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Communication and Optimality in Biosocial Collectives

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Raymond Trevor Bradley and Karl Pribram's chapter, ***Communication and Optimality in Biosocial Collectives****, is unique among the chapters in this book in that it deals with optimality in social systems composed of people, rather than individual nervous systems composed of brain regions. It is related to this book's other chapters, however, because of the strong analogies between different levels within complex nonlinear dynamical systems. Just as typical neural networks, whose nodes are brain regions rather than individual neurons, include effects that can be described by the average of effects in single neurons, social networks include effects that can be described by the average of effects in individual brains.*

Bradley and Pribram describe two key variables in the dynamics of urban communes that need to be in optimal ranges for a commune to have a good chance of surviving over periods of four years or more. These two variables they call flux and ***control****. Flux is defined as the density of interactions between different members of the commune. Because flux is related in some sense to the amount of "excitement" or "stimulation," optimal flux appears to be related to the criterion, developed in Rosenstein's chapter of this book, of optimal "income" within an individual brain. Control is defined as the extent to which rules or hierarchies govern these interactions.*

The optimal patterns of flux and control can be related in many ways to theories of individual brains and neural networks. Pribram relates these variables, by analogy, to physical energy variables, and concludes that the stable states correspond to configurations that obey some kind of least action principle. Previously, in joint work with Diane McGuinness, Pribram had related such principles to optimal functioning of a brain system that includes the frontal lobes *and hippocampus, among other areas. Also, the optimal states can be described as states that lie in a region, as Bradley and Pribram say, "between total randomness and total organization." These states are described by a thermodynamic analogy also used in neural networks developed, for example, by John Hopfield, Geoffrey Hinton, and Terrence Sejnowski.*

Bradley and Pribram's chapter can be considered part of the same project as Leven's chapter in this book (and, to some degree, the chapters by Levine, Prueitt, and Werbos). That project aims to bring insights from neural network theory and cognitive science to bear on developing new theories in the social sciences (in the case of this chapter, sociology). This project should address the sore need in the social sciences for foundations that (a) are quantitative and at the same time (b) integrate the dynamics of real human behavior and emotions.

ABSTRACT

A theory of communication is developed to explain optimization in the social collective: to explain how energy expenditure interacts with control operations to form an efficient information processing system that results in a stable, effective collective. The theory shows how two orders of social relations, flux and control, act on the biosocial energy of the collective's members to create quantum-like, elementary units of information. Each unit of information contains a description of the collective's endogenous organization. Constructing and distributing such descriptions throughout the collective on a moment-by-moment basis, the interaction between the two orders operates as a communication system that *in*-forms (gives shape to) the expenditure of energy and results in stable, effective collective action. Results from a longitudinal study of 57 social collectives offer empirical support for the theory. Only those configurations of flux and control that produced a path of least action — one which entailed the smallest amount of turbulence — resulted in a stable and thus effective social collective.

> One has the vague feeling that information and meaning may prove to be something like a pair of canonically conjugate variables in quantum theory, they being subject to some joint restriction that condemns a person to the sacrifice of the one as he insists on having much of the other. (Shannon & Weaver, 1949, p. 117).

1. INTRODUCTION

The picture of reality that science portrays reflects the way science is organized. Broadly speaking, this organization divides science into distinct disciplines (e.g., sociology, psychology, biology, chemistry, and physics), each perceiving the natural world by way of its own perspective and techniques. Reflecting this organization, most behavioral science is a single-level enterprise generating bodies of data and theory specific to the phenomena of concern. This is especially true of contemporary sociological research which, since Emile Durkheim's *Les Regles de la Methode Sociologique* (1895/1938), has treated (human) social interaction as a separate order best understood by studying the ways social organization constrains the behavior of the individual and that of collectives of individuals (e.g., Burt, 1992; Coleman, 1990; White, 1992; a notable exception is Collins, 1975).

Essential as single-level enterprises are, some of the most exciting moments in the history of science have come when data collected from adjoining levels provide insights that point to the possibility that scientific knowledge can be woven into a single coherent tapestry. Such insights are the product of multilevel investigations that focus on the interlinkages between systems of organized behavior at adjacent levels.

The broader aim of this chapter, therefore, is to relate social phenomena to basic concepts that have developed in physics and control engineering. Beyond the urgency and importance of the development of a common scientific language (Bishop, 1995), we take this approach because single-level research in social science has not been successful in predicting the behavior of social collectives, and because we believe that the development of this understanding can be informed by concepts that have proven useful in these fields.

Two steps are usually required to obtain insights when using a multi-level approach. The first step is to discern commonalities in the behavior of collectives operating at different levels and to describe these in a common terminology. For instance, an assembly of neurons in the brain is conceived to obey the same laws of communication as an assembly of people in a social group. A formal approach to this step was taken by General Systems Theory (Miller, 1968; von Bertalanffy, 1969). The second step seeks an understanding of the intimate relations that connect two adjacent levels of inquiry. Ideally, the operation of these relations, formally described as transfer functions (transformations), must account for the results obtained in the first step (see Nicolis & Prigogine, 1977; Pribram, 1991). As an explanation of the periodic table of chemical elements, atomic number theory is a prime example of this second step (Bohr, 1921a, 1921b). In this report we take only the first of these steps to explain optimization in the social collective: to explain how energy expenditure interacts with control operations to form an efficient communication system that results in a stable, effective collective.

We draw our insights and formalisms from thermodynamics and information measurement theory to help understand the communicative structure of small social collectives. In a subsequent work, we plan to describe the transfer functions (rules) by which the processes these formalisms embody are translated into psychological and sociological mechanisms operative in the collective. Thus the multilevel strategy is *not* being employed in the service of reductionism; indeed, as essential as single-level science is, we believe it must be complemented with multilevel work if a general scientific account of the behavior of collectives is to be achieved.

Scientific exploration is often dependent on the invention and application of new technology. One of our premises is that ideas derived from the formalisms of mathematics provide a technology that can be applied to data acquisition and analysis, especially as implemented in computer programs. The formalisms provide ways of expressing, in precise form, problem-solving algorithms, that is, ways of thinking about data sets. Mathematics in this sense is the technology of thinking.[1]

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[1] This view of mathematics was expressed explicitly by Grassmann (Lewis, 1977, p. 104) who founded an algebra to represent the thought process. On the basis of Grassmann's work, Clifford developed an eight-valued (two-quaternion) algebra used by David Bohm and Basil Hiley (1993) in formulating issues in quantum mechanics.

Our report can be conceived, therefore, as an experiment in which we are tentatively applying computational devices, algorithms, found useful in stating and solving problems in other scientific endeavors. Computers are to the behavioral sciences what test tubes are to biochemistry. Both are "in vitro," silicon-based technologies, means by which energy relationships, control processes, and information transmission can be studied.

In what follows, we present a theory of global communication in social collectives. By *global communication* we mean a process by which information about the collective's internal organization is gathered, processed, and distributed throughout the system as a whole. A social collective is defined as a durable arrangement of individuals distinguished by shared membership and interaction in relation to a common purpose or goal. The theory shows how two orders of social relations act on the biosocial energy of the collective's members to create elementary units of information. Each of these units of information contains a description of the collective's endogenous organization. Constructing and distributing such descriptions throughout the collective on a moment-by-moment basis, the interaction between the two orders operates as an efficient communication system that informs the expenditure of energy to effect stable, effective collective action. We ground our understanding on the empirical results of a study of 57 social collectives.

2. PURPOSE AND APPROACH

The approach we develop differs in a number of important respects from the kind of understanding generally offered by social science in accounting for social behavior. A basic difference is our focus on an elemental order of communication, an order that is more inclusive than the restricted concept of (human) communication generally employed in social science. Emphasizing the cultural basis of *human* sociation, the term is generally used to denote interaction that involves the exchange of normatively defined meanings and understandings among purposeful social actors (Cherry, 1966). Irrespective of whether it occurs in an interpersonal or a collective context, communication is viewed as centered on the individual — transpiring between or among self-conscious actors, either in the pursuit of their own goals or in the roles they play as agents for collectives (Rogers & Kincaid, 1981; Jablin, Putnam, Roberts, & Porter, 1987).

The broader concept of communication that we develop here is similar to the notion of communication that underlies the "connectionist" computational models of "brain-style processing" (Rumelhart, 1992, p. 69). In these models synchronous parallel distributed processing among densely connected artificial "neural networks" is shown capable of encoding and "learning" quite complex patterns of "knowledge" and behavior (see Rumelhart, McClelland, & the PDP Research Group, 1986, and McClelland, Rumelhart, & the PDP Research Group, 1986, for examples). Here, information processing (computation) occurs *in the pattern of excitatory and inhibitory relations that interconnect all of the "neuron-like" nodes of the "neural network;"* it does *not* occur in the nodes themselves. This is the same core idea in our concept: a field of relations in which it is the interaction among different orders of social connection that processes and transmits information throughout the collective. Rather than being centered on the individual social actor, as is the case in the "block model" analyses (Freeman, White, & Romney, 1989; White, Boorman, & Breiger, 1976) and the "system dynamics" models of social systems (Forrester, 1968; Legasto, Forrester, & Lyneis, 1980), the locus of communication in our concept is the interaction among networks of social relationships connecting all members.

