the communication partner has said attribute. By considering such non-transferable information the model would become more structural in nature. Such information, in addition to environmental characteristics such as birth, death, emigration, immigration and discovery will affect not only whether the "ultimate" state of perfect stability can ever be achieved but the composition of that state. Further, by differentiating information it will be possible to examine more complex behaviors.

In addition, the particular functional form for the relationship of knowledge to interaction used in this paper [Eq. (3)] should be subjected to empirical investigation and alternate forms explored. Even without increasing the complexity of the model, for example, by adding new factors such as differentiated knowledge and proximity, given appropriate quantitative data it may be worth exploring alternate forms based on measures of path distance, perhaps similar to that proposed by Burt (1982, ch. 5) for perceived similarity. Although, such an empirical investigation is premature without more appropriate data.

In this paper, friendship and antagonism were derived from interaction probabilities in a manner consistent with Levine's analysis. Future studies are needed to determine whether the relationships observed by Levine are indeed empirical regularities. If there is a fixed empirical relationship between friendship, enmity, and interaction frequency then data collection can be simplified to collecting just interaction frequencies—which can be done through observation and is less

prone to error and bias than asking individuals to list their enemies or people whom they dislike. The reason for this is that friendship and antagonism as functions of interaction probabilities become subjective facets of the individual that change over time. Further, the constructural perspective suggests that due to the overall tendency toward solidarity in the long run conflict and cooperation are equally likely. In this case, specific cases of conflict would be quite random. A limitation of such an approach, however, is that it would not identify who actually were friends or enemies; but, would merely identify the probability of friendship and enmity between pairs of individuals.

In order to subject the proposed model to further empirical testing we need to collect data differently as well as to collect different data. As for social data, White, Boorman, and Breiger suggested that structure is better exhibited by multiplex of ties than rankings (White 1976). In contrast, this study suggests that structure is better exhibited by the interaction frequencies than the presence or absence of interactions or particular ties. In addition, this study suggests the need to collect data on self behavior. Such data, for example how much time the individual spends by himself or herself, is generally not collected. When this is coupled with the use of quantized data in which an interaction is either present or not the intensity of relationships is completely lost. According to the proposed model, societies in which individuals spend more time in isolation are slower to change. Thus knowing intensities and self behavior, and not just the presence or absence of relationships, is necessary if we are to examine over time behavior such as the rate at which the society changes and the rate at which information diffuses. As for cognitive data this study suggests the need to collect data on what people know or do not know, or at least indicators of how much knowledge they share. Qualitative estimates of shared knowledge used in conjunction with interaction data may be sufficient to establish initial interaction propensities and distribution of knowledge, however, this is a point for further research. Finally, there is a need to carefully define the group when collecting data. This study suggests that, given the overall trend toward solidarity, conflict and change between two groups can not be fully explained without information on both groups. And finally there is the question of overtime data. According to the proposed model, social structure and culture are continually constructed as individuals interact and exchange information. What this suggests is that we can not complacently assume that social structure is "fixed" and that cultural change is too slow to be noticeable. Rather, it is necessary to collect both interaction and knowledge data over time in order to track the rate of structural and cultural change.

SYNOPSIS

In this paper, individual behavior and the consequent social change and stability was examined from a socio-cognitive perspective. Unlike many theories of this genre an actual analytic model, enabling quantitative predictions, was described and used to analyze behavior. By using simulation it is possible to describe the interactive process and generate specific empirical predictions. Not only was the model able to predict general trends (average level of interaction increases, standard deviation increases) but it was also able to predict the pattern of change (69% of the dyadic behavior at time 2). Further, using simulation it was possible to do an incremental analysis of an actual historical situation. By building up a model of the situation, first looking at just the workers, and then the workers and managers, and then by going beyond interaction to friendship and antagonism it was possible to parsimoniously develop an explanation of the observed behavior.

In addition, to these specific empirical predictions CONSTRUCT provides general insights as to group stability. For example, it suggests that in one group societies, the size of the population has no effect on stability, rather stability is dependent on the complexity of the culture and the level of cultural homogeneity (Table 1). Irrespective of size, the less complex the culture, the greater the level of cultural homogeneity, the faster the society approaches this perfect stability. Since perfect stability is only achieved once everyone knows everything the faster this approach the faster the average rate of diffusion for any one piece of information, the more quickly, on average, any one individual becomes socialized, and so on. Let us step out of the model for a moment and consider some of the implications of these theoretical results. In the area of diffusion, what this suggests is that in the absence of turnover and to the extent that the Japanese are more culturally homogeneous than are Americans then one might expect Japanese firms to exhibit faster internal rates of adoption than American firms. In the area of religion, one might expect that the length of time it takes a potential convert to become a convert to be faster in cult religions (which are generally less complex and whose members are more homogeneous with respect to their knowledge and beliefs) than in traditional religions (which are generally more complex and whose members are more culturally heterogeneous).

