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From Private Attitude to Public Opinion: A Dynamic Theory of Social Impact

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A computer simulation modeled the change of attitudes in a population resulting from the interactive, reciprocal, and recursive operation of Latané's (1981) theory of social impact, which specifies principles underlying how individuals are affected by their social environment. Surprisingly, several macrolevel phenomena emerged from the simple operation of this microlevel theory, including an incomplete polarization of opinions reaching a stable equilibrium, with coherent minority subgroups managing to exist near the margins of the whole population. Computer simulations, neglected in group dynamics for 20 years, may, as in modern physics, help determine the extent to which group-level phenomena result from individual-level processes.

Writing about social phenomena, social scientists have produced empirical generalizations and theoretical analyses of social processes representing differing levels of social reality. Some analyses concern the cognitions, feelings, and behavior of individuals; others deal with small, medium, or large groups, collectivities, and organizations; still others involve such large-scale human aggregates and systems as nations, societies, or cultures.

Theories can be and are formulated and tested independently for phenomena at each of these levels, but one can also ask about the relations between mechanisms operating at different levels (Doise, 1986; Kenny, 1987; Nowak, 1976).

These relations may be of two kinds. The functioning of higher level units (e.g., social groups) may be partly or completely determined and therefore explained by mechanisms known from theories describing phenomena at lower levels (e.g., human individuals). Alternatively, the functioning of lower level units (e.g., individuals) may be affected by the higher level units to which they belong. In other words, individuals in a given social context behave differently than they would outside that context.

These relations, taken together, suggest that the interactive impact of individuals and their social context can result in the emergence of new regularities at the levels of both the individual and the collectivity that do not seem to be directly explainable by laws about human individuals as studied outside the given social context. Laws operating on lower levels of social reality may have unforeseen, seemingly emergent, consequences for higher levels, which, in turn, will affect the social environment facing lower level units.

When dealing with relatively small groups and fairly simple mechanisms of individual behavior, these interactions may seem relatively clear, and social scientists feel comfortable explaining laws about groups by laws about individual responses to groups, and vice versa. In other words, the deductive correspondence between laws and theories on these two levels can be assessed fairly easily. As group size increases, as laws about individual responses become more complex, and as the macrolevel property requires long and complicated sequences of individual interactions, however, we reach the limits of human intelligence. The possibility of accurately checking the correspondence between mechanisms at two such levels simply with mental formulas or paper-and-pencil calculations becomes more and more remote. There is a need for improved media for representing theoretical ideas (Harris, 1976; Ostrom, 1988b).

Computer Simulation

We believe the best solution to such problems is through computer simulation. If we can formulate in a computer program the rules that govern the reactions of each individual to the social environment, running the program will allow us to observe the consequences on the group level of those rules as the individuals interact with each other over time.

These consequences may indeed turn out to be trivial—simple reflections or summations of the laws imposed at the individual level. More interestingly, however, systems may exhibit emergent properties that are new, compared with the properties of individual units.

This procedure, using the computer to discover the consequences of the repeated application of simple laws governing lower level units for determining the properties of higher level systems, can be called *reductive simulation*. It is not the only

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kind of computer simulation. One can also investigate, as economists and sociologists do, the effect of varying parameters in a set of simultaneous equations directly describing the higher level system (Hanneman, 1986) or plug in theoretically estimated stochastic parameters to Markov models (Carley, 1989; Friedkin & Cook, 1989), but we do not consider those sorts of simulation here.[1]

In this article, we examine some possible consequences of simulating on a computer a theory describing the functioning of individuals in the presence of others, having in mind the more general methodological consequences of this kind of analysis. In particular, we simulate Latané's (1981) theory of social impact as applied to attitudes and explore the consequences for public opinion of the operation of social processes affecting individual attitude change.

Individual Influence and Public Opinion

The mystery of public opinion becomes particularly salient before every election, as pollsters try to follow the shifting preferences of the electorate. In part, these preferences reflect common reactions to events and images shared through the mass media and diverse concerns arising out of economic and social circumstances. In part, however, they reflect a process of group interaction as people discuss their beliefs and impressions with relatives, friends, neighbors, coworkers, and others. Presumably, if social scientists could understand this process of social interaction, they could be in a better position to predict public opinion.

Suppose one were to allow a number of persons with varying opinions to talk among themselves before surveying their attitudes? How would their final beliefs be distributed? With no pretense of any systematic review of the considerable literature relevant to this question, let us caricature our present state of theory and knowledge.

Innumerable studies of individual attitude change have shown that people are prone to change their stated beliefs in response to persuasive arguments or even the mere knowledge that others hold a certain opinion. Sometimes these changes represent public compliance without private acceptance, and sometimes they reflect true conversion, and they vary according to a large number of more or less well-understood circumstances, but the changes are predominantly in the direction of greater agreement with the source or sources of influence.

From these findings, one might expect that groups would move toward uniformity of opinion, as individuals converge on the most common viewpoint. In fact, the implicit null hypothesis seemingly held by most social psychologists is that group processes, if allowed to work themselves through to their conclusion, should lead to a final distribution of opinion with a mean equal to that of the initial distribution but with zero variance. Abelson (1964), in fact, was able to show explicitly that "universal ultimate agreement is an ubiquitous outcome of a very broad class of mathematical models" (p. 153) of social influence that assume that individuals move toward each other.

We know, of course, that this null hypothesis cannot be correct and, in fact, is flawed in at least two ways:

1. *Social influence processes do not by themselves create uniformity of opinion.* Festinger's (1950) influential theory of pressures toward uniformity in groups needed to include rejection of deviates as a contributory process. Even so, empirically, most groups include a healthy diversity of opinion, and our world remains incredibly divided even on basic factual issues. Minorities maintain their discrepant views and sometimes even convince the majority of their correctness.

The problem for theory, then would seem to be to explain how minority viewpoints manage to maintain themselves in the face of opposing majorities. Perhaps in response to this need, Moscovici (1976, 1985) has developed an important theory of minority influence based on the idea that different influence processes come into play when individuals espouse unpopular opinions. Latané and Wolf (1981), on the other hand, argue that the differences between majorities and minorities primarily reflect their differing size and status, rather than qualitative differences in modes of influence.

2. *Social influence processes do not lead to the convergence of public opinion on the mean of the initial distribution of private attitudes.* Research that has come to be considered under the rubric of "group polarization" (Isenberg, 1986; Moscovici & Zavalloni, 1969; Myers, 1982; Myers & Lamm, 1976) shows that discussion often leads group members to shift systematically so as to become more extreme, leading to great debate about whether such effects are due to unequal persuasiveness of majority versus minority arguments (Burnstein, 1983; Burnstein & Vinokur, 1977), a self-presentational need to appear at the vanguard (or at least not at the rear) of social movements (Brown, 1965), or a desire to have a distinctive group identity (Hogg, 1988). Polarization processes, carried to an extreme, should lead to group convergence at extreme positions, and the rarity of such outcomes suggests that polarization may be a self-limiting process. The problem for theory, then, would seem to be to explain not only why polarization takes place but why it remains incomplete.

Social Impact Theory

In this article, we suggest that a simple model of individual influence, operating in accordance with some general principles of social impact, can, if extended to reflect how individuals influence and are influenced by each other over time, lead to plausible predictions of public opinion. In particular, we suggest, a computer simulation of these principles may lead to partial polarization at the group level. If so, the need for special assumptions to account for the failure of our implicit null hypothesis of convergence to the group mean may be eliminated.

Latané (1981) defines social impact as any influence on individual feelings, thoughts, or behavior that is exerted by the real, implied, or imagined presence or actions of others. His theory of social impact is a metatheory that attempts to characterize

[1] Davis and his colleagues have developed useful ways of representing the effects of group discussion on group problem solving, group decision making (Davis, 1973), and group attitude change (Kerr, 1981). Several other authors have recently developed interesting computer models based on these ideas, especially in the context of jury decision making (Davis & Kerr, 1986; Penrod & Hastie, 1980; Stasser, 1988; Tanford & Penrod, 1983).

how the many ways in which individuals affect each other are subject to the constraints of time and space, and specifically, how impact is moderated by the strength, immediacy, and number of other people in the social environment.

Social impact theory has been applied to a wide variety of social processes ranging from diffusion of responsibility (Latané & Darley, 1970; Latané & Nida, 1981), to social loafing (Latané, Williams, & Harkins, 1979), stage fright (Jackson & Latané, 1981; Latané & Harkins, 1976), and persuasive communication (Latané & Wolf, 1981; Wolf & Latané, 1983). This theory has been tested in numerous experiments and reanalyses of previously collected data. The appeal of the theory in the present case, aside from its generality and wide range of applications, lies in the fact that it is formulated as a mathematical model, making it suitable as the basis for a computer simulation.[2]

Social impact theory concerns the magnitude of impact that one or more people or groups (sources) have on an individual, and thus is a static theory of how social processes operate at the level of the individual at a given point in time. One part of the theory deals with how much impact is experienced by an individual as a function of the strength, immediacy, and number of sources of impact. According to the theory, impact is a multiplicative function of three classes of factors: $\hat{\imath} = f(SIN)$, where $\hat{\imath}$ denotes the magnitude of impact, f denotes a function, S the strength of the sources (e.g., their authority or power of persuasion), I the immediacy of the sources (e.g., their closeness in space or time), and N the number of sources.

The theory more closely specifies the relationship of the number of sources with the magnitude of impact, and the relationship turns out to be a power function, where $\hat{\imath} = sN^t$.