Another difference concerns our use of formalisms in place of the metaphorical analogies often used to portray aspects of the social collective that appear to endow it with the qualities of a sentient entity. Emile Durkheim used the notion of "collective consciousness" to portray what he believed to be the collective's psychic capabilities:

> The collective consciousness is the highest form of the psychic life, since it is the consciousness of the consciousnesses. Being placed outside of and above individual and local contingencies, it sees things only in their permanent and essential aspects, which it crystallizes into communicable ideas. At the same moment of time that it sees from above, it sees farther; at every moment of time it embraces all known reality; that is why it alone can furnish the mind with the molds which are applicable to the totality of things and which make it possible to think of them. (Durkheim, 1915/1965, p. 492)

More recently, largely in response to the emergence of so-called "cognitive science," a growing number of social scientists have drawn parallels between the organization of information processing in the brain and communication and behavior in the social collective (Bougon, 1983; Bradley, 1987; El Sawy, 1985; Garud & Kotha, 1994; Glazer, 1986; Hutchins, 1991; MacKenzie, 1991; Morgan & Ramirez, 1984; Sandelands & Stablein, 1987; Weick & Roberts, 1993). For instance, Hutchins (1991) drew on the distributed properties of neural processing to describe how redundancy in "overlapping" cognitive knowledge among individuals within a collective forms a system of mutual constraints to coordinate actions at the collective level. Sandelands and Stablein (1987) extended the analogy further and argued that in the same way that connections among neurons encode concepts and ideas in the brain, connections among social activities encode concepts and ideas in the collective. And although Weick and Roberts (1993) acknowledged that such metaphorical reasoning is a "shaky basis" for a theory of "organizational mind," they nonetheless contended that connectionism's sociological utility lies in the "insight" it offers, namely, that "relatively simple [social] actors may be able to apprehend complex inputs if they are organized in ways that resemble neural networks" (Weick and Roberts, 1993, p. 359; our addition).

However, although these analogies may offer descriptive imagery with which to characterize these poorly understood features of collective organization, there is always the risk of false attribution, which can yield obfuscation instead of explanation. Thus, we use the more neutral term *communication* instead. Because the formalisms we employ provide explicit principles that appear to account for such properties of collective organization, they offer a rational basis — one based on reason and logic — for building scientific understanding.

Social science has long recognized the importance of two basic patterns of social organization. Although these have been expressed in a variety of terms — formal versus informal organization (Roethlisberger & Dickson, 1939), rational versus natural systems (Selznick, 1948), sociotechnical versus socioemotional systems (Trist & Bamforth, 1951), mechanistic versus organic organization (Burns & Stalker, 1961), instrumental versus expressive leadership (Bales, 1958) among others — underlying these conceptualizations is a deeper (often implicit) dimensionality: a distinction between *hierarchical* and *heterarchical* forms of organization, between a pattern of organization based primarily on explicit relations of social rank and social control and a pattern of social connection that is more fluid and transitory involving an equivalence among individuals.

Previous analyses of the groups in this study (Bradley, 1987; Bradley & Roberts, 1989a, 1989b), have shown that these two patterns of organization form the communicative structure of the social collective — a heterarchical field of energy expenditure (that we refer to here as flux) and a constraint system of hierarchical controls (see Fig. 21.1). The heterarchical field, a distributed, massively parallel network of symmetrical relations in which members of the collective are essentially interchangeable, activates and unifies the biosocial energy of individuals. The hierarchical controls, a densely interconnected stratified order of asymmetrical relations in which the position of each individual is unique, operate on this field to produce an information processing network. By constraining the paths of energy expenditure, the controls render the potential for an informed pattern of collective action.

Following up on these earlier findings, the question posed here is whether insights and formalisms derived from thermodynamics can illuminate the biosocial interactions that compose the heterarchical order, and whether insights and formalisms derived from control engineering can illuminate the functions of the hierarchical order. Finally, our purpose is to enquire whether the interaction between heterarchy and hierarchy can be best understood as an instance of information processing in which data about flux (unfolding sequences of relations) and position (spatial-temporal location) are combined to create elementary units of information that provide optimal, moment-by-moment descriptions of the collective's endogenous organization.

3. THEORY

3.1. Assumptions

We begin our experiment in theory by limiting our task in four ways. First, our interest is restricted to collectives that have an explicit boundary distinguishing members from nonmembers; our account does not include partially bounded structures such as cliques or open-ended entities such as social networks.[1] Second, we leave aside any influence that normative elements, such as cultural values, norms, and roles, may have on the organization and action of social collectives, and on the behavior of their members. Third, apart from their biosocial potential — their capacity for physical and social activity — we ignore effects that the characteristics of the

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[1] It is important to note that *all* members of the collective are included; this follows from our concept of communication, the interaction among networks of relations connecting all individuals in a collective. As mentioned, it is the same notion that underlies connectionist models of "neural networks." This is a different approach than that employed by most social networks researchers and system dynamics modelers in which the criterion of "mutual relevance" (Laumann, Marsden, & Prensky, 1982) is used to include only those actors who are (contextually) relevant to each other in the system.

collective's members, as individuals (e.g., gender, age, personality etc.), may have on system behavior.

Our fourth restriction is to limit our focus to the endogenous operations that characterize the collectives under study. Here we make the simplifying assumption that, to be exogenously effective, the collective must be stable. Our interest lies in exploring the efficiency of the *endogenous processes* by which stability is achieved, of developing an understanding of which patterns of endogenous organization are *optimal* for the collective's actions that result in stability (Coleman, 1990, p. 42). We will leave for a later discussion the question of the collective's effectiveness in its environment.

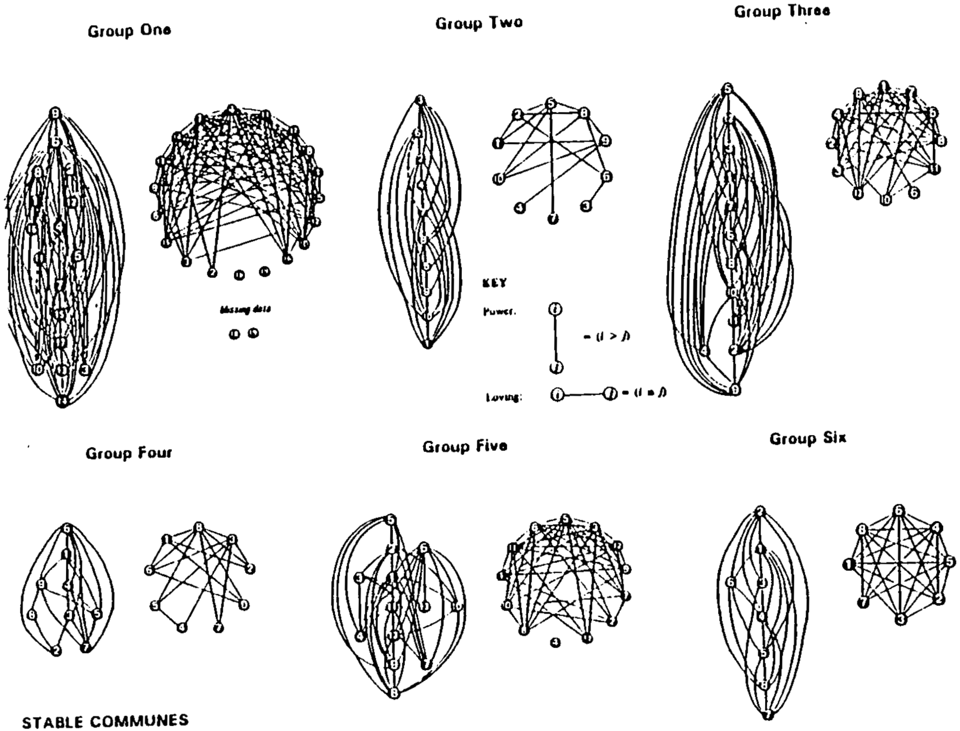
3.2. Energy and Least Action

The *distinction between effectiveness* and efficiency is derived from a rigorous definition of energy. Because *energy* is a rarely used term in social science — one that when it is used, is used as a metaphor (e.g., Collins', 1990, notion of "emotional energy") instead of as a scientific concept, we turn to the natural sciences for our use of the concept.

In the physical and biological sciences, energy is a measure of an amount of (physical) work that can be accomplished (McFarland, 1971). Two types of energy can be *distinguished*, kinetic and potential. When work is actually being done in producing change, it is defined as *kinetic energy*; the measure is directly proportional to the amount of kinesis, that is, to the amount of physical activity required to produce change. *Potential energy* is inferred from an estimate of the amount of possible work that a situation provides. It is an inference based on similarity to conditions that have been previously observed to transform potential into work.

In most physical and biological systems, there is a tendency to minimize work in order to conserve energy. This is known as the *least action principle* or the system's Hamiltonian function. In its general formulation, the principle holds that a system is maximally stable (i.e., at *equilibrium*) under conditions that maintain potential energy at a minimum (Considine, 1976, p. 1454). This means that any departure from equilibrium — any disequilibrating change in the system's structure — creates potential energy. For example, a pendulum at rest is at equilibrium: any change in conditions that disequilibrates the pendulum pushes or pulls it into positions in which the potential energy for returning to equilibrium becomes greater than that at equilibrium. In order to return to equilibrium, the system must expend the potential energy by performing work to use it up.

The *initial measure of efficiency came* from building steam engines. The aim was to convert the action of steam into useful work by minimizing its dissipation into friction and other useless generators of heat. Much experimentation with different engines was required to achieve this objective; it took effort to develop an efficient steam engine. *Effort*, in this sense, is directly related to *internally* attaining efficiency; whereas *effectiveness* deals with the total amount of work necessary to accomplish an *external* goal, irrespective of how much effort is expended (Pribram & McGuinness, 1975; Pribram, 1991, Chapter 9).



