Organized Social Complexity

CHALLENGE TO POLITICS AND POLICY

Edited by Todd R. La Porte

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Preface

Some collections are brought together and issued rapidly. Others, such as ours, seek an integration which has a much longer gestation time. The origins of these papers go back to the Spring of 1969 when a small seminar group set to work exploring what could be made of the phenomenon of organized social complexity. This book grew from that quite special experience. As we struggled through many of the abstract formalizations from works we thought could assist us, the swirl of the People's Park tragedy swept over us. Sometimes the familiar smell of riot gas invaded the seminar room; sometimes our discussions reflected the frustration of events crashing about us just three blocks away. This was Berkeley's ugliest episode during its Time of Trouble, and it became a disturbing symbol of the consequences of planning without substance or effect and politics gone slightly mad. It seemed as though we were living some of the implications of the work we were doing in the seminar. Was it possible that the fabric of social relations could rupture badly in the face of simplistic perceptions of it? It seemed that it was . . . it seems that it is.

Our effort has been to bring together an integrated set of papers reflecting a sustained conversation and exchange. The volume is dedicated to those who will come after us and who may take up some of the challenges we believe to be inherent in the increasing levels of organized social complexity that confront us.

Seven of the papers are revisions of those begun in those initial explorations. I knew of Garry Brewer's interest in a version of these problems. During the summer of the previous year we had exchanged enthusiasms and he had contributed an initial bibliography gleaned from his work at Yale University. Later I asked him to modify a portion of a longer paper so it could be included in this volume. Daniel Metlay was sufficiently intrigued by Brewer's effort to write a related chapter, the only one which *self-consciously* builds from another of the papers. All of the chapters, however, are vitally linked — despite the variety of contexts. To discover their collective unity and many points of congruence will profit the reader beyond the respective readings.

During the process of development, I found encouragement from my colleagues in the Department of Political Science, Professors Ernst Haas, Warren Ilchman and Martin Landau, who at crucial times shared conversation and critiques which suggested that the substance would be of sufficient importance to justify the extraordinary efforts needed to bring ne papers together. The Institute of Governmental Studies has been nvaluable in lending the support of its manuscript staff to the preparation f the several versions and reworkings needed for discussion drafts and or eliciting critiques from important readers. Catherine Winter has been specially competent in preparing the final draft. Others who have assisted bly are Linda Harris and Amy Alsbury. I thank them all. But I must eserve my highest thanks and praise for Mary Sapsis, who has been ntimately involved with the project for the past two years. She has handled ne problems arising from our own kind of complexity — in counseling vith eight different authors, caring for countless details, supervising the reparation of the final manuscript, and finally getting it into the hands f the publishers. She has taught us all a great deal about the uses of anguage. For a variety of reasons both the authors and our readers will rofit from her dedicated and professional efforts.

Todd R. La Porte

Berkeley, California
February 1974

PART ONE

Explication of the Concept of Organized Complexity: Studies in Its Effects

Chapter I

Organized Social Complexity: Explication of a Concept

TODD R. LA PORTE

Introduction

One particularly striking aspect of modern political and social development has been the capacity of men to construct social systems encompassing more and more groups. Our lives are bounded by agencies, organizations, combines, coalitions, and associations: networks of hundreds of connected groups and persons. In part this condition has been a self-moving outgrowth of economic and technological progress which has stimulated proliferating organizational and social differentiation. In part men have intentionally linked group to group, organization to organization, nation to nation in efforts to gather specialized and mutually required resources. National development of such resource capacity has been a major driving force of politics and commerce. Indeed, cooperation and mutual exchange provide the foundation of modern life and the consuming attention of public policy concerns. Our national penchant in solving public problems is through policies which increase the connections between groups and which tend toward mutual dependence among public and private organizations.

One consequence of these increases in group connections — both spontaneous and purposive — has been the tightening of organizational dependencies affecting social dynamics and political movements. Another has been a rapid increase in the number of people and agencies affecting the day-to-day experiences of individuals. Closely related to this increase has been one in the number of surprises we encounter. They are generally disturbing surprises, caused by the interruption or frustration of our expectation by some hitherto unrecognized dependency. These surprises we often "account for" with the somewhat bewildered assertion, "It's a complex situation," implying that they are unaccountable. Somehow the unexpected occurs frequently, especially in matters of politics and social and organizational life. Perhaps such situations have always been unaccountable, but at present they seem to affect more people in a shorter span of time. They seem somehow to have intensified. The pervasiveness of such surprise-producing dependences is exploited by contemporary advertising. Repeatedly we are told that such and such a product or service will "uncomplicate" things: will "simplify" matters in the kitchen, "expedite" getting from here to there, "ease" the process of paying our bills by reducing our indebtedness to one loan compounded from the unwieldy burden of many creditors. The sensitive nerve endings of the advertising copywriter have intuitively gauged the degree to which the surprises of complexity prompt feelings of uneasiness and frustration within everyone.