The exponent t is hypothesized to be less than 1, reflecting a marginally decreasing impact of additional sources, and empirical studies have shown it to vary around an average of approximately .5. For example, for petition signing, the influence of others is proportional to $N^{.38}$ (Latané & Wolf, 1981); for stage fright, $N^{.56}$ (Latané & Harkins, 1976); and for the interest value of news events, $N^{.55}$ (Latané, 1981). The symbol s represents the net of the various scaling and other constants characteristic of specific situations.

When an individual stands with others as the target of influence, the theory suggests that impact will be diffused or divided, and the magnitude of impact experienced by a single target can be represented as $\hat{\imath} = 1/f(SIN)$, where the symbols mean the same as defined earlier. In this situation, impact is an inverse function of the strength, immediacy, and number of others who share the position.

Besides the formulas, Latané (1981) offers intuitions that social impact follows rules similar to those affecting physical forces (for example, electromagnetic forces).

Social impact theory is now widely cited in textbooks and in the research literature in social psychology. It provides a useful framework for understanding how a person is affected by his or her social environment. As formulated in 1981, however, social impact theory was a static theory. Although it recognized that people are not merely passive recipients of social impact but active participants in shaping the social environment, the theory did not have needed mechanisms for considering the reciprocal effects of individuals on their social environment and the dynamic consequences for groups as each person affects and is affected by others.

Applying Social Impact Theory to Attitude Change

Latané's (1981) theory of social impact is a metatheory—it specifies in broad terms the effects of certain kinds of social variables on the operation of specific social processes but does not itself describe the nature of those processes. Fortunately, a great deal of research and theory in social psychology has addressed the question of how attitudes are changed.

According to Petty and Cacciopро (1986), when people are heavily involved in an issue, arguments will be processed centrally, and persuasion will depend on their relevance and quality. On the other hand, when personal involvement is low, people do not pay full attention to messages, and persuasion is determined by such peripheral cues as the source's expertise (Hass, 1981; Hovland & Weiss, 1952), trustworthiness (Eagly, Wood, & Chaiken, 1978; Walster & Festinger, 1962), attractiveness (Chaiken, 1979; Eagly & Chaiken, 1975), and similarity to the self (Brock, 1965; Goethals & Nelson, 1973).

With regard to peripheral persuasion, at least, the application of social impact theory is relatively straightforward. To the extent that individuals are relatively uninvolved in an issue, they should be influenced by the strength, immediacy, and number of people advocating a contrary position. In this case, strength can be represented by sources' credibility and attractiveness, immediacy by their physical closeness, and number by how many there are.

Although source characteristics are often considered to be enduring characteristics of an individual, in fact they probably should be considered relative rather than absolute. Thus, a physician may be considered expert in matters relating to medicine but not with respect to rock music, a businessman or businesswoman may be considered more trustworthy when arguing for the public good rather than from self-interest, a person may be more impressed when a conservative argues for rather than against raising taxes, and people may be more inclined to agree with a politician who reflects their own ideology than one who generally takes an opposite tack (Bochner & Insko, 1966; Goethals & Nelson, 1973; Walster, Aronson, & Abrahams, 1966; Wood & Eagly, 1981). Thus, the same person might be seen as more credible or persuasive when arguing one side of an issue than the other, and someone who is very persuasive to one person might not be considered credible by someone whose views differ from that individual's.

Most research on source characteristics has dealt with homogeneous subject populations exposed to sources tailor-made to experimental requirements. Because interest has focused on the determinants of individual response to persuasive messages advocating opposing points of view, experimenters have not generally explored the possibility that a given communicator may be highly credible to some members of an audience and rejected as untrustworthy by others. Furthermore, because interest has

[2] Tanford and Penrod (1984) and Mullen (1983) also have developed mathematical models of social influence that might serve as the basis for such simulations.

been in attitude change in response to opposing arguments, little attempt has been made to study the effect of hearing support for one's own position (but see Holtz & Miller, 1985; Kelley & Volkart, 1952). Finally, to our knowledge, there has been little or no investigation of the effects on a communicator's credibility of changing his or her mind.

For these and other reasons, in the simulation we report, it seemed desirable to distinguish two forms of communicator strength—one with respect to people who share the communicator's opinions, and one with respect to people who oppose them. Thus, *persuasiveness* refers to the ability to induce someone with an opposing position to change, and *supportiveness* refers to the ability to help those who agree with someone's own point of view to resist influence from others.

One can imagine reasons why persuasiveness and supportiveness might be correlated. For example, persons with high social status, expertise, and integrity could be perceived as especially credible by both supporters and opponents, leading to a positive correlation. On the other hand, an extreme advocate of one position on a polarized issue may be very credible to those who agree, but anathema to those who disagree, leading to a negative correlation. In the present simulation, we made no assumption about which correlation would predominate.

The present, admittedly extreme, view takes at least some attitudes as collectively determined, flimsy and unstable, a social product of both one's own and opposing groups. A given individual's likelihood of change will be a direct function of the strength (persuasiveness), immediacy, and number of those advocating change, but an inverse function of the strength (supportiveness), immediacy, and number of those sharing his or her point of view. The problem for the simulation is to see what happens when many such individuals come together.

Simulating Social Impact on a Computer

The theory of social impact as presented in 1981 specified three classes of variables affecting the single act of influence. As Latané (1981) observed, it was a static theory, concerned with the effect of the social environment on an individual, and did not then have a needed dynamic aspect whereby individuals were considered to have a reciprocal influence on their environment. We suggest that in many real-life situations, social impact is an ongoing chain process of reciprocal and continuing influence among individuals in a social setting. At the same time, a given individual may be a recipient of impact from some and the source of impact for others. Individuals that change as a result of the impact of others later influence others to their new positions. We are interested in the consequences of social impact theory applied not to a single act but to an ongoing group process extending over time.

In our simulation program, each individual is represented by a set of four parameters or attributes affecting the degree to which he or she is influenced by and influences others: the individual's attitude, two indicators of strength—the ability to persuade people with opposing beliefs to change their minds and the ability to provide social support to people with similar beliefs—and his or her location in the social structure. The computer then repeatedly calculates the consequences of the shifting forces for change on each individual until such time as the system reaches equilibrium.

Attitude

The key attribute, of course, was the attitudinal position or opinion of each individual in the group, which could take one of two values. The interpretation of the meaning of these values does not, of course, affect the simulations. However, one can think of the values as people being for or against a given idea (like the right to abortion), returners of "guilty" versus "not guilty" verdicts, members of different political parties, and so on. This attribute can be used to classify the population into two subgroups holding different opinions. The size of each group (N in Latané's formula) equals the number of individuals sharing the same attitude. In the figures to follow, individual attitudes are represented by graphic signs, either vertical or horizontal bars.

Persuasiveness

Each individual in our simulations was characterized by a second attribute—persuasiveness—in the form of a randomly assigned number in the range (0–100), which entered the formulas for calculating impact but did not show on the group structure printout.

Persuasiveness, in the terms of social impact theory, is a strength variable. Here it refers to the extent to which an individual is motivated and successful in influencing people who initially disagree with him or her. This attribute describes how others react to a person—is the person involved, articulate, credible, trusted? We assumed that persuasiveness is a function of both the opinion one holds and the intensity with which one holds it, and thus represents credibility with respect to a given position, rather than as a stable property of an individual. Thus, in the simulation, an individual's persuasiveness changed whenever his or her attitude changed.

One could advance arguments to support the idea that persuasiveness should *increase* after attitude change. The recent convert might be especially motivated to proselytize, the born-again Christian may be more fervent than the lifelong churchgoer, and, by virtue of having been a member of the opposing group, the former sinner may be seen as uniquely knowledgeable and unbiased. On the other hand, one could argue that the credibility of an individual should *decrease* following a change of attitude. Someone changing sides could be seen as wishy-washy, unstable in his or her opinions, overly responsive to immediate situational pressures, and lacking true knowledge or conviction. Because both effects are likely, persuasiveness was simply reassigned randomly after each change of attitude.

Supportiveness

In addition to advocates of the opposing viewpoint, people who share an individual's own view can affect that individual. In this case, however, impact shows up in the form of social support. We think that the ability to provide social support for members of one's own group to resist attitude change may be a different property than the ability to persuade members of the opposing group to change their attitudes. Therefore, as a third attribute characteristic of each individual, we introduced the analog of persuasiveness, supportiveness. Again, supportiveness was represented by a random number in the range (0–100), and, as in the case of the persuasiveness parameter, this number was randomly reassigned if the individual changed opinion.

We adopted the theoretically neutral assumption that strength parameters have a uniform rather than a normal or bimodal distribution. To the extent that the underlying factors affecting persuasiveness and supportiveness combine additively, we might expect a normal distribution. To the extent that they interact multiplicatively, however, the distribution becomes skewed. If strength is a combination of negatively correlated variables, one might expect a bimodal distribution. We chose the uniform distribution as a compromise.

A second advantage of using the uniform distribution is that it alleviates the necessity of making assumptions about the size of the standard deviation relative to the mean. Small standard deviations would have an effect similar to assigning the same values for everybody, whereas large standard deviations would be like the uniform distribution. In a forthcoming article we will explore the effects of different reassignment rules and parameter distributions on emergent social processes.

Immediacy

Groups and societies have structure, that is, individuals are in some relationship to one another. The term used in the theory of social impact related to group structure is *immediacy.* Group structure can be defined as a pattern of immediacies between group members. Immediacies can be viewed as physical distances between individuals with specific spatial locations. We decided, after Dewdney (1987), to represent individuals as cells in a square matrix (like cells on a grid paper). The immediacy of two individuals can then be calculated as the Euclidean physical distance between the cells representing two individuals in the matrix.