STABLE COMMUNES

(a)

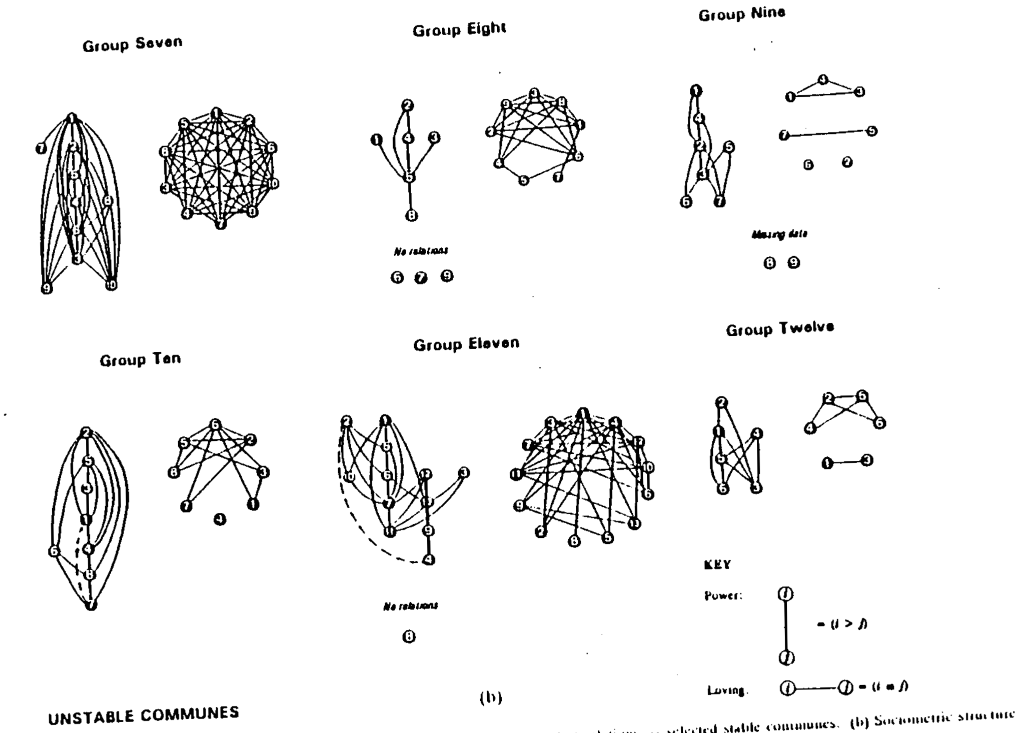


Fig. 21.1. (a) Sociometric structure of "power" (hierarchy) and "loving" (heterarchy) relations — selected stable communes. (b) Sociometric structure of "power" (hierarchy) and "loving" (heterarchy) relations — selected unstable communes.

To apply these concepts of energy, we assume that the members of the social collective are biologically capable of work — of engaging in physical behavior and activity, and that this capability is measurable as potential energy. When activated by the collective, the members' potential energy is converted into biosocial potential, the capability for engaging in social behavior or interaction. Actualizing this biosocial potential entails work; work is measured as kinetic energy. Because the dynamic operation of a collective requires an almost constant transformation of energy back and forth between potential and kinesis, as the collective continuously adjusts to internal and external changes, we use the term *flux* to characterize the medium of this continuous transfer of energy.

In its striving towards an efficient use of energy, the collective transforms potential to kinetic energy. The tendency to energy conservation requires effort on the part of the collective to explore and identify alternative paths of action to devise those that allow work to proceed efficiently, that is, with the least amount of dissipation.

How is a course of least action implemented? In the physical sciences a least action path (one that is *optimal* for the system) is determined by piecewise subtraction of potential by kinetic energy. Potential energy is reduced — through a series of successive fluctuations between potential and work — until its minimum level is reached.

One may conceive the path in this process as being determined by a landscape of constraints that channel the pattern of the actualization of potential into work. An example is when a river emerges from a mountain lake to course its way, by virtue of gravity, down the hillsides to the sea. Although at each point of the flow the river's potential energy is determined by the point's elevation above sea level, the flow path of the river — the pattern of its actualization of potential into work — is influenced by constraints obtaining to the terrain such as climate, vegetation, topography, geology, and so forth. A region of hard rock will interpose turbulence and require more effort than that of soft rock for the river to carve a direct, and thus an energy-efficient, path to the sea.

In an analogous fashion, a social collective constructs a landscape of social constraints to channel the actualization of the potential energy of its members into useful collective work. To the extent that least action holds, the effort demanded is that of seeking and then implementing an optimal landscape of endogenous relations that promote efficient group action. For instance, Henry Ford experimented with different ways of joining together the energy of his factory workers to find the maximally efficient organization for manufacturing cars (Lacey, 1986). To do this, he implemented a set of constraints, based on his invention of the production line and its associated techniques of mass production, that directed and thus optimized the action paths among the collective of workers; he produced automobiles at minimum cost, which, in turn, proved effective in the market place.

3.3. Conjunction and Control

Within this theoretical framework, two processes can be identified that act to generate descriptions of the collective's internal organization. The first is *conjunction*, which joins the biosocial potentials of the individuals composing the collective. The second is *control*, the construction of a landscape of social constraints that efficiently directs the transformation of potential into action. As detailed shortly, the landscape determines a communication processing network that generates patterns of actualization of the potential of the collective. The intricacy (complexity) of each successive configuration of these patterns is processed by the collective as a measure of information — as the means for describing its endogenous organization. Thus, the measure of information provides moment-by-moment descriptions of the endogenous order that are communicated by a holographic-like process throughout the collective (Bradley, 1987, Chapter 9).

Conjunction is achieved within a field of reciprocally equivalent (*equi-valent*, of equal value) relations among individuals. Within such a field a heterarchical order operates in which there is an absence of differentiation in terms of social status or rank, so that all individuals share in common a connection of social equality. As a result, the individuals are mutually open to each other and, by extension, open to the collective as a whole. Thus, the field of heterarchical relations describes the potential biosocial energy — the potential for work — of the collective.

In the absence of other factors, initial conditions (such as negative feelings like fear, hatred, or jealousy) will block the efficient conversion of potential to kinetic energy; in non-linear dynamics such systems are characterized by negative Lyapunov exponents leading to stasis, ossification (complete [physical] equilibrium), or to fluctuations described by relaxation oscillators (Abraham, 1991). On the other hand, as elaborated below, initial conditions such as admiration, awe, or love create a kind of harmonic resonance in the relations among members that will enhance the conversion of potential to kinetic energy. The danger here, if this enhanced kinetic energy is unconstrained, is that undue dissipation of energy will ensue: in the language of nonlinear dynamics, chaos will result.

The second process is control, a landscape of social constraints that influences the conversion of potential energy to kinetic energy, that is, the patterning of flux. Control is achieved by a transitively ordered structure of social relations among members that prevents the dissipation of kinetic energy. By precluding undue dissipation, the controls shape the paths of flux, thereby *in-forming* — giving shape to — the relations among individuals.[1]

3.4. Information and Efficiency of Communication

Surprisingly, given the rich, dense flow of verbal and nonverbal signals that comprise human interaction, information is rarely used as a rigorous concept in social research: in three recent influential works (Coleman, 1990; Burt, 1992; White, 1992) it is employed as an undefined term. Irrespective of whether the term is explicitly defined (e.g., Rogers & Kincaid, 1981, pp. 48-51) or not, its use in social science corresponds to Shannon's (1949) concept of information, that is *as a reduction of uncertainty through choice among alternatives*. In this conception the smallest unit of information is the *bit*, the binary digit — nowadays corresponding to the smallest standard unit of information in computational information systems. Shannon's concept of information applies to symbol-based communication systems, like human language. In such systems each unit of information in a sequence contributes to resolution of the signal's message by reducing the probability of alternative meanings.

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[1] This conception is similar to Bohm and Hiley's notion of "active information" (see Bohm & Hiley, 1993, pp. 35-42, 59-71).

There is, however, a second concept of information used in the physical and biological sciences, virtually unknown in the social sciences. Because we employ this second concept to show how the interaction between heterarchy and hierarchy operates as a communication system to construct and distribute information, we turn to the natural sciences for our use of this concept.

Our discussion is informed by work on signal processing in telecommunications (see Cherry, 1966, for an excellent review). Two distinct properties of the signal have been utilized for transmission in telecommunication. One is the signal as a sequence of discrete pulses encoded in time, as in the use of Morse (or similar) code for telegraphic communication. The other encodes the signal as a pattern of energy oscillations across a waveband of frequencies, as in the encoding and transmission of vocal utterances for telephonic communication. Although the frequency aspects of a signal's oscillation are irrelevant for telegraphy, for telephone communication they are critical as fidelity is dependent on the spectral components of the signal (frequency, amplitude, and phase). It took some time, though, in the early part of this century, to realize that there was a relation between the rate of transmission of a given quantity of information and frequency bandwidth (Nyquist, 1924; Kupfmueller, 1924). This relation was generalized by Hartley (1928, p. 525): "the total amount of information which may be transmitted ... is proportional to the product of frequency range which is transmitted and the time which is available for the transmission."

Gabor (1946) formalized this relationship in his "Theory of Communication." He noted that there is a restriction to the efficiency with which a set of telephone signals can be processed and communicated. The restriction is due to the limit on the precision to which concurrent measurements of spectral components and the (space)time epoch of the signal can be made. This restriction is illustrated in the top of Fig. 21.2, in which time and frequency are treated as orthogonal coordinates. Although the frequency of a harmonic oscillation, represented by a vertical line, is exactly defined, its duration in time is totally undefined. Conversely, a sudden surge (a "unit impulse function") or change in the signal, the horizontal line, is sharply defined in time, but its energy is distributed evenly throughout the whole frequency spectrum. Thus, although accurate measurement can be made in time or in frequency, *it cannot be simultaneously made in both beyond a certain limit* (Gabor, 1946, pp. 431-432).