But advertising strategies and tired assertions that "things are complex" do little to provide satisfactory understanding of what is happening to us. We eagerly seek conceptions of the world which promise some explanation or insight about what we are experiencing. The conceptions available to us form a network of notions describing phenomena which are social, complex, and organized. This book is addressed to some of them and in some cases challenges their adequacy in the face of increasing levels of *organized social complexity*.

We have come to the collective conviction that the degree of social complexity, particularly that confronting modern industrial nations, has seriously eroded the quality of our traditional conceptions about social and political realities. Insofar as this is the case, the utility of our cause/effect beliefs about these realities must be seriously questioned — especially the utility of those that are currently used as the basis for the analysis of public problems and the construction of policy proposals. Part One of this volume (Chapters I–III) includes an explication of the concept of organized social complexity, explores its impact on the human intellect, and ends with a discussion of what is often asserted as the major cause for its increase. Part Two (Chapters IV and V) is devoted to analyses of two theoretical systems — public planning and systems analysis — which, while intended to provide direct control over social matters, may be neither direct nor regulatory. Part Three (Chapters VI–VIII) emphasizes methodological aspects and research applications. Part Four (Chapters IX and X) takes both a retrospective and prospective view of theories responding to social complexity.

The Concept of Organized Social Complexity

The term "complexity" appears in many areas of the social sciences, perhaps most often in the study of large scale, "complex" organizations. Very little, however, has been done to develop this concept so that the phenomenon intuitively ascribed to the term may be related to aspects of

social, political, or organizational life. In this chapter we shall attempt such an explication as an introduction to more particular considerations of the consequences for conceptual thought of increasingly complex organized social systems.

In an important article titled "The Architecture of Complexity," Herbert Simon avoids a formal definition of complexity, suggesting only that complex systems are ones "made up of a large number of parts that interact in a nonsimple way."[1] We shall attempt, perhaps more foolhardily, to advance beyond this generality by dealing with a particular kind of complexity, namely *organized social complexity*.[2] In emphasizing organized complexity we are following the distinction made by Weaver between unorganized and organized complexity.[3] Taken originally from formulations in the natural sciences, the former describes systematically unrelated elements, parts, or variables affecting the behavior or outcomes of systemic operations. These aggregates of randomly interacting elements, such as gas molecules under pressure, consumer behavior, and voters in general elections, are fruitfully described with statistical techniques. Despite the fact that each of the variables displays random behavior, each system as a whole has certain orderly properties which can be discovered through probability analysis.

Systems that are characterized by organized complexity, on the other hand, are those in which there is at least a moderate number of variables or parts related to each other in organic or interdependent ways. Systems, like the internal dynamics of living organisms, self-conscious social organizations and chemical molecular reactions, for example, cannot be adequately described through probability techniques and pose challenging conceptual and methodological problems.[4]

Our concern will be further limited to *social* systems possessing the characteristics of organized complexity. The most obvious empirical

[1]Herbert Simon, "The Architecture of Complexity," in *General Systems Yearbook*, 10 (1965), 63.

[2]The term "complexity" has at least two common-usage significations. Often it is used in a derivative sense to describe a situation that has so many aspects as to be unknowable or incomprehensible, prompting feelings of confusion. We are using it here in its stricter sense: to characterize phenomena in such a way as to distinguish a system which has many parts from a *simple* system which has only a few. In the next chapter, Langdon Winner pursues this distinction, noting how the former sense of the term has developed largely as a response to the latter sense, so that often " 'complexity' refers not so much to a neutral property of things in the world as to a kind of emotional response to certain perceptual and cognitive difficulties."

[3]Warren Weaver, "Science and Complexity," *American Scientist*, 36 (1948), 536–544.

[4]*Ibid.*, pp. 537–539.

referents are social groups with conscious purposes, such as formal organizations or informal, but cohesive, groups and associations. Members of such systems will be defined as those persons engaged in relatively self-conscious interaction with each other, recognizing their common relatedness to one another within the system. For our purposes, the self-conscious characteristic is crucial; it is central to the requirement that interaction among elements be interdependent and systematic. Lacking this self-consciousness, aggregate behavior in social groups could just as well be unorganized.