The advantage of this specific representation of immediacy is that the structure of the group can be easily visualized in the form of a printout (see Figure 1). We believe this representation to be quite neutral in its assumptions about group structure. Such a group structure may correspond to people gathered in an auditorium or meeting room, where immediacy is just the physical distance, or it may correspond to the structural relations among inhabitants of a living quarter. We discuss possible alternative ways of representing group structure in a later section.

Immediacy, of course, is an attribute not of an individual, but of a pair of individuals. In the present case, it can be thought of as the ease or probability of communication between individuals.

The Basic Formulas and Rules of Simulation

To translate any theory into a simulation program, all the relations among variables must be exactly specified. In the equations that constitute the theory of social impact as presented by Latané (1981), only the function linking impact with the number of sources has been specified: as a power function with the exponent in the (0, 1) interval. Experimental results, as mentioned earlier, estimate this exponent at approximately .5, so we used this value.

Latané (1981) uses the metaphor of physical force fields to describe the meaning of his formula. From this metaphor, we derived the relation between the magnitude of impact and the immediacy of the source. In physics, the force of the field (for example, gravity) diminishes with the square of the distance, so we used this rule (see also Carrothers, 1956; Catton, 1965; Knowles, 1980, for discussions of gravity models of social distance).

In Latané's theory, immediacy is a single value describing the distance in space or time or the clarity of the communication channels among individuals. In our simulations, we treated immediacy as a quantity that is given for every 2 individuals.

The problem then arises of how to enter immediacy into equations. In computing persuasive impact, we decided to divide the persuasiveness or supportiveness of each source by the square of their distance to the recipient to determine their contribution to the net impact. To avoid dividing by 0, the distance on each axis was increased by 1.

Latané's (1981) formulas, based on the simplifying assumption that all sources were homogeneous with respect to strength and immediacy, needed to be modified to work in the present situation where the sources of impact are presumed to vary in strength and immediacy. To capture his psychosocial law—that impact rises as a marginally decreasing power function of the number of sources—the feature that distinguishes social impact theory from mathematical descriptions of physical phenomena, we calculated the mean impact of all sources and then multiplied that mean by the square root of the number of sources.

Thus, the formula we used to calculate the total persuasive impact on a single individual of a set of N opposed sources differing in strength and immediacy had the form:

$$\hat{\imath}_p = N_o{}^{1/2}[\textstyle\sum(p_i/d_i^2)/N_o],$$

where $\hat{\imath}_p$ denotes persuasive impact, N_o the number of sources (individuals with an opposing view), p_i the persuasiveness of source i, and d_i the distance between source i and the recipient. The interpretation of this formula is that the persuasive impact of a group is the average force (persuasiveness divided by the square of the distance) exerted by each group member multiplied by the square root of the number of group members.

This formula, when applied to a situation where all sources are equally strong and equally distant from the recipient, is equivalent to Latané's (1981) original formulas, which treated the case where all sources were equal. When applied to a single source, the formula specifies that its impact will diminish with the square of its immediacy.

The impact of social support from those who share an individual's own opinion is given by the comparable formula:

$$\hat{\imath}_s = N_s{}^{1/2}[\textstyle\sum(s_i/d_i^2)/N_s],$$

with $\hat{\imath}_s$ representing supportive impact, N_s the number of individuals sharing the individual's view (including the individual), s_i the supportiveness of source i, and the rest of the symbols having the same meaning as—and the formula as a whole a similar interpretation to—the one above.

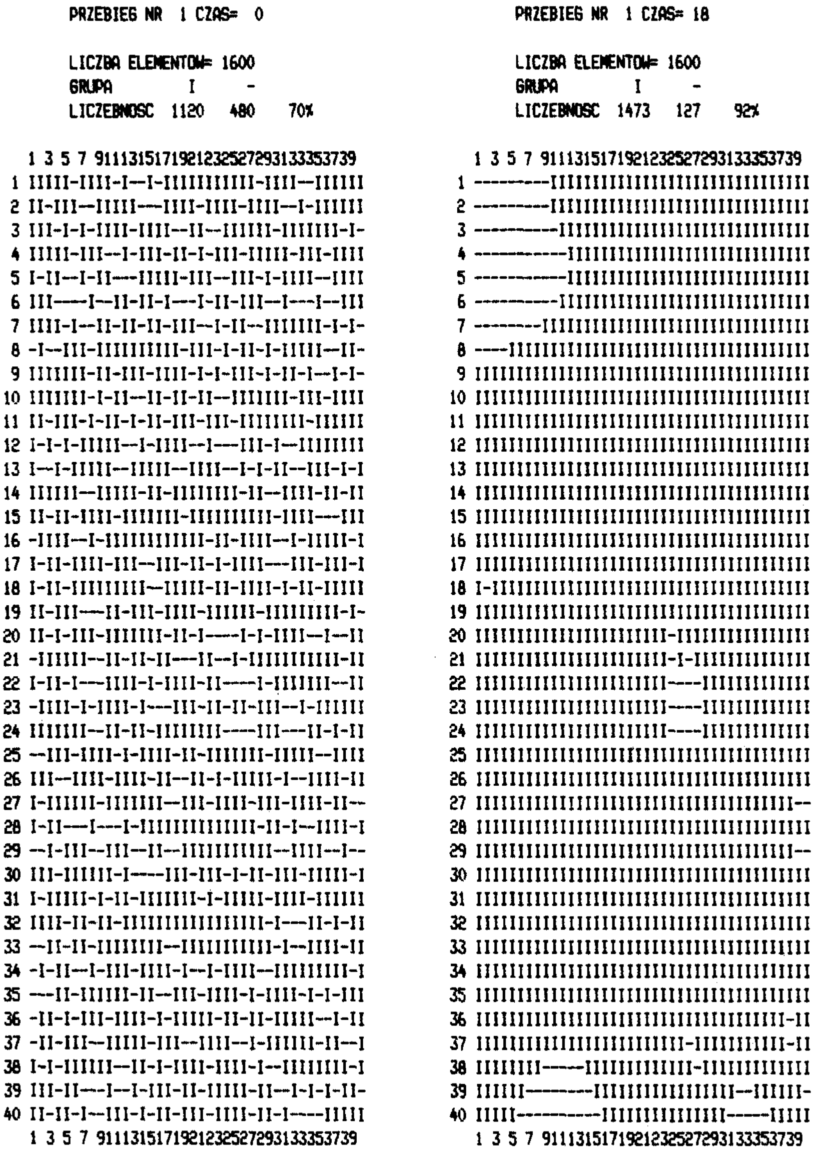

Figure 1. Example of random starting configuration of attitudes (left) and attained equilibrium 18 steps later (right). (Each cell represents an individual. Vertical bars represent the majority opinion; horizontal bars indicate the opposing viewpoint. PRZEBIEG NR = simulation number; CZAS = step; LICZBA ELEMENTOW = number of elements; GRUPA = group; LICZEBNOSC = frequency.)

Change rule. To determine whether someone maintained the same attitude or changed, we used the rule that whenever the impact on an individual from a group with a different opinion was greater than the impact of his or her own group, the attitude of that individual changed.

The simulation. In simulating the process of attitude change in an interacting group of individuals, we started from a distribution of attitudes such that the frequency of each position was controlled, but the starting configuration of attitudes was random. The values of the persuasiveness and supportiveness attributes were assigned as random values between 0 and 100. At each step of the simulation (comparable to a round of communication opportunities), the impact on each individual of those people with differing opinions was calculated and compared with the impact of those people who shared the same opinion. If the impact of the opposing group was greater than the impact of the supporting group, or, in other words, if $\hat{\imath}_p/(\hat{\imath}_s) > 1$, that person changed their mind, and their parameters for persuasiveness and supportiveness were reassigned at random. Of course, this feature of random reassignment means that a given initial configuration could lead to many differing equilibria.

New values for each member were calculated from the old matrix before any changes were substituted into a new matrix. Thus, we simulated a process of parallel, simultaneous processing. An alternative would have been a Monte Carlo, sequential process of randomly selecting elements with replacement and checking for change. Steps of the simulation continued until there were no further changes in attitude in successive runs.

Most simulations used a square 40 × 40 matrix representing 1,600 individuals (we ran a few simulations of 3,600 individuals arrayed in a 60 × 60 matrix, but these took much more computer time and produced approximately the same results). Because, even with 1,600 individuals, computations took a great deal of time (up to 1 hr for a single run), to speed them up we limited the range of impact to a distance of 10. The simulation program was written in FORTRAN, and simulations were run on a BASF computer at the University of Warsaw.

Results

The left-hand panel of Figure 1 provides an example of a starting distribution of opinions. Each cell in the 40 × 40 matrix represents an individual. As shown, 70% adopted the I viewpoint. Persuasiveness and supportiveness are not represented in Figure 1, but varied randomly for each individual between 0 and 100. In the final equilibrium distribution of opinion after 18 simulation steps, 92% of the group had come to adopt the majority position, and subgroups of like-minded neighbors had formed (Figure 1, right panel). This distribution is quite typical. Figure 2 shows the final distribution of two more simulation runs, each of which started with a 70% randomly distributed majority. In one, the majority increased to 86%, in the other to 94%, and in both, coherent subgroups had formed.