Gabor was able to show, mathematically, that this limit could be given formal expression by Heisenberg's uncertainty principle (Heisenberg had developed his mathematical formulation of uncertainty to define the discrete units of energy, *quanta*, emitted by subatomic radiation). In its rigorous form the uncertainty relation is given as $\Delta t\ \Delta f \geq \frac{1}{2}$, which states that t (time) and f (frequency) cannot be simultaneously defined in exact terms, but only with a latitude of greater than or equal to one-half in the product of their uncertainties. Since certainty can be obtained only by minimizing uncertainty on both coordinates, the *minimum measurement* of the signal in time *and* frequency is $\Delta t\ \Delta f = \frac{1}{2}$, which defines an *elementary unit of information* (Gabor, 1946, pp. 431-437).

This unit of information both minimizes uncertainty and provides the maximally efficient description of communication (the minimum space or time of transmission occupied by the signal that still maintained the fidelity of telephonic communication). Gabor called his unit of optimal efficiency a *logon*, or a *quantum of information* (illustrated in the middle of Fig. 21.2), and showed that the signal that occupies this minimum area "is the modulation product of a harmonic oscillation of any frequency with a pulse in the form of a probability function" (Gabor, 1946, p.

435). This fundamental unit of information is a sinusoid variably constrained by space-time coordinates; it differs from Shannon's unit of information, the binary digit (BIT), which is a Boolean choice between alternatives (Pribram, 1991, p. 28).

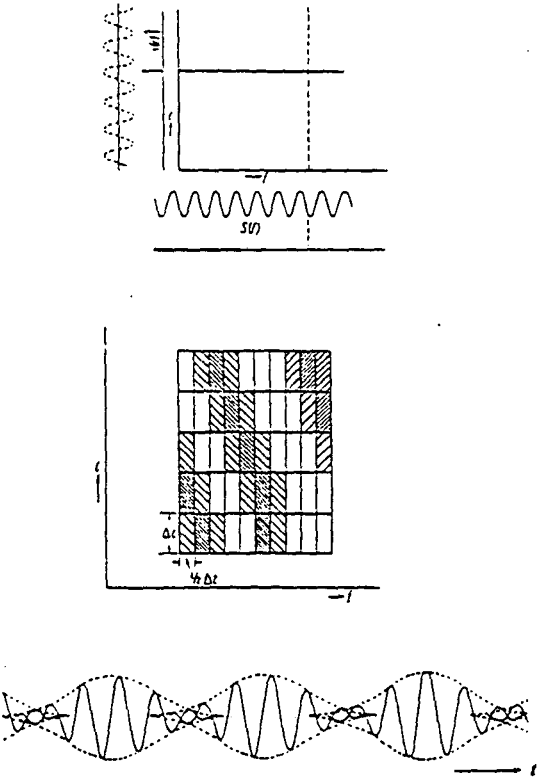

Fig. 21.2. (Top) Limits of concurrent measurement of time (t) and frequency (f) of a signal. (Middle) Representation of a signal by logons. (Bottom) Representation of the overlap of logons. (From Gabor, 1946, Figs. 1.3 and 1.7. Adapted with permission.)

A final point concerns an important implication of the use of these mathematics for the role of causality in communication involving these elementary units of information. Because logons are not discrete units but occur as overlapping sinusoids, each wrapped in a Gaussian probability envelope (illustrated in the bottom of Fig. 21.2), each logon contains, in Gabor's words, an "overlap (with) the future." This is a result of using time as one of the (measurement) dimensions because "the principle of causality requires that any quantity at an epoch *t* can depend *only* on data belonging to epochs earlier than *t*. ... In fact, *strict causality exists only in the 'time language'*" (Gabor, 1946, p. 437; our emphasis). What is of special interest here is the extent to which this overlap (interference) among logons yields a communicative system in which the data in succeeding logons is contained, in a nontrivial way, in the logons that preceded them: in other words, that information about the "future" order is enfolded into the elementary units of information being processed in the "present" (see Bradley, 1996, for more on this).

The Gabor elementary function, as it is often referred to, has been found to characterize perceptual processing in the cerebral cortex (see Pribram, 1991, for a review). It is, therefore, an alternative unit for biological information processing to Shannon's (1949) unit of information, the BIT. Moreover, two previous findings from the social collectives examined in this study document an order of communication that does not seem describable within the terms of Shannon's concept but appears more readily understood within Gabor's terms. One is a holographic-like order in which information about the organization of the collective as a whole was found to be distributed as a nonlocalized order to all individuals, and the second is that this order was found to be constrained by a system of hierarchical relations (see Bradley, 1987, Chs. 8 and 9, respectively).

To summarize (Fig. 21.3), two very different modes of organization characterize the hierarchical and heterarchical operations of relations within the collective. Because individuals are asymmetrically connected in the hierarchical order, the system of controls operates differentially on the collective's members, both with respect to their particular socio-spatial location as well as with respect to actualization during particular frames of time. By contrast, the symmetric bonds of the heterarchical order indicate that individuals are essentially equivalent in terms of the pattern of distribution of flux within this endogenous field. As this field is an energy field, it lies within the spectral domain (energy is measured in terms of frequency times Planck's constant) and is related to space and time by way of a transformation (the Fourier transform).

The operation of hierarchical controls on the heterarchical distribution of flux generates a moment-by-moment — *quantized* — description of the collective in terms of both structure (spatial-temporal position) and flux (frequencies of oscillation of unfolding relations). By providing, thus, a succession of descriptions within space-time and spectral coordinates, quantum-like Gabor units of information are constructed and communicated, via a holographic-like process, throughout the collective. These units of information characterize the endogenous order as it evolves in a continuing series of interactions. Because each unit of information overlaps with the unit that succeeds it, each unit contains information about the future (potential) order of the collective. However, whenever there is an imbalance between the amount of distribution of flux and the amount of control, the efficient operation of the collective becomes impaired and the probability of instability is increased. This impairment is due to what Ashby (1956) characterizes as the necessity for "requisite variety."

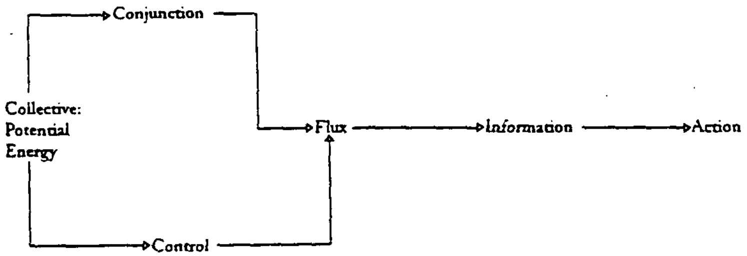

Fig. 21.3. Logic of theoretical model.

4. METHOD AND DATA

The data were gathered over a decade ago as part of a nationwide longitudinal field study of 60 urban communes (Zablocki, 1980); a commune was operationally defined as a minimum of three families, or five non-blood-related adults (persons aged 15 years or older), who shared, to some degree, common geographical location, voluntary membership, economic interdependence, and some program of common enterprise, usually spiritual, social-psychological, political, cultural, or some combination of these (Bradley, 1987, p. 14). Stratified on a number of basic social characteristics, and sampled in equal numbers from six Standard Metropolitan Statistical Areas (Atlanta, Boston, Houston, Los Angeles, Minneapolis-Saint Paul, and New York), various formal and informal methods were used to study the communes. Data from 57 communes are used in this report; three communes from the original sample were not included as membership in these groups was not completely voluntary (for more detail on the methods and sample of the original study, see Zablocki, 1980, & Bradley, 1987).

In terms of the sample's social characteristics (Table 21.1) at the time of the first wave of data collection (the summer of 1974), the communes ranged in size from 5 to 35 permanent adult members (mean size = 10 members) and had been in existence from 3 months to 9 years (mean commune age = 3 years). A total of 566 adults (15 years and older; mean age = 25 years), with slightly more men than women, were residing in the communes; most had never been married. Being a generally well-educated population, most reported working at a full-time white collar or professional job. In terms of social organization, the communes covered a wide spectrum of cultural values and included Christian religious, Eastern religious, personal growth, family, countercultural, and political ideologies. Most communes had special requirements for membership, and most also had incorporated elements of formal organization into their social structure (e.g., chore rotation, mandatory rules, positions of leadership and office, decision-making procedures, group rituals etc.).

The following set of items is from "page three" of the "Relationship Questionnaire" (see Bradley, 1980, for the complete instrument) and is the source of most of the relational data Bradley employed in his study. Each respondent received a questionnaire with multiple copies of "page three" inserted in it — one page for each other adult resident. A respondent in a commune with a population of nine, for example, would receive a questionnaire with eight page threes. Each of these page threes had one of the commune members' names typed in at the top (e.g., "This sheet is about ______________"). By completing this questionnaire, each respondent supplied information systematically describing his/her reaitionship with each of the *other* members of their commune.