Self-conscious relatedness implies a distinction between perceived and unperceived relatedness. The former is based on the individual's recognition of his connections to others around him — his awareness that his activities directly impinge on the activities of others and theirs upon his. When dependence and connectedness are recognized, an individual is likely to base his actions on some reckoning of their effect on those involved with him. Unperceived relatedness exists when the structure of a situation, e.g., work structure, holds persons in remote and indirect but important relationship to one another. In these cases dependencies are not likely to be recognized, and an individual's actions are not likely to reflect a conscious concern for how they might affect others indirectly dependent upon him. Such actual but unrecognized dependence is revealed when the relationship falters: suburban homeowners' sudden recognition of their dependence upon garbage collectors when confronted with a garbagemen's strike; the city dweller's realization that there is an administrator downtown who is crucial in the determination of his housing conditions.

In this introduction, our concerns are mainly fastened on self-conscious, perceived relatedness rather than on social complexity of the unperceived variety. With these distinctions as a preface, we can now move to a working definition of *organized social complexity*.

The degree of complexity of organized social systems (Q) is a function of the *number* of system components (C_i), the relative *differentiation* or variety of these components (D_j), and the degree of *interdependence* among these components (I_k). Then, by definition, the greater C_i, D_j, and I_k, the greater the complexity of the organized system (Q).

A *component* of an organized social system is defined as a *person* or *group* occupying a position within the system and evincing these characteristics: (1) sufficient mutual agreement or consensus about this position so that he or she or it is the object of expectations and actions from other members and (2) recognition on the part of the person or group of the legitimacy of the others' expectations and positive response to those expectations, at least to the degree required for maintaining membership in and avoiding expulsion from the system.[5]

Differentiation of components is defined as the number of different social roles or positions within the system, based on the degree of mutual exclusiveness of the activities distributed among the roles in an organization.[6] These differences are based, in turn, on those activities expected of a role occupant by other members of the system. To develop operational indicators of differentiation can become very difficult. Without accepting them as necessarily definitive, we could consider formal job descriptions to be such indicators; survey research instruments and techniques of analysis to determine high norm concensus might also be developed.

The most difficult element of our definition is the *interdependence* of components. It is by far the most important and the least developed. Interdependence among persons or groups assumes varying degrees of *reciprocal* relationships between them. Interdependence means an exchange relationship of at least one resource between at least two persons. Interdependent relationships can vary between any two members (a, b) exchanging resource r_1 as follows:

1. member A dominant over member B, i.e., B depends on A for some desired resource $(a \gg b)_{r_1}$
2. A and B mutually dependent upon one another for a resource both parties desire $(a \ll \gg b)_{r_1}$
3. B dominant over A $(a \ll b)_{r_1}$.

Our basic illustration contains only one resource; however, in many situations several resources may be exchanged with all three dependence relationships obtaining between two persons. For example,

$$(a \gg b)_{r_1}, (a \ll \gg b)_{r_2}, (a \ll b)_{r_3}$$

[5]See specifically Theodore Caplow, *The Principles of Organization* (New York: Harcourt Brace, 1964), pp. 1–3. But there is a more fundamental matter that should be recognized. The notion of component is rooted in the language of functional systems; that is, a component is so designated in terms of the part of a system thought to be useful to it for purposes of survival or adequate functioning. Thus, from different perspectives, the same *person* on the one hand may be designated a component and on the other the *group* of which that person is a member may be so designated. Thus, there is no fixed referent which can be used to calculate the number of components within a system. This referent must be set first by the analyst and then used to figure the number of components. This limitation is inherent in the language of systems and need not confuse the meaning of social complexity once the limitation is recognized. (I am grateful to Kai N. Lee for pointing out this qualification.)

[6]N. Gross *et al.*, *Explorations in Role Analysis* (New York: Wiley, 1958), esp. Chs. 1–4; Daniel Katz and Robert Kahn, *The Social Psychology of Organization* (New York: Wiley, 1966).

when r_1 is promotion, r_2 is mutual protection, and r_3 is expertise. On the operational level, determining the degree of interdependence requires that the persons in question perceive or recognize their relatedness. In behavioral terms, a person will not consciously behave in dependent or dominant ways with regard to another unless he recognizes this relationship. Independency of two parties, parenthetically, implies a nonrelationship, i.e., *no* connection between A and B.

In order to clarify this notion, let us consider three examples with different degrees of interdependence for systems composed of a number of components. Still dealing with only one resource, we can describe the most simple system as a "tree" or simple hierarchy. In general, a hierarchy is defined as "a system that is composed of interrelated subsystems, each of the latter being, in turn, hierarchic in structure until we reach some lowest level of elementary subsystem."[7] More formally, a collection of elements forms a tree or simple hierarchy if, and only if, all elements in the collection are directly or indirectly connected to a single superordinate element, and elements are only directly or indirectly connected with each other through a common superordinate element.[8] Figure 1–1 illustrates this form of dependence for one resource.