Similar processes occurred in almost all the simulations, despite great variations in the number of majority and minority members. In the beginning, we observed frequent changes of attitude as each position lost and gained adherents. Generally, the majority gained more members and the minority lost more.

Attitudes tended to change so as to increase the coherence of attitudes in local areas of the matrix. Individuals surrounded by differing opinions were more likely themselves to change, leading to a tendency for local subgroups of neighboring people with similar attitudes to emerge from the initial random configuration. As the simulation continued, those subgroups became more coherent as smaller subgroups were absorbed by the larger ones. Figure 3 shows the initial and final distributions of subgroup sizes, with many fewer small groups at the end than at the beginning of social interaction.

Smaller subgroups of people holding minority opinions could survive mainly on the margin of the matrix. This phenomenon, observed in most simulations, seems to bear analogy to small minority groups living on a social margin.

As the simulation went on, the frequency of attitude changes decreased, because individuals within larger subgroups were less likely to change their attitudes. After some number of simulation steps, the modeled society reached a state of equilibrium in which there were no further changes. The time to reach equilibrium depended on the starting proportions (Figure 4) and was longer when groups were more even in proportion.

The final distribution of attitudes was a (nonlinear) function of the initial distribution. Figure 5 shows the final proportion holding a given opinion as a function of the starting proportion, based on 10 simulation runs for each point on the figure. In general, the group that dominates in the beginning dominates even more at the end, and this supremacy is a function of the starting dominance.

When the minority consisted of 10% of the population, it was erased in some simulations and in others reduced to less than 1% of all individuals. A minority of 20% was never completely erased, although it was usually reduced to approximately 1%. A 30% initial minority resulted in final proportions ranging from 2% to 16%.

When groups were equal in size at the start of simulation, the end result was most unpredictable. One of the groups usually started to dominate, and final proportions ranged from 26% to 74%.

Interesting dynamics were observed with minorities ranging from 10% to 30%. After an initial dramatic drop in the number of minority members, those who survived spread their opinions, becoming seeds for new minority subgroups most often positioned on the margin of the matrix. In some simulations, a small minority subgroup at the margin of the matrix was able to induce a change in a majority member. In later steps, all the members of the original minority changed their attitudes to coincide with the majority, but the newly converted member resisted change and later, converting in turn majority members, became the nucleus for a group, positioned on the margin, of up to 25 persons.

If minority members survived the first few simulation steps (due to their high supportiveness), majority members around them were often converted. The average supportiveness of minority members was higher at the end than at the beginning of the simulation, especially when there were relatively few minority members. Presumably, this effect resulted from a process of selection. Minority members who were high in supportiveness were more likely to resist majority pressure, both directly, from including own supportiveness in the calculation of supportive impact, and indirectly, from being more likely to help others resist change, thereby contributing to the existence of a friendly neighborhood that in turn further helped them resist change. Those minority members low in supportiveness were less likely to survive the majority pressure.

Discussion

Our computer simulation has demonstrated that the theory of social impact can be applied to group dynamics, predicting a complicated process of changing individual attitudes leading to two emergent group phenomena—the shifting of attitudes toward incompletely polarized equilibria, and the formation of coherent clusterings of subgroups with deviant attitudes. Do these results correspond to real-world phenomena?

Polarization has been the subject of a great many laboratory experiments. Although our simulation was not designed to reproduce either the size or the structure of the discussion groups typically studied in the laboratory, it did produce a surprising finding reminiscent of those studies—the partial polarization of attitudes, with participants moving toward the majority point of view, but not achieving uniformity of opinion.

In our setting, *polarization* may have a slightly different meaning than in the usual laboratory experiment, where it is measured as a shift of individual attitudes toward more extreme versions of the group modal position after interaction. However,

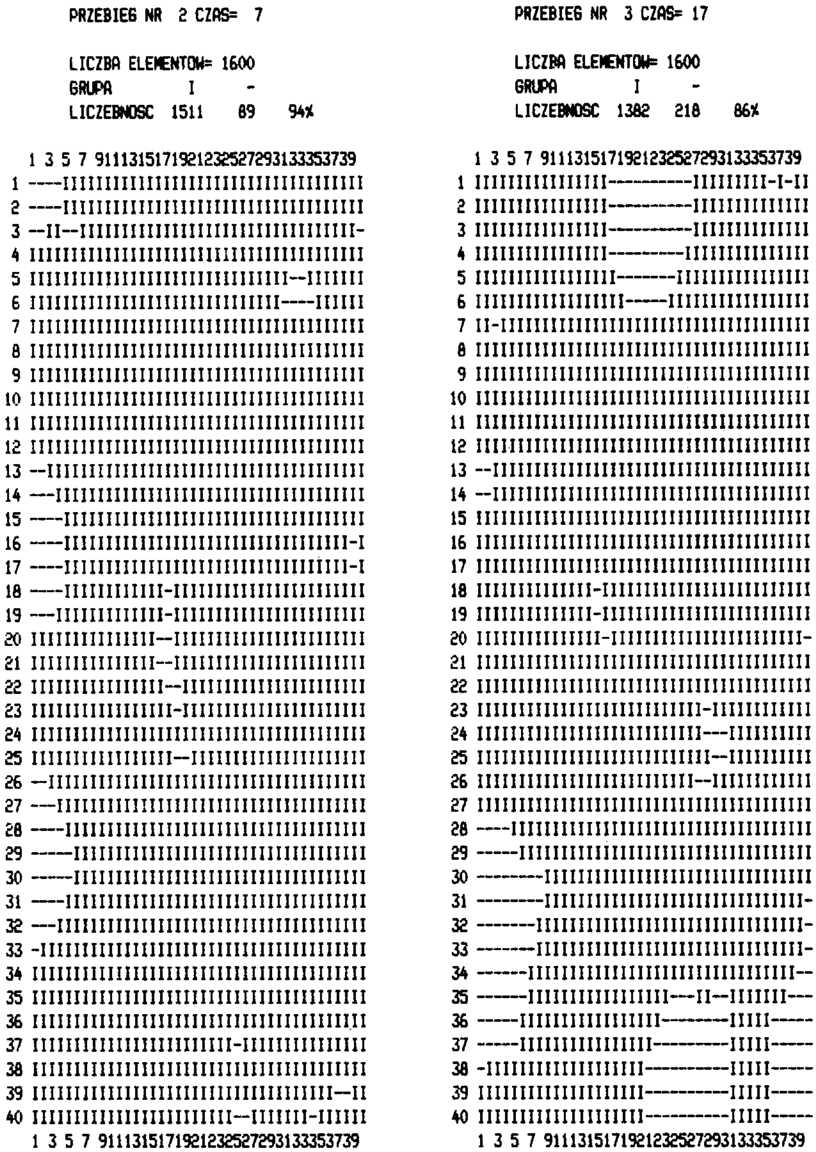

Figure 2. Two further examples of equilibrium solutions. (Vertical bars represent individuals holding the majority position; horizontal bars indicate those holding the opposing viewpoint. PRZEBIEG NR = simulation number; CZAS = step; LICZBA ELEMENTOW = number of elements; GRUPA = group; LICZEBNOSC = frequency.)

it is similar to the phenomenon described by the German survey researcher, E. Noelle-Neumann (1984) and often found in U.S. elections, in which there is a pronounced shift toward the majority position just before the election, so that the results are more extreme than predicted by preelection polls.

Although there are clear empirical referents for polarization, it is less clear where to turn for real-world evidence of clustering. Perhaps clustering is so pervasive that we often fail to notice it. For example, human geographers routinely make maps showing the geographical distribution of languages, religions, political orientations, food habits, agricultural practices, criminal behavior, and other mores and customs without remarking on the reasons for such spatial clustering. Presumably these fall into three classes—clustering may result from independent reactions to common environmental circumstances, from selective migration of individuals seeking to settle near like-minded others, and from social influence processes.

In a seminal study, Festinger, Schachter, and Back (1950) interviewed 100 residents of Westgate, a housing project constructed for married World War II veterans enrolled at MIT, about their attitudes toward a proposed tenants council. Couples were randomly assigned to the nine identical courtyards composing Westgate, so there were no differences in environmental circumstances nor any chance of selective migration. The power of social influence processes to create spatial clustering (or "group standards" in Festinger et al.'s terminology) is

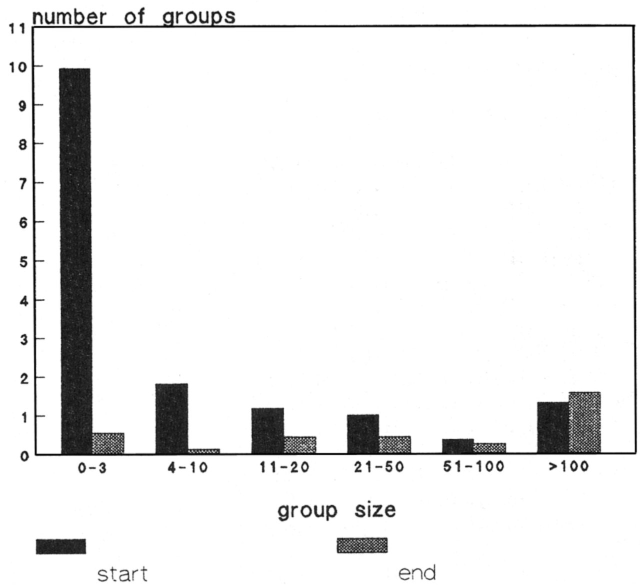

Figure 3. Initial and equilibrium distributions of sizes of coherent attitudinal groups.