5. This sheet is about ______________
   a. How long have you known the above named person?
      Years ________ Months ________
   b. In your own words briefly characterize the changes which have occurred in your unique relationship with this person as a fellow commune member over the last twelve months or, if less, for the time you have known each other.
      ____
   c. How many hours in a typical week do you spend just by yourselves?
      ____
   d. If you happen to know it, state what kind of work (his/her) father did while the person named above was growing up.
   e. Even the most equal of relationships sometimes has a power element involved. However insignificant it may be in your relationship with this person, which of you do you think holds the greater amount of power in your relationship?
      ____
   f. If this commune did not exist, would you want to have a close relationship with this person?
      ____
   g. For the list of descriptions below, indicate if the following are involved in your relationship with the person named above by checking the appropriate answer. *Please answer each of the following:*

Work together	Yes ____	No ____	Sometimes ____
Spend free time together	Yes ____	No ____	Sometimes ____
Mind children together	Yes ____	No ____	Sometimes ____
Sleep together	Yes ____	No ____	Sometimes ____
Confide in each other	Yes ____	No ____	Sometimes ____
Loving	Yes ____	No ____	Sometimes ____
Exciting	Yes ____	No ____	Sometimes ____
Awkward	Yes ____	No ____	Sometimes ____
Feel close to each other	Yes ____	No ____	Sometimes ____
Tense	Yes ____	No ____	Sometimes ____
Jealous	Yes ____	No ____	Sometimes ____
Agree on communal policy	Yes ____	No ____	Sometimes ____
Feel estranged from each other	Yes ____	No ____	Sometimes ____
Exploitive	Yes ____	No ____	Sometimes ____
Hateful	Yes ____	No ____	Sometimes ____
Improving	Yes ____	No ____	Sometimes ____
Sexual	Yes ____	No ____	Sometimes ____

   h. Do you feel that the overall relationship between the two of you is more important to you, or do you feel it is more important to the above named person?
      ____ More important to you ____ More important to him/her
   i. In your relationship with this person, does he/she ever act to you as a father or mother, sister or brother, son or daughter, or none of these?
      ____

Table 21.2. Sociometric Instrument.

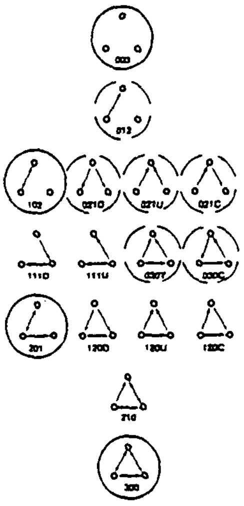

Fig. 21.4. Holland and Leinhardt's 16 isomorphic triad types: the 16 isomorphism classes for digraphs with $g = 3$ (that is, the triad types). Triad labeling convention: the first digit is the number of *mutual* dyads; the second digit is the number of asymmetric dyads; the third digit is the number of *null* dyads; trailing letters further differentiate among the triad types. Four symmetric triad types (unbroken circle) were used in the structural analysis of flux relations and seven asymmetric triad types (broken circle) were used in the analysis of control relations; the "vacuous" 003 triad was used in both analyses. From Holland and Leinhardt (1976, p. 6, Fig. 2. Adapted with permission.)

The triad types are distinguished from one another structurally by their composition in terms of three kinds of dyads: *m*utual dyads (M), in which a symmetric relation connects the two individuals; *a*symmetric dyads (A), involving an ordered or directed relation between the two; and *n*ull dyads (N), in which there is no relation between the two. Hence each triad type can be uniquely identified and labeled in terms of its dyadic composition. For example, the 012 triad (see Fig. 21.4) has no *m*utual relations, one *a*symmetric relation, and two *n*ull relations.

Of the 16 triad types, 3 are symmetric in form in that they are composed exclusively of positively reciprocated dyads (see Fig. 21.4: the 102, 201, and 300 triad types, enclosed by a solid circle). Aggregated across the "loving," " improving," and "exciting" relations, the mean sum of these three triads as a proportion of all possible triads in a commune was used to measure the amount of flux. A bar graph in Fig. 21.5 plots the results of this procedure and shows a positively skewed distribution for the measure of flux (mean sum = .629, standard deviation [SD] = .196).

Seven other triad types (enclosed by a broken circle in Fig. 21.4) are composed exclusively of asymmetric dyads. Based on their successful use in previous analyses (Bradley, 1987; Bradley & Roberts, 1989a), three of these triad types (the 021C, the 021D, and the 030T, summed and expressed as the proportion of all possible triads) were used to measure the amount of control. Aggregated for "power" relations, the three triad types constituted just over half (.509), on average, of all possible triads of control in the communes. A bar graph of the result for all communes is shown in Fig. 21.5 in which a flatter distribution is evident (mean sum = .510, SD = .218). The mean results of the triadic census for all communes for symmetric relations of flux and the asymmetric relations of control are provided in the Appendix.

Stability, the degree to which the collective is able to maintain itself as an enduring, self-sustaining entity, was measured by a commune's survival status at a specific moment in time. Classified into one of two categories, *survivor* or *nonsurvivor*, each commune's stability was determined at each of the four successive 12 month intervals that observations were collected; Time 0 is the point in time when a commune was founded and Time 1 is moment of the first wave of data collection (August 1974). Starting with Time 1, measurement of each commune's stability (survival status) was made at 12-month intervals for the succeeding 4 years, that is, through Time 5. Twenty-two (48%) of the 46 communes survived the 48-month observation period. A pattern of declining instability over time was observed, from 24% by the end of the first 12 months, at Time 2, to 8% after 60 months, at Time 5 (see Appendix).[1]

5. EMPIRICAL ANALYSES

5.1. Verification of the Theory

Testing the theory entailed an analysis to determine the degree to which the observed patterns of commune behavior with respect to our measures of flux, control, and stability were consistent with the expected patterns. Among other techniques, a spatial representation of the data was derived as the theory rests on a field-theoretic concept of energy — a conceptualization of the collective's potential for action as an endogenous *field* of biosocial energy that operates along two dimensions: an unordered dimension of *equi*-valent, symmetrical relations (flux); and an ordered dimension of (transitive) asymmetric relations differentiated by spatiotemporal position (control).

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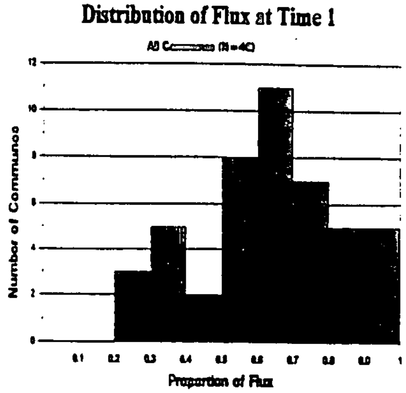
[1] Although the communes ranged in group age from 3 months to 9 years at Time 1, there is little evidence that "period effects" (differences in group age at the time data collection commenced) explain the variability in survival status. Dividing the sample into "young" (2 or less years; $N = 23$) and "old" (more than 2 years; $N = 23$) categories of group age at Time 1, and cross-tabulating these classifications by survival status grouped in three categories (dissolved by Time 2 or Time 3: $N = 17$; dissolved in Time 4 or Time 5: $N = 7$; survived beyond Time 5: $N = 22$) shows nonexistent (0%) to modest (12%) nonstatistically significant differences between the "young" and "old" categories of communes (*chi*-square coefficient with two degrees of freedom = 1.260, pr. = .533).



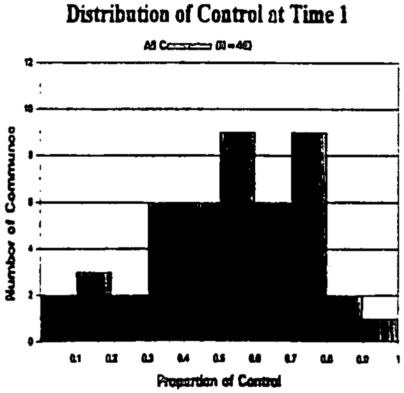


Fig. 21.5. Bar charts showing commune distribution for flux and control at Time 1.

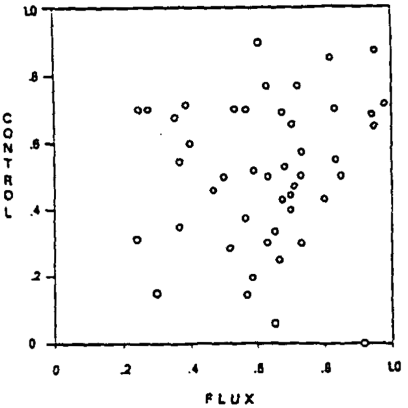


Fig. 21.6. Scatterplot of all communes (N = 46) by flux and control at Time 1 (outlying cases are hollow dots).

Theoretically, it was expected that an efficient communication processing network required a certain amount of flux in interaction with a certain amount of control, and that the tendency toward least action would result in an increasingly closer correspondence in their respective values at higher magnitudes of flux. This is because there would be an increased risk of turbulence, resulting from undue dissipation of kinetic energy, when the conversion of potential to kinetic energy is enhanced at higher levels of flux. Data bearing on the relationship between flux and control are shown in the scatterplot in Fig. 21.6. In accordance with the dimensionality of our concepts of flux and control, the measure of control is the vertical ordinate and that for flux is the horizontal ordinate. It can be seen that the null hypothesis — an equal or random distribution of groups over all locations in the endogenous field — does not hold, and that the low nonsignificant correlation (Pearson's r = .12; pr. > r, .43) actually masks a nonlinear association. Moreover, with the exception of five outlying cases (hollow dots in Fig. 21.6), the observed pattern — a triangular distribution with a wide base and its apex in the high-flux/high-control region (upper right quadrant) — is consistent with the theory. Thus, there is an absence (with one exception) of communes in the high-flux/low-control region (lower right quadrant), an absence in the low-flux/high-control region (upper left quadrant), and (with two exceptions) an absence of communes in the low- flux/low-control region (lower left quadrant).

In addition to the relative amounts of flux and control involved, theoretically it was expected that there also was a limit on the *total amount* of information processed by a collective in a given unit of space or time. Thus, when the total amount of information exceeds the processing capacity of the communication system, it is processed as "noise" and results in unsynchronized action with a high likelihood of turbulence and instability; on the other hand, when the total amount of information is insufficient to convey current descriptions of the ever-evolving endogenous order, collective action will be largely uninformed and ineffective, with dissolution a likely result.