Figure 1–1. A Tree of Dependence

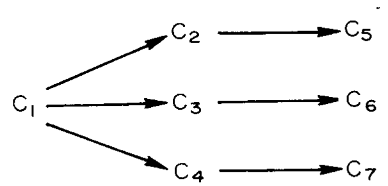
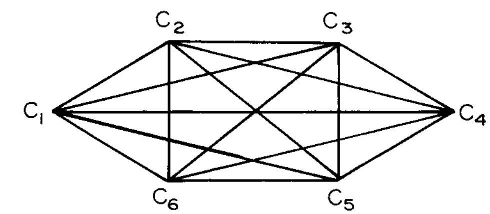


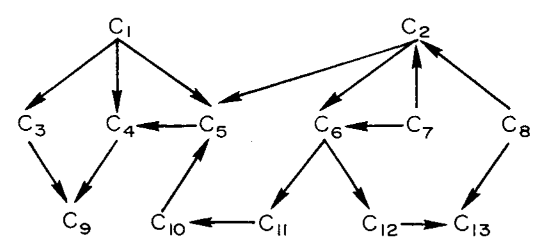
Figure 1–2 represents a system of completely reciprocal interdependence between members for obtaining a resource. The behavior of every member with respect to this resource is reciprocally related to and dependent upon every other member. Were we to describe this as a matrix it would be a complete or "full matrix" $(A_{ij})_{r_1}$; the other examples can be described as partial matrices. More formally, a collection of elements forms a full matrix (see Figure 1–2), if, and only if, each element in the collection is connected with every other element, and no element is in superordinate relation to any other element. In graph theoretic language this would be a complete and symmetrical digraph; a complete lattice in terms of lattice theory.[9] The appendices to this chapter contain a discussion of these two formal languages and a short description of these structures displayed in matrix form.

Figure 1–2. A Full Matrix of Dependence



Finally, intermediate between these two extremes is the incomplete matrix, termed "semilattice" in the language of lattice theory. These are systems of relationships between members that are characterized by overlapping or multiconnected relationships wherein some members are dependent upon several other members but no member is in complete control of the resource. Formally, a collection of elements forms a semilattice if, and only if, any single element in the collection may be connected directly to any other single element and no single element is in a superordinate relation to all other elements (see Figure 1–3).[10]

Figure 1–3. A Semilattice of Dependence



Intuitively, in terms of one's own experience, the world is not overly populated either by trees or by "full matrices" of dependence. Very seldom

[7]Simon, "Architecture of Complexity," p. 64.

[8]Christopher Alexander in "A City is Not a Tree," *Architectural Forum*, 122 (April–May 1965), 60; Dorwin Cartwright, "The Potential Contribution of Graph Theory to Organization Theory," in *Modern Organization Theory*, ed. Mason Haire (New York: Wiley, 1959), Ch. 9.

[9]O. Ore, *Graphs and Their Uses* (New York: Random House, 1963), p. 7, 84; Gabor Szasz, *Introduction to Lattice Theory* (New York: Academic Press, 1963), p. 59f.

[10]Cf. Alexander, "A City"; M. F. Friedell, "Organizations and Semilattices" *American Sociological Review*, 32 (1967), 46–54; and Szasz, *Lattice Theory*.

are relationships as simple as in the simple hierarchy illustrated above. Similarly, our personal patterns of dependence upon others and theirs on us are rarely, if ever, so predominantly interdependent as in the "full matrix." We shall return to some of the reasons why this latter condition is not likely; first, however, a few more notes are called for on the relationships between the elements of our definition of organized complexity.

Social Complexity as an Independent Variable

Before organized social complexity is used as an independent variable or as the antecedent condition from which we may expect certain things to follow, a warning is in order. Comparisons between the complexity of different social organizations at the same point in time or of the same social organization over time present several analytical difficulties. McFarland, in discussing complexity similarly defined, asserts that the three dimensions of complexity are not additive, and therefore comparisons are likely to be methodologically rather tricky. Including in his definition degrees of change, he states, "[I]f one system has fewer components but greater interdependence and variability [i.e., changes in degrees of differentiation over time] than another, it would be difficult or impossible to determine which system is more complex, unless the system with fewer variables is identical to a subsystem of the second system."[11] Thus he asserts that if we are to order and compare systems on the basis of complexity, we must demonstrate that "one system exhibits a greater magnitude than the other on all three dimensions of complexity."[12] Although this view seems overly impressed with the difficulties of examining the effects of increases in one of the variable elements, while holding the others constant, it poses the necessary warning that operationalizing organized complexity is no trivial matter. Having observed the warning, let us go on to consider more detailed aspects of social complexity as an independent variable.