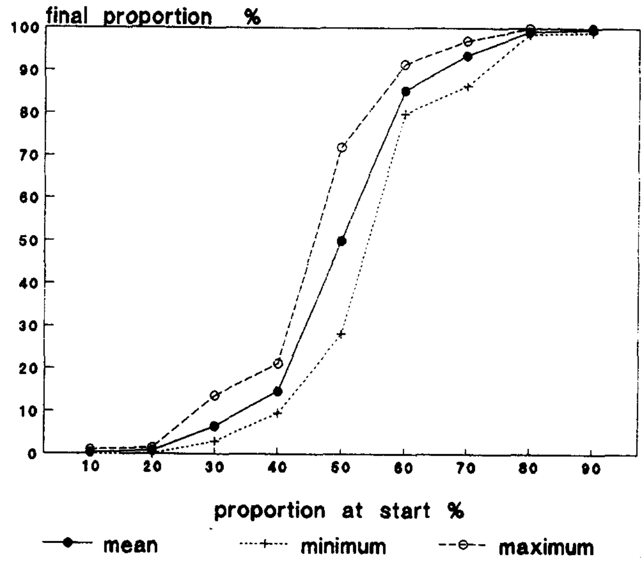

Figure 5. Final proportion holding an opinion as a function of initial proportion.

shown by the relative homogeneity of attitudes within courts (only 38% of residents deviated from the modal attitude pattern of their court) with heterogeneity of opinion between courts (with 78% of the residents deviating from the modal pattern of the project as a whole)—clear support for the tendency in our simulation for attitudes to cluster.

Within courts, Festinger et al. (1950) found that those people who lived in corner houses or isolated apartments had less social contact with other residents and were more likely to deviate from the majority opinion than were those who lived in more

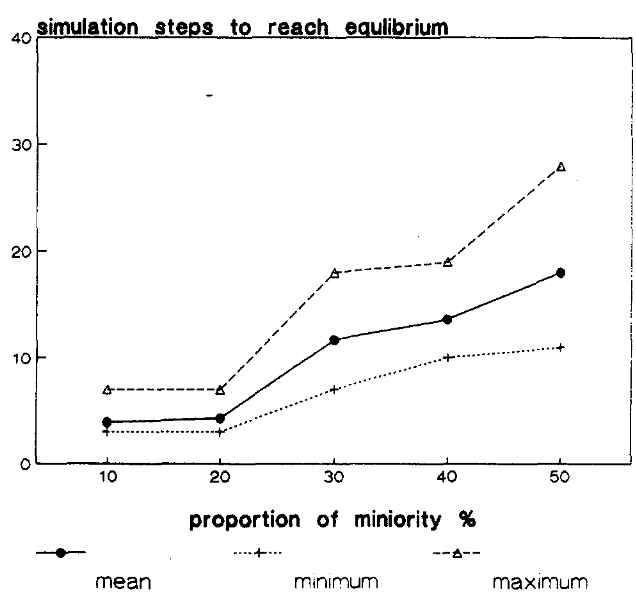

Figure 4. Number of steps required to reach equilibrium as a function of initial distribution of opinions.

central locations—clear support for the finding in our simulation that minority clusters tended to be more likely to survive on the borders of the population. Thus, we believe the results of our simulation are plausible with respect to real life.

Further evidence supporting the relevance of our findings from computer simulation to the real world can be found in studies by political scientists. For example, MacKuen and Brown (1987) demonstrate that the social environment shapes the way the citizen views politics. In a study of a referendum, Greer (1963) found that political conversations were most likely with relatives, friends, work associates, and neighbors, with political agreement showing the same order. Finifter (1974) found evidence for the clustering of political attitudes among factory workers in Detroit in 1961, with Republican autoworkers being more likely to have reciprocated friendship choices than majority Democrats. Putnam (1966) found that the Kendall tau between the reported vote of active members of community associations and the presidential vote in their county was .32, significantly greater than the value of .00 for nonmembers, indicating that marginal people were less likely to bow to local pressure. Greer and Orleans (1962) show that differences in the characteristics of residential areas are associated with differences in access to the networks of social relationships that transmit politically relevant information, leading to reduced political competence and participation. Finally, Greer and Orleans (1964) reviewed studies pointing to a relationship between weak social attachments with the majority and susceptibility to extremist ideology and concluded that highly segmented, geographically segregated communities are the most likely to generate extremist politics.

On Explaining Group Polarization

Why polarization? The results of this simulation lead one to wonder why polarization has been such a puzzle for social psychologists. At least in some sorts of situation, polarization would seem to be an inexorable effect of interpersonal influence, whether normative or informative, as each person is swayed to the prevailing majority.

Although Moscovici and Zavalloni (1969) claimed that their results could not be explained by a phenomenon of influence by a "majority of individuals who have reached the same judgment over a minority of dissenters" (p. 132), it seems likely that many examples of polarization may result from a minority on one side (whether pro or con) of an issue acceding to the views of the majority side (see also Davis & Hinz, 1982, and Myers, 1982, for some arguments for and against the view that majority influence may account for group polarization).

Why not uniformity? Abelson and Bernstein (1963) advised "in formulating mathematical rules for repeated change in attitude positions within a group of interacting persons, it is vital to have some feature which maintains extreme attitude positions, lest the rules inexorably produce ultimate attitude agreement in the entire group of individuals" (p. 106). Moscovici (1985) made a similar point in claiming that majority influence, by itself, would lead to uniformity of opinion with no possibility for change.

These conclusions seem too pessimistic. In the present simulation, the formation and continued existence of locally coherent pockets of opinion is made possible by the mere fact that the simulation allows for variation in persuasiveness, supportiveness, and immediacy, so that areas that happen to include strong minority representation can be sheltered from the overall majority. The nonlinear, flip-flop nature of the attitudes modeled here is probably also crucial.

The present simulations do not, of course, prove that all social influence phenomena can be accounted for by such simple processes as those modeled here. They do, however, suggest the desirability of discovering the consequences of the simple laws to determine what still needs to be explained.

Comparison with previous simulations of social processes. A flurry of interest in the computer simulation of social influence erupted approximately 25 years ago as a small number of sociologists, geographers, and psychologists attempted to be the first to exploit the power of the new computers arriving on campus. At Stanford, the sociologist B. Cohen initiated an extensive attempt to model influence in the Asch paradigm (Cohen, 1963; Cohen & Lee, 1975), creating a four-state Markov model predicting individual errors and alternations as a function of the social environment. This model, however, did not go beyond static modeling of the effects of social influence on an individual. More ambitiously, McWhinney (1964) attempted to simulate information exchange in small groups but found that, unlike real groups, no simulated group managed to learn an efficient procedure, "perhaps because simulated subjects were not bright enough to get themselves organized" (p. 82). At about the same time, the geographer Hägerstrand (1965) modeled the diffusion of innovation with a simple spatial model in which the probability of contact is a function of physical distance, but once one comes into contact with an innovation, adoption follows.

The sociologist J. Coleman (1965) developed some interesting stochastic models of teenage smoking based on the twin assumptions that teenagers are likely to adopt their friends' habits and that they are likely to choose their friends in part on the basis of what those habits are. Similarly, Rainio (1965) studied sociometric group structure, applying a stochastic theory of social interaction that assumed that friendship changes as a result of the rewarding or punishing effects of attitude similarity and difference.

Finally, Abelson and Bernstein (1963) created an extremely complex model of changing opinions in a community referendum. They simulated the effects of 49 different change rules in a population of 400 individuals characterized by over 300 attributes each. Abelson (1968) provides a useful discussion of these simulations oriented toward social psychologists.

Interest in these simulations soon seemed to die down, perhaps as a result of the ad hoc quality of many of the assumptions of the models, perhaps because of dissatisfaction with the plausibility of their outcomes despite their dependence on extensive parameter estimation, or perhaps because they were introduced at a time when computers were still cumbersome and slow and programming time-consuming and expensive.

Recently, several attempts have been made to get at the dynamics of public opinion analytically. Weidlich and Haag (1983) offered sophisticated mathematical solutions derived from synergetics, but only a rudimentary theory of individual response, limited to the assumption that all individuals equally share a probabilistic preference for one position and a stochastic tendency to move to the group average. Boyd and Richerson (1985) applied formulas derived from the theory of genetic evolution but were limited by their assumption that an individual's attitudes are completely determined by the probabilistic selection of a single "parental" position.

The present simulation differs from earlier ones in being explicitly based on an independently conceived and well-tested theory of individual response to social influence. It differs from the more recent simulations of jury decision making cited earlier by including a representation of social structure as well as variations in individual influence parameters. It also has the advantage of building on an extensive body of theory and simulation experience in theoretical physics and statistical mechanics.

Ferromagnets. When some metal alloys are heated, the magnetic moments of their constituent particles become chaotic and random. As the alloy is cooled, the magnetic moments of the particles become ordered according to very simple laws—the magnetic moment or *spin* of each particle is adjusted to the sum of the influences of the other particles. This simple principle gives rise to very complicated dynamic processes, the properties of which are in the center of interest of modern theoretical physics (McCoy & Wu, 1973; Ziman, 1979). The statistical interactions of elements, each characterized by one of two states of spin, are so complex that computer simulations are the main method of investigating them.

The study of such Ising models of magnetic phenomena, especially those known as spin glasses (see Anderson, 1987, for a brief description of spin-glass theory as an emerging synthesis of statistical mechanics with computer science, biology and neuroscience, and Chowdhury, 1986, for a more extensive technical review) has recently provided the conceptual basis for parallel distributed processing models of memory (Hopfield, 1982; Rumelhart, Hinton, & Williams, 1986). We believe it is also relevant to the problem of understanding how the social influence processes affecting an individual's beliefs interact and cumulate in groups to create public opinion.