A measure of the total amount of information processed by a collective at a given moment in time was computed by summing and averaging, for each commune, the total for flux and control at Time 1 (mean for all communes = .569, median = .552, and SD = .155). The values for all communes were grouped into .10 intervals and, holding these values on this measure constant at Time 1, the sample was partitioned by survival status and the distribution of survivors and nonsurvivors was plotted on a time series of bar charts at 12-month intervals, that is, from Time 2 through Time 5 (see Fig. 21.7).

Examining the pattern of results in Fig. 21.7, two things stand out. First, the distribution for the total amount of information for all communes at Time 1 is bell-shaped with 67% falling within one standard deviation of either side of the mean. Second, this bell-shaped distribution gradually devolves over time into *two contrasting patterns* that are virtually the *inverse* of each other by Time 5: a single-peaked distribution for the 22 survivors with its mode (9 cases, 41%) in the .500—.599 interval; a bi-modal distribution for the twenty-four nonsurvivors with its trough (2 cases, 8%) in the .500—.599 interval and its twin peaks (6 cases (24%) each) in the two adjacent intervals of .400—.499 and .600—.699. This difference in survival rates between the groups in .500-.599 interval and the other groups outside this range is statistically significant (chi-square = 6.695, pr. = .010).

Taken together, these two patterns appear to mark the *bounds* of a region where the probability of stability is maximized, that is in the *.500—.599 interval*. So that although, in this interval, the rate of instability for all communes is lowest (18%, 2 of 11 groups), it rises sharply in the adjoining intervals: 60%, 6 of 10 groups in the each of the .400—.499 and .600—.699 intervals; 75%, three of four groups in each of the .300—.399, .700—.799, and .800—.899 intervals. When computed for the communes in these adjoining intervals at Time 1, the rate of instability by Time 5 for these two sets of intervals is 63% (twelve of nineteen groups at .600 and above, and ten of sixteen groups at .499 and below), which is *significantly* different than the 18% for the eleven groups in the .500-.599 interval (chi-square = 6.966, pr. = .035). Thus it would appear that the total amount of information in the intervals above .599 was excessive in terms of information processing capacity, whereas the amount of information in the intervals *below* .500 was insufficient to sustain a viable collective.

Two further interrelated theoretical expectations were investigated. The first of these was that there would be restrictions on the *relative* amounts of flux and control involved in communication — that there would be both a *lower* and an *upper* limit on the amounts of each of these processed by an effective collective. Combinations of flux and control that fall outside the limits were expected to result in collective dysfunction. The second expectation, for collectives operating within these limits, was that the disposition of the collective at a future moment would be enfolded in the information processed by the communicative structure in the present. This follows from the overlap among these logon-like elementary units of information by means of which the present order is *in*-formed (given shape to) by the order implicit in the

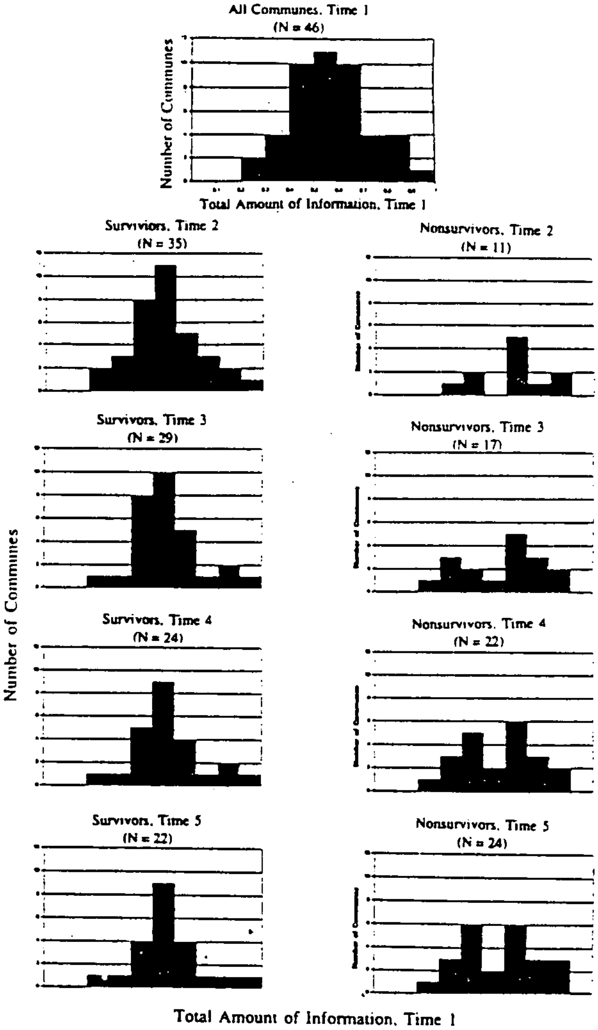

All Communes, Time 1
(N = 46)
Survivors, Time 2
(N = 35)
Nonsurvivors, Time 2
(N = 11)
Survivors, Time 3
(N = 29)
Nonsurvivors, Time 3
(N = 17)
Survivors, Time 4
(N = 24)
Nonsurvivors, Time 4
(N = 22)
Survivors, Time 5
(N = 22)
Nonsurvivors, Time 5
(N = 24)

Fig. 21.7. Bar charts showing distribution of communes for total amount of information at Time 1 by survival status at Time 2 through Time 5.

series of succeeding moments (see Bradley, 1996). Thus, combinations of flux and control within the limits at a given moment were expected to yield an increased potential for effective action in succeeding moments.

Figure 21.8 presents a time-series of scatterplots showing the relationship between flux and control at Time 1 to stability at Time 2 and at Time 3--in other words, the relationship between the composition (in terms of flux and control) of the information provided by a collective's communication system at a given point in time, and the stability of the collective at two successive moments in the future. The scatterplot on the far left-hand side is for all communes plotted by their values for flux (horizontal ordinate) and control (vertical ordinate) at Time 1, the first point of measurement. Holding the values for each commune on flux and control constant at Time 1, the scatterplots for Time 2 and Time 3 are divided into a plot for survivors (top row of scatterplots in Fig. 21.8) and a plot for nonsurvivors (bottom row). This provides a view of the relationship between information on the endogenous order at a given moment in time and collective stability at twelve and at twenty-four months later.[1]

Starting with the baseline pattern at Time 1 for all communes, three related patterns become increasingly evident as survival status is plotted at Time 2 and Time 3. First, instability tends to be highest for groups in the peripheral regions of the field — that is, for groups with the greatest imbalance between flux and control. Second, with the exception of three stable groups in the high-flux/high-control region, survivors tend to form a triangular pattern with most groups clustered together in the mid-region. And third, that location in this mid-region at Time 1 is strongly related to survival at Time 3, 24 months into the future. What is most striking about the results is that the pattern for survivors is virtually the complement of that for nonsurvivors: *there is a complete absence of nonsurvivors in the mid-region where the greatest concentration of survivors is observed.*

Looking more closely at the pattern for the 17 nonsurvivors, two bands of instability become clearly apparent by Time 3: the upper band of 12 (71%) nonsurvivors, marks a region of high instability; the lower band formed by the other 5 nonsurvivors, appears to define a lower bound to the region of stability. In short, the two bands of instability seem to distinguish functional from dysfunctional combinations of flux and control.

To test the veracity of this interpretation, we divided the full sample of communes into stable and unstable sets such that the probability of survival was maximized for the former while being minimized for the latter. Operationally, this entailed establishing partitions that would mark the upper and lower bounds to the region where stability is optimized.

The boundary of the lower bound was established by the four communes (see the scatterplot for nonsurvivors, Time 3, Fig. 21.8) on a line in the lower band of instability orthogonal to the low-flux-low control/high-flux-high control axis. A total of six communes was observed in this region, of which five (83%) had become nonsurvivors by Time 3. For

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[1] This time series of scatterplots on stability was run out across the full 48 months (i.e., Time 1 through Time 5) for which observations were collected on the communes. The results for the first 24 months (i.e., through Time 3 as shown in Fig. 21.8) suggest this is a reasonable period over which to aggregate survival status to accumulate enough nonsurviving cases (nonsurvivors at Time 3 = 17 cases) for the analysis; the scatterplots for Time 4 and Time 5 (not displayed) show evidence of a deterioration in the "predictive power" of the information provided by flux and control at Time 1 for stability beyond 24 months.

comparison, the baseline rate of instability over all communes was 37%, 17 nonsurvivors out of 46 groups.

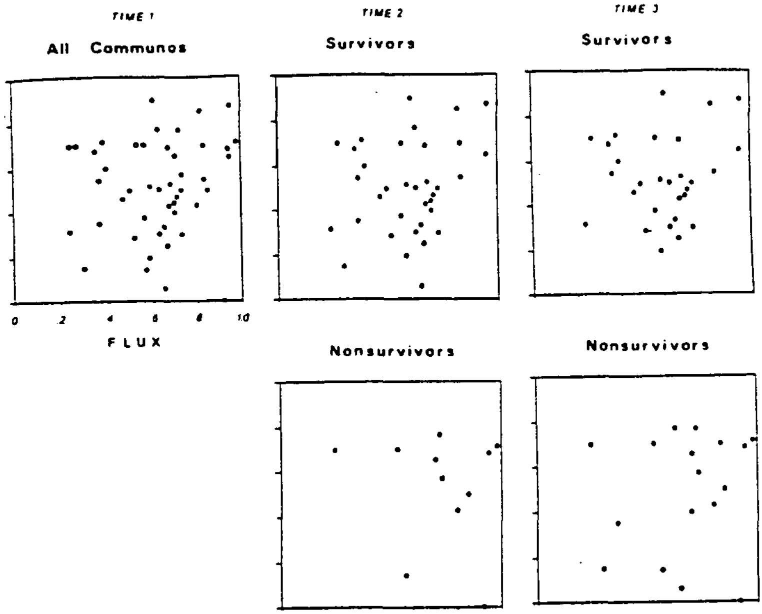

Fig. 21.8. Scatterplots of communes on flux and control at Time 1 by stability (survival status) at Times 2 and 3.