Perhaps the most fruitful way to begin is by considering what is minimumly required to constitute a system which is organized and complex; that is, is there a way of constructing a basic unit of complexity? Following from our definition, the requirements of differentiation and interdependence are the basis for such a determination. At least two different types of positions are implied by the condition of differentiation. And interdependence between different elements requires reciprocal exchange. This implies at least two resources: for example, the coordination of

[11]Andrew S. McFarland, *Power and Leadership in Pluralist Systems* (Palo Alto: Stanford University Press, 1969), p. 17.

[12]*Ibid.*, p. 18.

someone saying, "Heave" (r_1) with the physical effort (r_2) needed to move a large rock. At minimum, then, two persons (C_i) are differentiated into two roles (D_j), exchanging two resources (r_n) in *inter*dependent ways (I_k). In formula, then,

$$\text{complexity } Q_x = (C_i, D_j, I_k)_{r_n},$$

where $C = 2$, $D = 2$, $I = 2$, and n has a range of 2. If any of the elements of the relationship falls below two, the system cannot be said to be organized or complex. Note here that the limit of differentiation is (C_i).

Starting at this minimum level, we can now ask what are the consequences for system behavior as the number of components increases, holding *constant* D_j and I_k. What, for example, are the effects of increases in C upon communication patterns if D and I are held constant? It seems clear that operational and conceptual questions regarding the number of components and differentiation can be worked out.[13] Some work also has been done in relating size, differentiation, and "integration," though this term has a much less precise meaning than *interdependence* as used in this book.[14] This research suggests the general notion that increases in size put strong pressures on the system to increase internal differentiation and interdependence as requirements for coordination increase. It is quite probable that as size increases and D_j and I_k are held constant, the system will begin to take on *unorganized* characteristics and ultimately will dissolve.

Say that organizations are ordered in terms of their size, differentiation and internal interdependence; we can begin the task of examining the consequences of increases in one or the other of our definitional elements. Holding variable aspects of organized social systems constant,[15] we can ask

[13]See William H. Starbuck, "Organizational Growth and Development" in *Handbook of Organization*, ed. James G. March (New York: Rand McNally, 1965), pp. 495–505.

[14]See D. S. Pugh et al., "Dimensions of Organizational Structure," *Administrative Science Quarterly*, 12 (1968), 65–105; and P. R. Lawrence and J. W. Lorsch, "Differentiation and Integration in Complex Organizations," *Administrative Science Quarterly*, 11 (1967), 1–47.

[15]One of the methodological difficulties prompted by "interdependence" and needing attention crops up here. The notion of interdependence differs from both the ordinal variables, differentiation and component, in that it is a pattern variable describing a potential matrix of exchange relationships which could be in a number of different patterns. Until a way of ordering such pattern variables can be devised, such as the attempt by Metlay in the technical note below, holding variables constant would have to mean maintaining the types and directions of dependencies between components as the size of the system increases. This point, made to me by Kai N. Lee, is very likely to be an excellent entry for fruitful methodological research. See also Chapters VI and VII below.

what consequences there are for other types of behavior within the system or between systems as they deal with their external environment. This can be asked about different organizations at a single point in time or about one organization over time.

It appears that, in general, as size and differentiation increase, there is a subsequent increase in the amount of interdependence as well. But what does this mean operationally? If we think of the amount of interdependence (I_k) as the degree to which persons share dependencies (interact, make allocation decisions) for resources distributed among them, then some measure of overall dependence may be constructed. The limiting case would be an organization requiring only two types of resources — the organization of, for example, ten persons occupying at least two types of positions exchanging two resources, say coordinative skill (r_1) and physical labor (r_2). Staying with our example, nine of them pull ropes attached to a granite boulder while the tenth coordinates their action. Thus the pullers are dependent upon the coordinator for direction and he on them for their collective response. In a sense, such a situation closely parallels Thompson's "pooled interdependence" — the pullers being dependent upon the director, but not directly dependent upon each other.[16]

Given this situation, how would interdependence increase? As more resources (valued objects, skills, etc.) are included in the exchanges between persons in the organization, more kinds of dependencies are established.[17] This accounts for an expansion of the basis of dependence and possible control. If, for example, the block of granite is to be cut into a particular shape, then one puller must take on the job of stonemason, contributing stone-cutting skill as a resource (r_3). This contingency increases differentiation by one and increases the resource dependencies for the leader. He must now coordinate not only the pulling, but the time and place of stone-cutting. The total amount of complexity has increased as D_j increases and as the sum of the dependencies increases.