Extending the Theoretical Model and Modifying the Simulation

Although we find the results of our preliminary simulations fascinating, they represent only a promising first step in the development of useful models of the dynamics of public opinion formation. Here, we outline some of the directions we think further theory and simulation should take.

Attitude. Our simulation treated attitude as a two-state flip-flop system whereby individuals could be either pro or con, Republican or Democrat, in favor or opposed, rather than having graduated degrees of favorability. This treatment is consistent with the thrust of cognitive psychology, which treats attitudes as fundamentally categorical rather than dimensional in nature (Ostrom, 1988a). It also simplifies the simulation. It would be relatively easy, however, to model three-state systems, such as those suggested by Latané and Nida (1979) and Latané and Wolf (1981), in which groups of undecided or independent people are present.

We believe the crucial feature that makes our simulations have different properties from previous ones is the essential nonlinearity of the impact–attitude relationship, which results from this categorical representation. In physical systems such as those discussed earlier, when relationships between variables become nonlinear, the properties of the system may change dramatically, and, in some cases, systems governed by simple rules may exhibit very complex behavior.

Although we believe that complex behavior of the type observed in our simulations can be achieved only when the relationship between social pressure on an individual and his or her attitude is nonlinear, we do not think that the assumption that attitudes are dichotomous is crucial. The physicist Hopfield (1984) has shown that his neural network models still work with continuous rather than dichotomous variables, as long as the relationship between the forces acting on a given element and the state of that element is nonlinear. Evidence for nonlinear effects in attitude research can be found in Tesser (1978) and Crano and Cooper (1972).

In our present model, nonlinearity arises from the fact that when the ratio of persuasive to supportive impact is even slightly greater than 1, one's attitude shifts completely, so the resultant attitude is not proportional to the relative strength of persuasive and supportive forces. Even if we were to treat attitude as a continuous variable (i.e., a point on a scale), we could achieve similar results as long as the value of the attitude is some nonlinear function of the ratio of persuasive to supportive impact.

One such nonlinear function could include the hyperbolic tangent $[(e^{**}2x - 1)/(e^{**}2x + 1)]$, which has a very steep slope at intermediate values. With such a function, when the ratio of persuasive to supportive impact is approximately 1, the resulting attitudes will have intermediate values, but as the ratio departs from 1, attitudes quickly become extreme, as in our dichotomous model. The resulting distribution of attitudes will thus become bimodal, even though continuous, and should exhibit similar phenomena of polarization and clustering to those discussed earlier. Evidence for such a process can be found in the fact that, at least for important issues, attitudes are not distributed normally but rather tend toward bimodality (Latané & Martz, 1989; Suchman, 1950).

Random attitude changes. Our preliminary simulation assumed that after the initial random assignment of parameters, attitude change was completely determined by the group configuration. In reality, attitude change also results not from group impact, but from individual experiences and thought processes. We can think of these as random factors affecting attitude change, occurring in addition to those resulting from social impact.

In statistical physics, *temperature* refers to the rate of random changes in spin. At certain critical temperatures, there are phase transitions, characterized by qualitative changes in the behavior of the system. Introducing similar changes to the present simulation would allow the possibility of dynamic equilibria, in which the whole configuration displays stable properties such as the proportion of minority beliefs, whereas individuals continue to change.

Different issues and different groups might be characterized by differing "temperatures." Some attitudes may be especially sensitive to personal experience (attitudes toward crime might be greatly affected by being mugged—or by having a friend falsely arrested). Some groups may be especially exposed to external influence and thus subject to random change, whereas others may be particularly cohesive (Festinger, 1950) and thus dependent on the opinions of other group members. We want to use computer simulations to explore the effects of varying temperature and whether to expect phase transitions in the domain of public opinion.

Two or more issues. A major extension would be to model the dynamics of two or more issues simultaneously. In doing so, the first step would involve *setting the agenda.* People may differ with respect to what issues they are interested in or willing to talk about, as well as their position on those issues. We plan to extend the theory to consider social impact as a two-level negotiation. On one level, members influence each other as to the issue for discussion—on another, as to what is the "right" attitude on that issue. Thus, 2 persons with opposing attitudes might have the same interest in putting the issue on the agenda—whereas those interested in other issues would be treated as a different group. On the other hand, once the issue is raised, those with opposing points of view represent different groups, whereas those interested in other issues might act like independents, having no opinion themselves on the issue. A somewhat similar model (called a Potts model) in statistical mechanics allows different rules for some interactions than for qualitatively different ones.

A related question is what determines people's willingness to express their beliefs publicly. Presumably, impression-management concerns play a role, and it would be interesting to derive the implications of the social impact analysis of evaluation apprehension (Jackson & Latané, 1981; Latané & Harkins, 1976) for predicting reluctance to speak up on controversial issues (see also Noelle-Neumann, 1984).

The second step would be to explore the *development of ideology.* Clearly, individuals may have opinions on more than one issue, and these opinions may bear some relation to one another. Opinions seem to form clusters or belief systems (Erickson, 1982). Seemingly unrelated opinions may be correlated (i.e., being a vegetarian and being a liberal), and common ideologies sometimes seem to include contradictory elements (i.e., being for the death penalty but against abortion). It is not always intuitively obvious why attitudinal elements cluster. The degree to which attitudes correlate has been taken as an index of the prevalence of ideology (Converse, 1964), and it seems that, on these terms, ideology in the United States has increased since the widespread introduction of television in the 1950s (Nie, Verba, & Petrocik, 1976).

In 1979, Abelson made the intriguing suggestion that the intercorrelation of attitudes may reflect the operation of social influence processes rather than ideology. If there is differential communication among members of a society, local clusters of agreement may form, so that, across clusters, there will be a correlation of attitudes with no basis in underlying philosophic principle. Erickson (1982) presented a more complex model of the emergence of ideologies and belief systems from structured social networks.

In the present model, changes in attitude depend on the structure of immediacy. Because this structure is the same for different issues, we should expect, as interaction proceeds, correlations to develop among initially uncorrelated attitudes, with the size of these correlations depending on the length of interaction and the relative importance of persuasiveness and supportiveness.

Persuasiveness and supportiveness. In computer simulation, when one does not have a specific hypothesis as to how variables are related, it is considered good practice initially to let them vary randomly, as we did with persuasiveness and supportiveness. It would, however, be interesting to explore several variations in the treatment of these parameters. For example, we would like to know the effect of allowing the mean levels of persuasiveness and supportiveness to differ, of assuming a positive or a negative correlation between persuasiveness and supportiveness, of forming specific hypotheses as to whether persuasiveness would go up or down after attitude change, of introducing a resistance-to-change parameter, and of allowing persuasiveness or supportiveness to assume negative values, such that other people would be led to move away from positions adopted by such an individual.

It would be especially interesting to test a model in which the strength parameters of a person would not be equal for all members of the own or other group, but would be allowed to vary across individuals, for some even being negative. For example, instead of considering persuasiveness and supportiveness as general characteristics of individuals, we could assign a signed number to every relation between individuals, such that the sign of the number would represent whether the direction of influence is positive or negative, and its magnitude how powerful the influence.

The introduction of such negative couplings would make the model similar to spin-glass models in statistical mechanics. These show much more complex behavior than Ising ferromagnets. In such models, it is possible to specify the equilibrium states that will result from particular sets of bonds, enabling strong predictions (and therefore stringent tests of the model).

Immediacy. We treated immediacy as the Euclidean distance between individuals located in a two-dimensional grid. Other structural assumptions are also plausible. Calculating immediacy in a city block, rather than a Euclidean metric, or packing individuals in a hexagonal rather than a square grid, would probably have little effect on the outcome of our simulations. Assuming a conference table structure—perhaps as some combination of linear, side-to-side (whisper) and cross-table (broadcast) distances—might have more effect. Other group structures such as those modeled by Bavelas (1950) or Leavitt (1951) could also be included.

We could also think of distances between cells in the matrix as a representation of psychological distances (for example, assuming that neighboring cells correspond to friendships), but then the two-dimensional structure of the matrix would be unrealistic. Immediacy can perhaps best be considered simply as a number assigned to each pair of individuals, without imposing the two-dimensional Euclidean rules of distance (Erickson, 1988). Although we suspect this will ultimately prove the most useful way to represent group structure, for these simulations we stuck with a two-dimensional spatial representation because this made it much easier to visualize the final distribution of attitudes within groups.

Nearly any type of relationship, including physical immediacy and ease of communication between pairs of individuals in a set, may be conceived of as a network. Such a configuration might be displayed as a directed graph (Harary, Norman, & Cartwright, 1965) or as a matrix in which the rows and columns represent individual members of the set and the cells the distance or difficulty of communication between each available pair of individuals.

This kind of representation would allow one to shape the group structure at will. For example, one could represent an actual network of social contacts as obtained from survey data. Alternatively, one could model an organizational structure including both formal and informal channels of communication. Such a representation could even allow for asymmetrical immediacy such as in many hierarchical organizations where it is easier for the boss to initiate communication to subordinates than for subordinates to approach the boss. A particularly interesting possibility would be to model computer-mediated communication networks of the sort that are increasingly common in business and academia (Latané, 1987, 1988). One could also give individuals the ability to change locations in the structure by moving from one position to another or changing friendship ties.