For a boundary marking the upper bound to the region of maximal stability, there were two possibilities. The first is the line (orthogonal to the axis just mentioned) established by the three communes at the bottom of the upper band of instability; this is *not* an optimal partition because although the probability of survival is maximized (100%; there are no nonsurvivors) for the 15 groups in the area defined by this line and the lower bound, the probability of instability is not maximized for the 25 groups classified by this line as belonging to the upper band region of instability (nonsurvivors = 12 communes, 48%). The second possibility is the line (orthogonal to the same axis) established by the four nonsurvivors immediately above the three communes. This second line meets our two criteria for an optimal partition. First, between the lower bound and this line marking the upper bound, 25 communes were observed, 22 (88%) of which survived through Time 3 — some 24 months beyond the initial measures of flux and control at Time 1. And second, on this line and above, 15 communes were observed, 9 (60%) of which had become nonsurvivors by Time 3.

The results of this procedure are shown in the scatterplot for all communes in Fig. 21.9. This scatterplot is identical to the scatterplot at Time 1 in Fig. 21.8 with the following additions: first, the two lines marking the thresholds of lower and upper regions of instability, as just established, are indicated; and second, the survival status for each commune is shown at Time 3 (nonsurvivors are shown as hollow dots in Fig. 21.9). It is clearly evident that the two partitions separate an area of stability in the mid-region from two adjoining regions characterized by a high probability of collective instability; the differences in the rates of instability, by Time 3, between the groups in the three regions are statistically significant (chi-square = 15.641, pr. = .0004). In addition to its extraordinarily high stability over the twenty-four month period from the point of initial measurement, the mid-region also is distinguished by the lack of dispersion of communes along the low control-high flux/high control-low flux axis. Instead, there is a strong tendency to locate between these extremes of rapid (high) flux and rigid (high) control in the area expected to define efficient information processing.

Finally, also shown in Fig. 21.9 are four communes that had a charismatic leader living in residence with the group (circled in Fig. 21.9). Of all communes in the sample, these were the collectives most intent on achieving a radical restructuring of social order. Although there are too few cases for a (statistically) reliable result, all four of these transformation-oriented (charismatic) communes — three of which were still in existence by Time 3 — are concentrated exclusively in the apex of the high flux/high control region; the fifth group (a nonsurvivor) is a noncharismatic commune whose members expressed a strong desire for charismatic leadership as the means to facilitate their efforts at social change. As established elsewhere (Bradley, 1987, pp. 167-193; 264-268), charismatic leadership is not only correlated with enormous increases in flux and control, but when these two are linked in a balanced coupling, charismatic leadership also is associated with an increase in the probability of group survival. However, for other (noncharismatic) collectives, not only were such high levels of flux and control rare, but when these conditions were observed they were found to be highly associated with instability.

5.2. A Multivariate Model of Optimality

To this point, our analysis has employed simple largely bivariate statistical techniques, which, given the small number of cases available, has been both necessary and appropriate. But because it was possible that the optimality we identified was the result of a more complex relationship between flux and control and a number of other sociological factors measured in the original study, a *discriminant function analysis* was conducted to ensure that this was not the case and, therefore, to confirm the veracity of our results.

Two features of discriminant analysis made it especially appropriate: first, the procedure aims to construct a multivariate linear (discriminant) function that maximizes the separation between two or more mutually exclusive categorical groupings of data; second, it offers a test of predictive power by comparing the a priori group classifications against those made by the discriminant function/s. As a measure, thus, of *statistical* optimality, discriminant analysis provides a rigorous means of verifying the finding that, in relation to the other factors examined here, our measures of flux and control provide the best means of predicting optimal collective action.

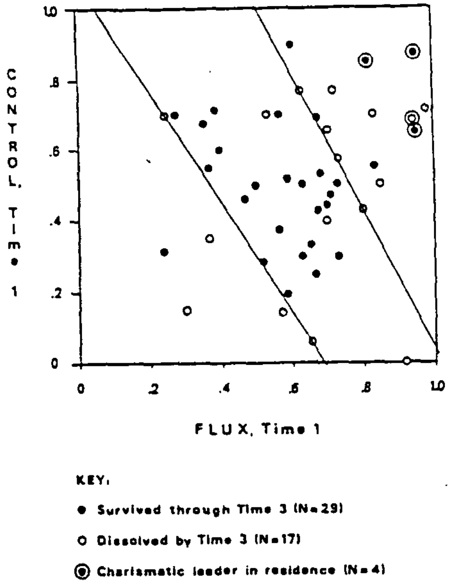

Fig. 21.9. Scatterplots of communes *on flux and control* at Time 1 by stability (survival status) at Time 3, and showing transformational communes (charismatic leader in residence).

To perform the discriminant analysis, the communes were classified into one of the three categories of stability at Time 3 established above, as shown in Fig. 21.9: *namely*, location in the upper region of instability (*N* = 15; survivors = 6 [40%] communes); location in the stable (mid) region (*N* = 25; survivors = 22 [88%] communes); or location in the lower region of instability (*N* = 6; survivors = 1 [17%] commune). For the purposes of this analysis, we will refer to these three groupings of the communes as *nonoptimal — upper region*, *optimal — mid region*, and *nonoptimal — lower region*, respectively. Along with our measures of flux and control, eight sociological variables with limited missing data were used as independent variables for the stepwise multivariate analysis. The univariate statistics (means, SDs, Wilks' lambda, and univariate *F* ratio) are given in Table 21.3a.

Table 21.3a
Discriminant Function: Univariate Statistics

	Optimality Groupings										
	Optimal — Mid Region		Nonoptimal — Upper Region		Nonoptimal — Lower Region		Total				
Variable	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Wilks' Lambda	Univariate F Ratio	Pr
(N)	(25)		(15)		(6)		(46)				
Admission requirements[a]	1.96	93	1.87	99	2.00	89	1.93	93	997	062	940
Extent of authority[b]	1.52	51	1.47	52	1.33	52	1.48	51	985	326	723
Affiliated to a larger organization[c]	48	51	33	49	33	52	41	50	978	484	620
Control	457	178	688	136	286	231	510	218	603	14.156	000
Flux	581	149	802	122	396	174	629	196	517	20.055	000
Mean group age, years	3.36	1.91	2.20	1.08	2.67	1.51	2.89	1.69	899	2.413	102
Degree of ideological consensus[d]	1.40	50	1.47	52	1.00	00	1.37	49	908	2.174	.126
Mean propn. old members[e]	.46	29	48	34	.41	35	46	31	995	.117	890
Formal rules[f]	1.40	.50	1.40	51	1.50	55	1.41	50	.995	.101	904
Group size[g]	9.20	4.44	8.20	2.08	8.67	2.73	8.80	3.59	984	.358	702

Note: SD, standard deviation; Wilks' lambda, *U*-statistic; pr., statistical significance with 2 and 43 degrees of freedom.

[a] Admission requirements: 1 = if room/see individual; 2 = trait required/group ready; 3 = trial membership/novitiate required/group closed

[b] Extent of authority: 1 = none/a little; 2 = some/a lot

[c] Affiliated to a larger organization: 0 = not affiliated; 1 = affiliated

[d] Degree of ideological consensus: 1 = a little/some; 2 = a lot/unity

[e] Mean propn. old members = proportion of adult members who joined commune before 1973

[f] Formal rules: 1 = none/few; 2 = some/many

[g] Group size = number of adult members (≥ 15 years old)

Table 21.3b. Discriminant function analysis of optimality classification of communes by selected characteristics: Stepwise results and canonical analyses

Variable	Step	Wilks' Lambda	Pr.	Minimum D^2	Minimum Pr.	Equivalent F	Equivalent Pr.
Flux	1	.517	.0000	1.656	.0070	8.011	.0070
Control	2	.214	.0000	6.028	.0000	14.245	.0000

*Maximum significance of *F*-statistic to enter = .050; minimum significance of *F*-statistic to remove = .100.

Summary of Stepwise Analysis*
Test of Differences Between Pairs of Groupings After Step 2

Pairs of Groupings	F-statistic	Significance*
Optimal/Nonoptimal — Upper	43.848	.0000
Optimal/Nonoptimal — Lower	14.246	.0000
Nonoptimal — Upper/ Nonoptimal — Lower	64.451	.0000

*With 2 and 42 degrees of freedom.

Canonical Discriminant Functions

	Function 1	Function 2
Canonical Correlation	.887	.002
Squared Canonical Correlation	.786	.0005
Percent of Variance	99.99	.01
Eigenvalue	3.674	.001

Unstandardized Canonical Discriminant Function Coefficients

	Function 1	Function 2
Control	6.080	3.546
Flux	7.652	-3.574
(Constant)	-7.911	.440

Table 21.3c. Discriminant Function — Classification Results

Actual Group	Predicted Group: Optimal — Mid Region N	%	Nonoptimal — Upper Region N	%	Nonoptimal — Lower Region N	%	Total N	%
Optimal — Mid Region	25	100.0	0	0.0	0	0.0	25	100.0
Nonoptimal — Upper Region	1	6.7	14	93.3	0	0.0	15	100.0
Nonoptimal — Lower Region	1	16.7	0	0.0	5	83.3	6	100.0
Total	27	58.7	14	30.4	5	10.9	46	100.0
Prior Probability		.54		.33		.13		100.0

Table 21.3. Discriminant Function Analysis of Optimality Classification Of Communes by Selected Characteristics. (a) Univariate statistics. (b) Stepwise results and canonical analyses. (c) Classification results.

latent relationships between our measures of flux, control, optimality, and the other sociological variables we examined is particularly noteworthy, for it flies in the face of conventional sociological theory (see Turner, 1986). This would suggest that location in the region of optimal stability may have its basis in a different logic and dynamics than that embodied by current sociological thinking (e.g., Burt, 1992; Coleman, 1990; White, 1992). It is toward an understanding of these dynamics and their implications that the following discussion is directed.