Similarly, CONSTRUCT provides general insights as to the relative stability of a minority. According to the model, in a two group society, the smaller and the more culturally homogeneous the minority relative to the majority the slower its rate of assimilation (see Table 2). The reason for this is as follows. Since interaction is based on relative similarity greater cultural homogeneity will lead to greater interaction between group members thus effecting higher intra-group interaction and increased cultural homogeneity in the group. But as the group grows larger the interaction between group members decreases and so the difference in the group members' relative similarity to non-group and group member decreases. This finding suggests a possible reason why Jews as opposed to Catholics have maintained a stronger group identity in America.

These overall general tendencies in group stability result from the concurrent exchange of information and consequent self-development as information is

acquired by all members in the society. In the short run, this concurrent process can produce conflict. In the case of the tailor shop, conflict occurred even though workers were coming to interact more with, and share more information with, both other workers and managers. Conflict occurred specifically because the differential in increased interaction between workers and other workers versus workers and managers led to a greater potential for friendship ties to form among workers and enmity ties to form between workers and managers. This differential, and indeed the increase in this differential over the course of time 2, enables the workers to engage in a successful strike. Thus, it is the differentials in interaction and the evolution of such differentials that engender the production of conflict.

This approach, in sharp contrast to other models of conflict such as that suggested by Blau (1977, 1984), sees conflict as a direct product of cognitive changes rather than specific economic, social or cultural conditions. For example, Blau sees opportunity for interaction as enabling conflict and then draws on cultural (excessive in-group salience) and socio-political or economic conditions (inequality), which in his theory are not functions of nor direct contributors to interaction opportunities but instead act in an exogenous fashion, to determine conflict. Whereas, in this account, factors such as excessive in-group salience (such as nationalism) and inequality engender conflict only to the extent that they produce the necessary differential in knowledge and hence interaction. Thus, in the proposed model, conflict is in some sense easier to produce and avert as changing the distribution of information in the society can alter the potential for conflict. Further, extreme inequality or extreme social consolidation (such as when all blacks are poorly educated and hold low income low status jobs and whites just the opposite) may be less likely to produce conflict due to lack of a basis for interaction than will moderate levels of inequality or less social consolidation as such moderation (in the context of the proposed model) produces "enough" shared knowledge to produce moderate interaction levels. Thus, socio-economic policies which lead to more freedoms, less inequality, or less consolidation, may, ironically, in the short run lead to more conflict. Indeed, observors have argued that it was just such changes that precipitated the conflict in Tiannamen Square in China.

According to the constructural perspective used in this paper neither unity nor conflict are endemic in the short run. Rather, they emerge as gradual changes occur in the patterns friendship and enmity. Such gradual changes in conflict and unity emerge as a byproduct of changes in the underlying interaction patterns which in turn result from changes in the distribution of knowledge. Thus, a gradual individual level process of knowledge acquisition and exchange, a process which if unimpeded will produce cultural and social solidarity, has the potential in the short run to produce at the social level both unity and conflict.

APPENDIX 1: SYMBOL DEFINITIONS

Symbol	Definition
I	Population—number of people in society
K	Cultural Complexity—number of pieces of information (facts)
$F_{ik}(t)$	Knowledge—individual i knows fact k at time t collectively this is culture
$P_{ij}(t)$	Interaction Probability—probability that individual i interacts with individual j at time t collectively this is social structure
$INT_{ij}(t)$	Actual interaction—individual i interacts with individual j at time t
$C_{jik}(t)$	Communication—individual j communications fact k to individual i at time t
$A_j(t)$	Interaction Availability—individual j is available for interaction at time t

APPENDIX 2: TECHNICAL DETAILS

This appendix contains details on the implementation of the model.

Choosing a Fact to be Communicated

The u function ($u_{jk}(t)$) represents the random selection determination of whether individual j chooses to communicate fact k during time period t. The u function has the following property: all facts known by j are equally likely to be chosen. One way in which to implement the u function is as follows.