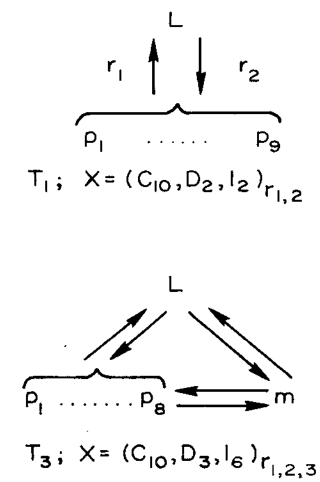
Using this reasoning, it is possible to describe various levels of complexity. Again recalling our example, if the stonemason were required to tell the pullers what rocks to haul before they can get to work, their dependence on him and the total complexity of the relationship would increase by one. The total number of resources exchanged in the system, however, would not increase. Figure 1–4 illustrates the first and last series of relationships and includes a symbolic summary of overall complexity.

It is possible to imagine doing this kind of elementary designation of C_i, D_j, and I_k for various subgroups within larger organizations, thus

[16]J. D. Thompson, *Organizations in Action* (New York: McGraw Hill, 1967), p. 54.
[17]See A. S. Tannenbaum, *Control in Organizations* (New York: McGraw Hill, 1968).

developing a way of roughly ordering complex systems. In the Technical Note at the end of this chapter, Metlay has developed a method of ordering complex systems, using the matrix ranking concept. It may provide a way to begin the difficult task of operationalizing and comparing such systems. If we attempted a descriptive analysis on such a detailed level for groups as they become larger, more differentiated, and included more types of resources, it would be clear that keeping track of relationships, flows of resources, and so on, quickly becomes very difficult to manage. When we remember that the basic element in complex social systems is the exchange *interaction* among people, we see that such a multitude of relationships can become the source of considerable distress for them. Here lies the root of the limitations to the complexity to which social forms are subject.

Figure 1–4. Increases in Complexity: An Illustration



Limitations of Complexity

While organized social systems theoretically *can* take a "full matrix" dependence configuration, this happens only rarely, and then only with very small systems. As the size of the organization increases, for example, the relatively inelastic limit of individual information processing capacity prevents nearly complete interdependence.[18] In discussing this limitation,

[18]Information, in the general sense used here, means stimuli issuing from a person's environment, whether physical or social. It is distinguished from information as a resource in exchange relationships. Information as a resource is specific facts or descriptions of events and attitudes not immediately available to a person in need of them.

Miller demonstrates that

> If the human observer is a reasonable kind of communication system, then when we increase the amount of input information the transmitted information will increase at first and will eventually level off at some asymptotic value. This asymptotic value we take to be the *channel capacity* of the observer: it represents the greatest amount of information that he can give us about the stimulus on the basis of an absolute judgment. The channel capacity is the upper limit on the extent to which the observer can match his responses to the stimuli we give him.[19]

A further limitation is a relatively narrow span of immediate memory; combined with the limitation of absolute judgment, this reduces the amount of information a person can absorb and understand at a given time.

These restrictions become a nearly absolute limit to the number of persons and/or amounts of information any member of a group or an organization can deal with. If we think of organizational members as having a finite number of open connections available for receiving information or connecting with others, it follows that when all connections become engaged no more can be made without overloading the person or eliminating previously made relationships.

One of the consequences of increasing complexity is an increase in the number of people and/or types of interaction they experience within the organization. At some point, individual channel capacities are saturated, and no additional relationships are likely to take place. When this happens, a system which has exhibited complete interdependence can no longer maintain this as its size increases. There are simply too many other people to take into account. Overload occurs and to relieve this situation delegation begins.

There are ways of temporarily overcoming information saturation, e.g., by regrouping and reorganizing information inputs into summary units or "chunks" of information. "Since the memory span is a fixed number of chunks, we can increase the number of bits of information that it contains simply by building larger and larger chunks, each chunk containing more information than before."[20] This recoding, however, is itself limited by the ability of the recoder to develop new codes which have a rough correspondence to reality. The larger and more swiftly changing the social system, the more difficult this is to accomplish.

[19]George Miller, "The Magical Number Seven, Plus or Minus Two," *Psychological Review*, 63 (1956), 82.
[20]*Ibid.*, p. 93.

Finally, the development of highly interdependent organizational systems is limited by the degree to which members are aware of their interdependence. Members must be aware of their relatedness, or they are not likely to act in consciously interdependent ways. As the number of potentially interdependent actors increases, this awareness relatively declines. Thus the related limitations of information processing capacity and perceptual awareness make quite unlikely the development of very highly interdependent systems. Rather, as systems become larger than a fairly good sized primary group, they are slowly transformed into a growing number of relatively stable subsystems that are semilattice in form and loosely coupled together. Among other things these subsystems attempt to adapt to problems of information absorption, recoding, and transmission. The remaining part of this chapter will be a general discussion of some properties of such internally transformed systems. Extension and elaboration of the discussion below will be found in Chapters VI and VII.