6. DISCUSSION

6.1. Model of Global Communication

Drawing on the theory and empirical results presented above, a model of the communicative structure of the collective was constructed (see Fig. 21.10). In the terms of this model, the communicative structure is formed by the interaction of networks of endogenous relations organized along two dimensions in which the values allocated in each dimension define points within a relational field (Bradley & Roberts, 1989a). The values ascribed to the horizontal dimension represent flux, the amount of activation of potential energy in a social collective. The values ascribed to the vertical dimension represent the amount of *control* (the degree to which individuals are interconnected by a transitive network of relations) exercised at that location. The coordinates representing the dimensions bound a phase space within which each value represents an amount of information (in Gabor's terms) characteristic of the communicative structure of the collective.

Two regions of stability can be distinguished within the phase space. These are regions associated with viable patterns of global communication. They are located within a larger region in which the minimum values for global communication are *not met* so that various forms of collective dysfunction result.

All regions are separated from each other, marked, in the terms of nonlinear dynamics, by a phase transition from psychosocial instabilities to {*far-from-(physical)-equilibrium*} psychosocial stabilities in collective organization (Prigogine & Stengers, 1984). The region of optimal function represents, therefore, a qualitative change in psychosocial organization. The phase transition from dysfunctional to stable collective forms (which includes the area between the two stable regions) is described by fluctuations in potential and control that end in a point (the bifurcation point) where the patterns of energy activation and expenditure no longer dissipate into the environment — no longer average out to equal the energy levels of the surrounding context, but coalesce to crystallize as an emergent stable collective order. To defy the tendency toward entropy (disorder), and sustain the stable collective order, requires minimizing the fluctuations by linking the activation of potential to the control operations so that the energy expenditure of all members is *in*-formed in relation to the collective's action. In the dysfunctional region, the patterns of potential and control are therefore either unable to establish or unable to sustain stable forms of collective organization. Values of low potential and low control (the area labeled as *insufficiency* in Fig. 21.10) fail to provide stability because, in addition to requiring a certain minimum of kinetic energy, stability also requires at least a *minimum* of direction given to that energy. As shown above, this direction comes from the interaction between flux and control that in-forms the paths by which kinetic energy is expended in action. Thus, in terms of the data presented in Fig. 21.1, stable organization requires *both* a minimum of flux *and* a minimum of control: a network of reciprocal *equi*-valent connections linking every individual to at least one other person; this connection must be coupled to a transitive ordering of asymmetric relations linking the action of each individual to that of at least one other person. Failing to meet these minima, a collective would devolve into a loose aggregation of disjointed cliques and isolated individuals unable to communicate and, consequently, function as a social collective.

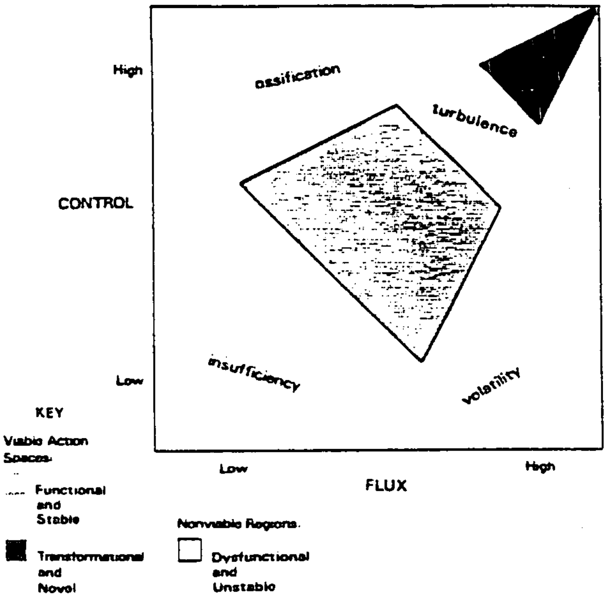

Fig. 21.10. Model of dynamics of communication and collective action.

Two other combinations are also shown to produce instability. Coordinate values representing high control and low flux (labelled *ossification* in Fig. 21.10) delineate a rigid organization in which insufficient flux is available for global communication. The lack of communication means that the paths to action are fixed, not adequately informed by current circumstances, and are therefore unable to adapt and evolve as the situation changes.

At the other extreme, combinations of high flux and low control (labelled *volatility*) delineate a turbulent situation in which little of the enormous flux is guided by hierarchic controls. Communication is inadequate as insufficient information about the ever-changing situation is distributed.

The region of dysfunction surrounds the region of optimal collective function which is centered along a main diagonal of the phase space, and which, as noted, embodies a qualitative change in psychosocial organization. The lower and upper boundaries of this region define the values representing efficient information processing; this region is consistent with thermodynamically inspired connectionist models of neural networks (e.g., Hinton & Sejnowski, 1986; Hopfield, 1982). In such models efficient pattern matching is found to occur in a region between total randomness and total organization; in our terms, between rapid flux and rigid organization. The relationship between flux and control narrows progressively from many degrees of freedom at the low end of the phase space, to an almost one-to-one correspondence at the high end. Thus the shape of the space of optimal function is triangular. Figure 21.10 shows that this space can be subdivided into two distinct kinds of global communication: functional and transformational. Transitions from one subregion to another are not gradual but involve qualitative change; distinct types of communication can be defined. In between subregions is a phase transition characterized by turbulence and instability. Each subregion is composed of different combinations of values of flux and control so that a social collective can only have one of these communication patterns at any given time.

Furthermore, there is considerable difference in vulnerability to collective dysfunction between the patterns constituting the subregions. At the low end of the functional subregion, the range of combinations of flux and control is great and there are thus many different viable patterns of communication possible. As a result of this loose articulation between flux and control, communication tends to be effortless but minimally efficient. At the high end of this subregion, there is a close articulation between flux and control so that the patterns of information processing here tend to be optimal — maximally efficient and highly stable.

Beyond this, at the apex of the viable region, is a small subregion, labeled *transformational* (separated from the region of stability by a turbulent gap), defined by an almost one-to-one ratio between flux and control. To assure stability this ratio must be maintained, a not-so-easy task: the greater the flux the more control must be exercised and vice versa, taking much effort. Often, when such an effortful course is in operation, a sudden organizational spasm occurs. The spasm has two possible outcomes. One is a structural transformation in the pattern of information processing, resulting in total reorganization to form a novel, qualitatively different collective. The other is structural devolution, the complete breakdown and collapse of the collective as a viable social entity.

7. SUMMARY AND IMPLICATIONS

7.1. Efficiency of Communication and Optimal Collective Action

Our model concerns the internal structure of the collective. This internal structure is conceived to be based on the biological potential of the individuals composing the collective to engage in work, measured as energy. This biological potential appears to be heterarchically organized and, when activated by the collective, is made available for social interaction and behavior as a pool or field of latent biosocial energy. We have labeled this dimension of the endogenous order *flux*.

In the other dimension, individuals are connected hierarchically. We have labeled this dimension *control* because it appears to direct and regulate the activation of the biosocial energy of the collective. Controls over the activation and distribution of flux result in global communication by way of quantum-like units of information (logons) — moment-by-moment descriptions, in terms of space-time and spectral coordinates, of the collective's endogenous organization. Because these elementary units of information overlap as a series, the collective's order at a given moment is informed by the order implicit in the units of the succeeding moments.

A simplifying assumption was that stability can be identified with survival. Unless the collective remains a stable, durable social entity, there is little to enquire about. Thus in order to understand how stability is accomplished, we have restricted our concern to the structure and internal dynamics of the collective, and have left aside its behavioral effectiveness as an entity operating on its environment. It may well be that less stable collectives could be more effective under certain conditions than hyperstable ones (Roberts & Bradley, 1988).

The efficiency of the internal dynamics, and its relationship to the collective's action, was found to display an optimal (energy conserving) combination of flux and control that is associated with stable collective action. Our results thus show that for the group to survive as an effective working unit, an efficient communicative structure was required. Only those configurations of heterarchy and hierarchy that produced a path of least action — one that entailed the smallest amount of turbulence — resulted in a stable, effective collective. The findings indicate, in the terms of Shannon and Weaver (1949) at the opening of this chapter, that heterarchy and hierarchy are related as conjugate orders: that within the limits of its biosocial energy, the social collective must achieve an optimal combination of flux and control to produce efficient communication.

A final point concerns the implications of this multilevel investigation for the single-level approach generally pursued by social science. In contrast to such discipline-specific accounts of collectives, our approach has been to seek a common scientific language — to explore the degree to which insights and principles from thermodynamics and information measurement theory could be used to build a rigorous and testable understanding of the communicative structure of social collectives. Although this account has drawn little from (and found little empirical support for) the normative sociological concepts usually employed to explain the behavior of social collectives (viz., ideology, values, formal organization, role structure, leadership, member commitment etc.; see the review by Turner, 1986, or Jablin et al., 1987, for examples), we believe that our results demonstrate the utility of an approach that grounds explanation in the commonalities and dynamics of collectives more generally. This is *not* to say that the factors identified by single-level descriptions are unimportant, but rather that a general understanding of collectives will only arise as a result of complementary work on the interlinkages between systems of organized behavior at different levels (e.g., Csányi, 1989). In this way the relationship between general principles of system behavior and the specific conditions that obtain at different structural levels will be addressed and a general science of social behavior will be born.

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