Size. Although whether we used 1,600 or 3,600 people did not make much difference in the present simulations, reducing group size drastically might have substantially more effect, increasing the ratio of marginal to central areas.

Varying the rules. To simultaneously represent the impact of many people differing in strength and immediacy, the simulations reported earlier used the *average* impact of all the single individuals in the group multiplied by the square root of the number of individuals. Another alternative, which we now prefer, is represented by the formula

$$\hat{\imath}_p = [\sum(p_i/d_i^2)^2]^{1/2}.$$

This approach is also equivalent to Latané's (1981) original formula when strength and immediacy are constant but has the advantage of being less sensitive to the inclusion of people with extremely low immediacy in the group. Exploratory simulations suggest that it is unlikely that use of this alternative would make much difference in the present results.

There are several other interesting possible variations and additions to the rules of simulation, and it would be easy to complicate the model to fit any taste, introducing more psychological assumptions into the simulations. We wanted to keep the model as simple as possible to see what kinds of properties would emerge from these simple assumptions.

Individual differences in resistance to change and taste. In our simulations, we were mostly interested in modeling attitude change caused by social influence and did not include variables reflecting individual differences in resistance to change or personal taste, but these would be easy to model.

People may vary in their resistance to social pressure, changing attitudes only when pressure is greater than some threshold r representing individual differences in resistance: $\hat{\imath}_p/\hat{\imath}_s > 1 + r$.

Furthermore, attitudes may result not only from social context, but also from individual tastes and preferences. According to the functional theory of attitudes, individuals adopt attitudes that suit their interests. We can thus say that individuals are biased in favor of adopting particular attitudes. In contrast to resistance, which always makes change more difficult, bias will facilitate change in one direction and inhibit change in the other: $(\hat{\imath}_p \pm b)/\hat{\imath}_s > 1$, where b is added or subtracted according to the direction of influence.

Either of these variables could be allowed to vary with time or as a function of attitude change. It would be easy, for example, to specify that r increases after attitude change to model the hypothesis that after once changing, people grow more stubborn about future changes.

Advantages of Simulation

Computer simulation can serve as a test of a theory. Writing the simulation program is a test of the theory's completeness and lack of internal contradiction. The assumptions of the theory seem more valid when they produce phenomena that are known to occur in social reality. Sometimes, it is hard to test a theory on the level on which it was formed and useful to simulate it on a computer and find the consequences at a level that is easier to observe.

Computer simulation may reveal emergent properties of a social system stemming from laws assumed to operate on the individual level. When such properties do arise, we then need not assume group-level processes to explain them. For example, our simulations have shown that no special forces attracting people of similar attitudes to move closer together must be assumed to explain group coherence. Likewise, no special process of greater majority persuasion is required to explain group polarization, nor any notion of greater minority influence to account for the fact that polarization is incomplete. Latané's (1981) theory of social impact can unexpectedly explain such phenomena, showing that simple laws about individual social reactions can, when applied reciprocally and recursively, predict emergent group effects.

For reductive simulations such as the present in which the individual processes have been well documented, the simulation can help social scientists determine the limits of microlevel explanations for macrolevel outcomes. By analyzing the residual deviations from the model's null hypothesis baseline representing the cumulative consequences of individual processes, we can gain insight into desirable directions for postulating group-level processes.

James Gleick (1987), describing the development of the science of chaos over the last 20 years, reports on the growing realization that complex behavior does not imply complex causes but can arise from simple systems. This realization, by physicists, mathematicians, biologists, astronomers, and meteorologists, was greatly aided by the development of computer simulation. It is time we explored the possibility that seemingly complex social behavior may also result from simple processes. Perhaps some day we will be able to model not only the temporary equilibria reflected in laboratory groups and social surveys, but the shifting fads of popular culture and the deeper recurrent cycles of conservatism and liberalism (Schlesinger, 1986) that characterize society as a whole.

References

Abelson, R. P. (1964). Mathematical models of the distribution of attitudes under controversy. In N. Frederiksen & H. Gulliksen (Eds.), *Contributions to mathematical psychology* (pp. 142–160). New York: Holt, Rinehart & Winston.

Abelson, R. P. (1968). Simulation of social behavior. In E. Aronson & G. Lindsay (Eds.), *Handbook of social psychology* (Vol. 2, pp. 274–356). Reading, MA: Addison-Wesley.

Abelson, R. P. (1979). Social clusters and opinion clusters. In P. W. Holland & S. Leinhardt (Eds.), *Perspectives in social network research* (pp. 239–256). New York: Academic Press.

Abelson, R. P., & Bernstein, A. (1963). A computer simulation model of community referendum controversies. *Public Opinion Quarterly, 27,* 93–122.

Anderson, P. W. (1987). Spin glass Hamiltonians: A bridge between biology, statistical mechanics, and computer science. In D. Pines (Ed.), *Emerging syntheses in science* (pp. 95–112). Redwood City, CA: Addison-Wesley.

Bavelas, A. (1950). Communication patterns in task oriented groups. *Journal of the Acoustical Society of America, 22,* 725–730.

Bochner, S., & Insko, C. (1966). Communicator discrepancy, source credibility, and opinion change. *Journal of Personality and Social Psychology, 4,* 614–621.

Boyd, R., & Richerson, P. J. (1985). *Culture and the evolutionary process.* Chicago: University of Chicago Press.

Brock, T. C. (1965). Communicator–recipient similarity and opinion change. *Journal of Personality and Social Psychology, 1,* 650–654.

Brown, R. (1965). *Social psychology.* New York: Free Press.

Burnstein, E. (1983). Persuasion as argument processing. In H. Brandstatter, J. H. Davis, & G. Stocker-Kriechgauer (Eds.), *Group decision making* (pp. 103–122). London: Academic Press.

Burnstein, E., & Vinokur, A. (1977). Persuasive argumentation and social comparison as determinants of attitude polarization. *Journal of Experimental Social Psychology, 13,* 236–245.

Carley, K. (1989, February). *Group stability.* Paper presented at the Sunbelt IX Social Network Conference, Tampa, FL.

Carrothers, G. A. P. (1956). An historical review of the gravity and potential concepts of human interaction. *Journal of the American Institute of Planners, 22,* 94–102.

Catton, W. R. (1965). The concept of "mass" in the sociological version of gravitation. In F. Massarik & P. Ratoosh (Eds.), *Mathematical explorations in behavioral science* (pp. 287–316). Homewood, IL: Irwin.

Chaiken, S. (1979). Communicator physical attractiveness and persuasion. *Journal of Personality and Social Psychology, 37,* 1387–1397.

Chowdhury, D. (1986). *Spin glasses and other frustrated systems.* Princeton, NJ: Princeton University Press.

Cohen, B. P. (1963). *Conflict and conformity: A probability model and its application.* Cambridge, MA: MIT Press.

Cohen, B. P., & Lee, H. (1975). *Conflict, conformity, and social status.* Amsterdam: Elsevier.

Coleman, J. S. (1965). The use of electronic computers in the study of social organizations. *European Journal of Sociology, 6,* 89–107.

Converse, P. (1964). The nature of belief systems in mass publics. In D. E. Apter (Ed.), *Ideology and discontent* (pp. 206–261). New York: Free Press.

Crano, W. D., & Cooper, R. E. (1972, May). *A preliminary investigation of a hyperbolic model of attitude change.* Paper presented at the meeting of the Midwestern Psychological Association, Cleveland, OH.

Davis, J. H. (1973). Group decision and social interaction: A theory of social decision schemes. *Psychological Review, 80,* 97–125.

Davis, J. H., & Hinz, V. (1982). Current research problems in group performance and group dynamics. In H. Brandstatter, J. H. Davis, & G. Stocker-Kriechgauer (Eds.), *Group decision making* (pp. 1–17). London: Academic Press.

Davis, J. H., & Kerr, N. H. (1986). Thought experiments and the problem of sparse data in small group research. In P. Goodman (Ed.), *Designing effective work groups* (pp. 305–349). San Francisco: Jossey-Bass.

Dewdney, A. K. (1987). Computer recreations: Diverse personalities search for social equilibrium at a computer party. *Scientific American, 281*(July), 112–115.

Doise, W. (1986). *Levels of explanation in social psychology.* New York: Cambridge University Press.

Eagly, A. H., & Chaiken, S. (1975). An attribution analysis of the effect of communicator characteristics on opinion change: A case of communicator attractiveness. *Journal of Personality and Social Psychology, 32,* 136–144.

Eagly, A. H., Wood, W., & Chaiken, S. (1978). Causal inferences about communicators and their effect on opinion change. *Journal of Personality and Social Psychology, 36,* 424–435.

Erickson, B. H. (1982). Networks, ideologies, and belief systems. In P. V. Marsden & N. Lin (Eds.), *Social structure and network analysis* (pp. 159–172). Beverly Hills, CA: Sage.

Erickson, B. H. (1988). The relational basis of attitudes. In B. Wellman & S. D. Berkowitz (Eds.), *Social structures: A network approach* (pp. 99–121). Cambridge, England: Cambridge University Press.

Festinger, L. (1950). Informal social communication. *Psychological Review, 57,* 271–282.

Festinger, L., Schachter, S., & Back, K. (1950). *Social pressures in informal groups.* Stanford, CA: Stanford University Press.

Finifter, A. W. (1974). The friendship group as a protective environment for political deviants. *American Political Science Review, 68,* 607–625.

Friedkin, N. E., & Cook, K. S. (1989, February). *Peer group influence.* Paper presented at the Sunbelt IX Social Network Conference, Tampa, FL.