Some Properties of Organized Complexity

Simon argues that complexity takes the form of hierarchy, of a complex system composed of interrelated subsystems that, in turn, include their own subsystems, and so on.[21] Successive partitioning can be done until the most elementary subsystem is reached. As a whole, then, a complex system can be analyzed as a successive series of sets, subsets and subsubsets arranged in hierarchical order in the form of trees or semilattices.

Given the limitations on complexity discussed above, we would not expect the distribution of interdependence to be equally high throughout an organization, i.e., the system will not approach the nearly "full matrix" form. Rather there will be clusters of interaction and interdependence *within* subsystems and varying degrees of connectedness *between* them. Again, Simon:

> [W]e can distinguish between the interactions *among* subsystems on the one hand, and the interactions *within* subsystems — i.e., among the parts of those subsystems — on the other. The interactions at the different levels may be, and often will be, of different orders of magnitude. In a formal organization there will generally be more interaction, on the average, between two employees who are members of the same department than between two employees from different departments. In organic substances, intermolecular forces will generally be weaker than molecular forces, and molecular forces than nuclear forces.[22]

[21]Simon, "Architecture of Complexity," p. 64.
[22]*Ibid.*, p. 69.

Types of partitioning or decomposability can be distinguished on the basis of whether a system is completely or is nearly decomposable. *Completely decomposable* systems are made up of several independent subsystems, each one of which can be analyzed separately without reference to any of the others. A completely decomposable group, for example, is one in which every member has no other role outside of the group or, if he does, those other roles have no effect whatsoever on his behavior within the group.[23] In a sense, complete decomposability is the other extreme from complete interdependence; it seldom occurs in fact, and it is close to the condition of *unorganized* complexity. Put another way, if any single member of an organization so structured fails to contribute his share of resources, very little effects would be noticeable.

No system of organized complexity is completely decomposable, almost by definition. Again Simon advances a useful notion of "*nearly decomposable* systems, in which the interactions [interdependencies] among subsystems are weak, but not negligible."[24] That is, while the interaction *within* subsystems may be quite high and complexity extreme, the interdependencies *among* them are few and relatively weak. In systems or organizations of this sort should failure or loss of a connection occur between subsystems, the organization might devolve into relatively cohesive and independent subsystems. We see examples of nearly decomposable organizations in large conglomerate corporations and in portions of the Federal bureaucracy.

Two interesting propositions are associated with this form of complex system, and though derived from economics and physics, they can be fruitful for our understanding of the behavior of large moderately complex bureaucracies. They are that in nearly decomposable systems,[25]

1. The short-run behavior of each component subsystem is approximately independent of the short-run behavior of every other component subsystem.
2. In the long run, the behavior of any one component subsystem is dependent in only an aggregate way on the behavior of the other component subsystems.

This limited spillover effect is possible due to the small number of connections between component subsystems and is probably characteristic of most moderately complex organizations. However, if interdependence

[23]See Franklin Fisher and Albert Ando, "Two Theorems of *Ceteris Paribus* in the Analysis of Dynamic Systems," *American Political Science Review* 61 (1962), 108–109.

[24]Simon, "Architecture of Complexity," p. 69.

[25]*Ibid.*, p. 70.

between component subsystems increases, i.e., if the system becomes less decomposable, these propositions require modification.[26]

In a sense, the more tightly complex an organization, the closer it moves toward becoming a *disaggregative system*. This is a system in which the components are so tightly interdependent that should one component fail the whole system either collapses or becomes inoperative. Perhaps the best example of this system is the organization of some man-machine weapons system in which the failure of one or several computers would bring the whole enterprise to a halt. This singular type of hyperinterdependence — dependence upon every component for increasingly critical resource contributions — prompts the development of "fragile" systems. For fragile systems changes in conditions, availability of outside support, and so forth, which interrupt the flow of external or internal resources become critical for the continued operation of the organization, at least in its steady state. Less fragile or more adaptive organizations exhibit the property of internal redundancy.[27]

Redundancy in an organized system is essentially the degree to which various components carry on similar functions or activities. For example, public organizations are partially redundant if several subunits all carry on purchasing activities for the whole organization. In terms of our definition of organized complexity, the more differentiated the organization, the less redundant; that is, the fewer the units or persons carrying on the same activity. Put another way, holding the size of the organization constant, decreasing its differentiation of roles increases its redundancy and decreases overall complexity. One of the salient features of redundancy in complex organizations is its association with error correction and failure compensation. Whether functional and dysfunctional redundancy can be distinguished and examined is still a theoretical and empirical question. Some of the preliminary groundwork for pursuing it is covered in Chapter X of this book.