Let $u_{jk}(t)$ have the form $u(a,x,b)$. Then the selection of a fact is done by first choosing a piece of information to communicate. Which of the facts known by the individual is chosen to be communicated can be represented as:

$$x = r1 \sum_{l=1}^{K} F_{jl}(t) \tag{6}$$

where $r1$ is a random variable drawn from a uniform PDF between 0 and 1. The selected fact x is the x'th fact in the set of facts known by individual j. The x'th fact in the set of known facts is translated into the k'th fact in the set of all K facts by a and b. The variable a is the number of facts known by j whose index is less than k:

$$a = \sum_{l=1}^{k-1} F_{jl}(t) \tag{7}$$

The variable b is the number of facts known by j whose index is less than or equal to k:

$$b = \sum_{l=1}^{k} F_{jl}(t) \tag{8}$$

These variables (a and b) will differ by 1 if fact k is known by j, otherwise they will be equal. The u function will generate a 1 if k is the xth known fact and 0 otherwise; that is,

$$u(a, x, b) = \begin{cases} 0 & \text{if } x < a \text{ or } x > b \text{ or, } a = b, k \text{ is not communicated} \\ 1 & \text{if } a \le x \le b \text{ } k \text{ is communicated} \end{cases} \tag{9}$$

A different random variable, $r1$, is drawn each time period, and for each person.

Choosing an Interaction Partner

The v function determines whether individual i chooses individual j at time t to interact with. This function has the following property: the likelihood of all individuals not already interacting to be chosen is proportional to the choosing individuals probability of interacting with those remaining individuals. There are many ways in which this function could be implemented. One way in which to implement it is described below.

Let $v_{ij}(P_{ij}(t), A_j(t))$ have the form $v(a,y,b)$. Then The selection of an interaction partner is done by first choosing a random variable, y, from a uniform PDF between 0 and 1. The variables a and b determine the range of y which will be translated into a particular person for i to interact with. The variable a is the CDF for the probability that i will interact with any individual h between 1 and $j - 1$ conditioned upon h being available to interact. This can be represented as:

$$a = \sum_{h=1}^{j-1} \frac{P_{ih}(t) \times A_h(t)}{\sum_{d=1}^{I} P_{id}(t) \times A_d(t)}. \tag{10}$$

Similarly, the variable b is the CDF for the probability that i will interact with any individual h between 1 and j conditioned upon h being available to interact. This can be represented as:

$$b = \sum_{h=1}^{j} \frac{P_{ih}(t) \times A_h(t)}{\sum_{d=1}^{I} P_{id}(t) \times A_d(t)}. \tag{11}$$

The difference between (a and b) will be the probability that i will interact with j

conditioned upon the set of available people. The v function will generate a 1 if j is the individual selected to interact with and 0 otherwise; that is,

$$v(a,y,b) = \begin{cases} 0 & \text{if } y < a \text{ or } y > b, \text{ or } a = b, j \text{ is not selected} \\ 1 & \text{if } a \leq y \leq b \; j \text{ is selected.} \end{cases} \quad (12)$$

A different variable y is chosen for each individual each time period.

APPENDIX 3: CALCULATING THE INITIAL KNOWLEDGE BASE

Based on Kapferer's argument that the workers were highly heterogeneous a maximally heterogeneous scheme for knowledge allocation was used. Since each individual is assumed to interact the same amount (78) each individual was assigned as knowing 78 facts. Maximal heterogeneity is achieved by having each fact shared by no more than 2 individuals at the same time. For each interaction that the individual has with another, the two individuals share 1 of their 78 facts. This fact is not known by any other individuals. Thus, the individuals share at most 2 facts. By way of example, consider a society with 4 individuals for which the maximal number of facts is 8 (rather than 78). If the interaction matrix is:

	Person 1	Person 2	Person 3	Person 4
Person 1	6	1	1	0
Person 2	1	4	1	2
Person 3	1	1	6	0
Person 4	0	2	0	6

then the knowledge matrix is:

Fact	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA
Person 1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Person 2	0	0	0	0	0	0	1	0	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Person 3	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	1	1	1	1	1	1	0	0	0	0	0	0
Person 4	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1	1	1	1	1	1