Gleick, J. (1987). *Chaos: Making a new science.* New York: Viking Press.

Goethals, G. R., & Nelson, R. E. (1973). Similarity in the influence process: The belief–value distinction. *Journal of Personality and Social Psychology, 25,* 117–122.

Greer, S. (1963). *Metropolitics: A study of political culture.* New York: Wiley.

Greer, S., & Orleans, P. (1962). The mass society and the parapolitical structure. *American Sociological Review, 27,* 634–646.

Greer, S., & Orleans, P. (1964). Political sociology. In R. Faris (Ed.), *Handbook of modern sociology* (pp. 808–851). Chicago: Rand McNally.

Hägerstrand, T. (1965). A Monte Carlo approach to diffusion. *European Journal of Sociology, 6,* 43–67.

Hanneman, R. (1986). *Computer-assisted theory building: Modelling dynamic social systems.* Beverly Hills, CA: Sage.

Harary, F., Norman, R. Z., & Cartwright, D. (1965). *Structural models: An introduction to the theory of directed graphs.* New York: Wiley.

Harris, R. J. (1976). The uncertain connection between verbal theories and research hypotheses in social psychology. *Journal of Experimental Social Psychology, 12,* 210–219.

Hass, R. G. (1981). Effects of source characteristics on cognitive responses and persuasion. In R. E. Petty, T. E. Ostrom, & T. C. Brock. (Eds.), *Cognitive responses in persuasion* (pp. 142–172). Hillsdale, NJ: Erlbaum.

Hogg, M. (1988, June). *Social identity and group polarization.* Paper presented at the Eleventh Nags Head Conference on Groups, Networks, and Organizations, Kill Devil Hills, NC.

Holtz, R., & Miller, N. (1985). Assumed similarity and opinion certainty. *Journal of Personality and Social Psychology, 48,* 890–898.

Hopfield, J. J. (1982). Neural networks and physical systems with emergent collective computational abilities. *Proceedings of the National Academy of Sciences USA, 79,* 2554–2558.

Hopfield, J. J. (1984). Neural networks with continuous element states also show emergent properties. *Proceedings of the National Academy of Sciences USA, 81,* 3088.

Hovland, C., & Weiss, W. (1952). The influence of source credibility on communication effectiveness. *Public Opinion Quarterly, 15,* 635–650.

Isenberg, D. J. (1986). Group polarization: A critical review and meta-analysis. *Journal of Personality and Social Psychology, 50,* 1141–1151.

Jackson, J. M., & Latané, B. (1981). All alone in front of all those people: Stage fright as a function of number and type of co-performers and audience. *Journal of Personality and Social Psychology, 40,* 73–85.

Kelley, H. H., & Volkart, E. H. (1952). The resistance to change of group-anchored attitudes. *American Sociological Review, 17,* 453–465.

Kenny, D. A. (1987). Social behavior at multiple levels. *Social Science, 72,* 104–106.

Kerr, N. L. (1981). Social transition schemes: Charting the group's road to agreement. *Journal of Personality and Social Psychology, 41,* 684–702.

Knowles, E. (1980). An affiliative conflict theory of personal and group spatial behavior. In P. Paulus (Ed.), *Psychology of group influence* (pp. 133–188). Hillsdale, NJ: Erlbaum.

Latané, B. (1981). The psychology of social impact. *American Psychologist, 36,* 343–365.

Latané, B. (1987). Social science should invest in infrastructure. *Social Science, 72,* 1–16.

Latané, B. (1988). Social psychology and how to revitalize it. *Journal of Social Behavior and Personality, 3,* 1–12.

Latané, B., & Darley, J. M. (1970). *The unresponsive bystander; Why doesn't he help?* Englewood Cliffs, NJ: Prentice-Hall.

Latané, B., & Harkins, S. (1976). Cross-modality matches suggest anticipated stage fright a multiplicative power function of audience size and status. *Perception & Psychophysics, 20,* 482–488.

Latané, B., & Martz, J. (1989). [Attitude importance and extremity]. Unpublished raw data.

Latané, B., & Nida, S. (1979). Social impact theory and group influence.

In P. Paulus (Ed.), *Psychology of group influence* (pp. 3–34). Hillsdale, NJ: Erlbaum.

Latané, B., & Nida, S. (1981). Ten years of research on group size and helping. *Psychological Bulletin, 89,* 308–324.

Latané, B., Williams, K., & Harkins, S. (1979). Many hands make light the work: Causes and consequences of social loafing. *Journal of Personality and Social Psychology, 37,* 822–832.

Latané, B., & Wolf, S. (1981). The social impact of majorities and minorities. *Psychological Review, 88,* 438–453.

Leavitt, H. J. (1951). Some effects of certain communication patterns on group performance. *Journal of Abnormal and Social Psychology, 48,* 401–409.

MacKuen, M., & Brown, C. (1987). Political context and attitude change. *American Political Science Review, 81,* 471–490.

McCoy, B. M., & Wu, T. T. (1973). *The two-dimensional Ising model.* Cambridge, MA: Harvard University Press.

McWhinney, W. H. (1964). Simulating the communication network experiments. *Behavioral Science, 9,* 80–84.

Moscovici, S. (1976). *Social influence and social change.* London: Academic Press.

Moscovici, S. (1985). Social influence and conformity. In E. Aronson & G. Lindsay (Eds.), *Handbook of social psychology* (Vol. 2, pp. 347–412). Reading, MA: Addison-Wesley.

Moscovici, S., & Zavalloni, M. (1969). The group as a polarizer of attitudes. *Journal of Personality and Social Psychology, 12,* 125–135.

Mullen, B. (1983). Operationalizing the effect of the group on the individual: A self-attention perspective. *Journal of Experimental Social Psychology, 19,* 295–322.

Myers, D. G. (1982). Polarizing effects of social interaction. In H. Brandstatter, J. H. Davis, & G. Stocker-Kriechgauer (Eds.), *Group decision making* (pp. 125–157). London: Academic Press.

Myers, D. G., & Lamm, H. (1976). The group polarization phenomenon. *Psychological Bulletin, 83,* 602–627.

Nie, N. H., Verba, S., & Petrocik, J. R. (1976). *The changing American voter.* Cambridge, MA: Harvard University Press.

Noelle-Neumann, E. (1984). *The spiral of silence: Public opinion, our social skin.* Chicago: University of Chicago Press.

Nowak, S. (1976). *Understanding and prediction: Essays in the methodology of social and behavioral theories.* Dordrecht, The Netherlands: Reidel.

Ostrom, T. (1988a, May). *Attitudes are categorical, not dimensional.* Paper presented at the Eighth Nags Head Conference on Social Cognition, Kill Devil Hills, NC.

Ostrom, T. (1988b). Computer simulation: The third symbol system. *Journal of Experimental Social Psychology, 24,* 381–392.

Penrod, S., & Hastie, R. (1980). A computer simulation of jury decision making. *Psychological Review, 87,* 133–159.

Petty, R., & Cacciοppo, J. (1986). The elaboration likelihood model of persuasion. In L. Berkowitz (Ed.), *Advances in experimental social psychology* (Vol. 19, pp. 123–205). New York: Academic Press.

Putnam, R. D. (1966). Political attitudes and the local community. *American Political Science Review, 60,* 640–654.

Rainio, K. (1965). Social interaction as a stochastic learning process. *European Journal of Sociology, 6,* 68–88.

Rumelhart, D., Hinton, G. E., & Williams, R. J. (1986). Learning representation by back-propagating errors. *Nature, 323,* 533–536.

Schlesinger, A. M. (1986). *The cycles of American history.* Boston: Houghton Mifflin.

Stasser, G. (1988). Computer simulation as a research tool: The DISCUSS model of group decision making. *Journal of Experimental Social Psychology, 24,* 393–422.

Suchman, E. A. (1950). The intensity component in attitude and opinion research. In S. A. Stouffer, E. A. Suchman, L. C. DeVinney, S. A. Star, & R. M. Williams (Eds.), *The American soldier: Adjustment during army life* (pp. 213–276). Princeton, NJ: Princeton University Press.

Tanford, S., & Penrod, S. (1983). Computer modelling of influence in the jury: The role of the consistent juror. *Social Psychology Quarterly, 46,* 200–212.

Tanford, S., & Penrod, S. (1984). Social influence model: A formal integration of research on majority and minority influence processes. *Psychological Bulletin, 95,* 189–225.

Tesser, A. (1978). Self-generated attitude change. In L. Berkowitz (Ed.), *Advances in experimental social psychology* (Vol. 11, pp. 289–338). New York: Academic Press.

Walster, E., Aronson, E., & Abrahams, D. (1966). On increasing the persuasiveness of a low-prestige communicator. *Journal of Experimental Social Psychology, 2,* 325–343.

Walster, E., & Festinger, L. (1962). The effectiveness of "overheard" persuasive communications. *Journal of Abnormal and Social Psychology, 65,* 395–402.

Weidlich, W., & Haag, G. (1983). *Concepts and models of a quantitative sociology: The dynamics of interacting populations.* New York: Springer-Verlag.

Wolf, S., & Latané, B. (1983). Minority and majority influences on restaurant preferences. *Journal of Personality and Social Psychology, 45,* 282–292.

Wood, W., & Eagly, A. (1981). Stages in the analysis of persuasive messages: The role of causal attribution and message comprehension. *Journal of Personality and Social Psychology, 40,* 246–259.

Ziman, J. M. (1979). *Models of disorder.* Cambridge, England: Cambridge University Press.

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