APPENDIX 4: MANAGEMENT KNOWLEDGE BASE

Based on the events in Kapferer (1972, Appendix 2), Patel is coded as having the following level of interaction with each of these workers at time 1: Mukubwa (2), Chisokone (4), Mubanga (1), Adrian (1), Lyashi (1), Nkoloya (1), Abraham (1), Zulu (1), Chipata (1). With all other workers he is coded as having no interaction. The rest of the management group are coded as having no interaction with any of the workers. This interaction data is converted to knowledge data by giving Patel and each of these workers a unique fact in common for each "interaction". One of Patel's interactions was with Chisokone, Lyashi, Nkoloya, Abraham, Zulu, and Chipata at the same time when they came as representatives of the workers. In coding this interaction all 7 individuals are given the same fact in common. This produced a total of 8 facts. These facts were not initially shared by anyone else.

The management was modeled as being highly interactive with each other and highly culturally homogeneous. This is based on Kapferer's observation that they were part of a socio-economic elite, highly homogeneous, and highly differentiated from the workers. This was modeled by having all 4 members of the management know the same 20 facts, none of which were known by any of the workers.

NOTES

1. All major symbols are defined in Appendix 1.
2. The term fact is used interchangeably with the term piece of information. No implication is being made about the legitimacy or truth value of the piece of information. A fact in this account is either "known" or "not known".
3. The symbol $\vee$ stands for the "logical or".
4. The symbol $\wedge$ represents the "logical and".
5. There are 12 stable configurations (A through K and P). Of these configurations, only P can be reached from other states. Thus, if the society is initially configured as A through K it will always be configured as A through K. And, any other configuration will, eventually, lead to P.
6. For example, a fully-connected society with 4 people and 4 facts has over 500 states, and, unlike the two-person two-fact case, there are states between the initial and final states. In the four-person four-fact case there are over 250,000 elements. Computations involving matricies with more than 10,000 elements are generally infeasible given current computational limits. In order to determine the rate of convergence for a fully-connected society, one would compute the convergence to the final state where everyone knows everything that anyone does from every possible initial state. In the general case, convergence is determined by

$$P\hat{}_F(n) = \sum_{x}^{X} P_x(0) f_x(n) \quad (5)$$

where F is the final state, x is a state counter, X is the total number of initial states, and $f_x(n)$ is the specific convergence function when x is the initial state. In the two-person two-fact example, f is $1 - .92^n$ for states L, M, N, and O. In the general case, however, different states will have different fs. Thus the relative stability, or endurance, of different societies can be determined by comparing their fs. For larger societies, although the eigen values can be computed they are degenerate and no one value dominates. Consequently, in order to compute the fs it is necessary to locate the eigenvectors which entails computing a matrix inverse.
7. This is implemented by assigning each individual to know 25%, 50%, and 75% of the facts. Who knew which fact was randomly determined. Since one can only know or not know a fact, the fraction of facts shared by two individuals was on average the square of the number known by an individual.

8. For each simulation run who interacts with whom and who initially knows which of the facts is determined randomly but subject to the constraints described above.

9. This standard deviation is an estimator of the difference in means for the population taking into account their covariance. The difference in means, $\bar{x} - \bar{y}$, is assumed to be distributed $N(\mu_x - \mu_y, \sigma_x^2/n + \sigma_y^2/n - 2\rho\sigma_x\sigma_y/n)$.

10. The worker's position is defined as the position Kapferer listed for that individual in Appendix 1. In those rare cases where Kapferer listed the worker in Appendix 1 as having two positions I coded the worker as having the "higher status" position.

11. The Bank Wiring data, available through UCINET (MacEvoy and Freeman 1988), is described at length by Roethlisberger and Dickson (1939) and Homans (1950). This study contains information on 14 workers in a wiring bank. For each pair of workers various information was kept including friendship, antagonism, and whether various forms of interactions such as job trading, helping, gaming, and conflict over windows occurred.

12. Levine predicted friendship and enmity from interaction. He did not first locate friends/enemies and then determine what level of interaction they were likely to have.

13. An example of a purely social theory of individual behavior is Blau's structuralism (Blau 1977; Blau and Schwartz 1984).

14. Examples of purely cognitive theories of individual behavior include Soar (Laird, Newell, and Rosenbloom 1987) and ACT* (Anderson 1983) which are at the individual level, much more powerful than CONSTRUCT; that is, they use structures of knowledge and different types of knowledge to produce more complex, and indeed a greater range of, individual behavior.

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