Summary and Further Questions

The concept of organized social complexity has been defined in terms of numbers of components and the differentiation and interdependence of these components. Various arrangements of interdependence can be described as the simple hierarchy or "tree," the semilattice, and the "full matrix" of dependence. Apparently semilattice structures are more

[26]See Metlay and Brewer below. Metlay demonstrates the magnitude of error associated with treating relatively complex systems as if they were nearly decomposable.

[27]See Martin Landau, "Redundance, Rationality, and the Problem of Duplication and Overlap," *Public Administration Review*, 29 (1969), 346–358.

common than either trees or full matrices. Trees are far too simple to meet most organizational or group situations. Full matrices are interdependent beyond the capacity of people to sustain such dependencies. The crucial limit on complex development is the capacity of individuals to process information, thus limiting the number and kinds of interaction they can engage in. We have attempted to provide here initial operational grounds for treating organized social complexity as an independent variable. Our approach was based fundamentally on conceptions of position and role, with exchanges of resources between interdependent positions. Finally, several properties of complex systems were discussed, which dealt with the relative influence of subsystems upon each other in systems of varied decomposability. The more complex a system, the less its decomposability, and the more directly the short-run behavior of one subsystem will influence other subsystems in the organization.

We began suggesting that the world about us seems to be becoming more connected, interwoven, and interdependent. We suddenly discover that this or that group or organization has become dependent upon other groups or organizations in curious and surprising ways. Part of this new awareness is due, we argued, to the objective increase of organized social complexity. Public and private organizations have grown much larger, they have become more internally specialized, and there are many more specialized types of large organizations. In addition, there are closer bonds of interdependence among and within the major institutions of our time. Of course, the extent to which these conditions prevail is an empirical question. It is a question that rarely has been asked. Yet if it is true that the texture of life and its social institutions has become increasingly complex and can be expected to continue so, the implications for social theory, for political science, for the techniques of inquiry, and — perhaps most important — for public policy are enormous.

This introductory explication of *organized social complexity* was developed on the basis of extended and vigorous discussion among the authors of this book. It represents a sustained attempt to treat complexity as an *Independent variable* — as a condition which if altered would in turn alter other important relationships. We were initially drawn together in examining the assertion that the major impetus to greater social complexity has been technological development. What follows is the result. Our preliminary study was done against the background of scholarship represented in the Selected Bibliography accompanying this initial chapter.

With one exception (see Chapter III), each author takes increasing levels of social complexity as his point of departure and examines a segment of the conceptual literature which purportedly enables us to understand social organization and to control it more effectively. Underlying these efforts is the question of how adequate that conceptual framework is for comprehending genuinely increasing levels of organized social complexity.

Chapter II, by Winner, takes up aspects of the epistemological challenge of increasing complexity. The limits of human understanding itself is examined, with emphasis upon the fractured character of knowledge in the wake of disciplines which have developed in the pursuit of differentiated understanding. The author points to science and technology as one source of this dilemma, but ends his discussion with speculations verging on the metaphysical. The notion of technology as complexifier is then explored by Taylor, who alone among the group treats social complexity as a dependent condition. He finds it is a complexifier, but not absolute in that quality: the way men have *thought* to organize has just as much to do with manifest complexity as have the processes of technological development. While the stuff of technology has fueled the incredible growth of organized complexity, men's imaginations and conceptions seem to control its metabolic rate and "organic" development.

Part Two includes explorations of two related bodies of thought which manifestly promise to be adequate bases for control over man's affairs — planning and systems analysis. Ruggie's essay investigates the impasse reached by the two major orientations in public planning — the comprehensive and the incremental — when faced by conditions of growing complexity. Neither moves any appreciable distance away from notions essentially founded on deceptively simple images of highly differentiated social units with little mutual interdependence. Their underlying metaphor is the *market*, no longer a valid arbiter of choices having "indivisible social consequences."

The systems approach does little better as a basis for coping with increasing organized social complexity. It presents a *premise* rather than a theory, and to have substance, its constructs must extend to other notions: the mechanistic equilibrium of the machine, the homeostatic equilibrium of the ecological niche, the adaptive dynamics of organic species. But as social systems' numbers and interdependencies grow, these analogies are a poor basis for action. Both the mechanistic and the homeostatic concepts simplify too much to be confident guides to policy and action. Only the adaptive construct holds a bit of promise, but its mettle has not yet been tested in the fires of politics and policy. Like the conventionally adopted planning perspectives, those afforded by systems analysis provide an inadequate conceptual basis for coping with the complexity of the social world.

Two kinds of methodological questions are addressed in Part Three — the analytic adequacy of present methodologies and their potential for empirical research based on notions of complexity. Brewer and Metlay present complementary essays which raise very serious doubts about the confidence we can put in linear programming and statistical analysis as tools for describing complex systems. The inadequacies of these methods extend even to systems which are still relatively small but whose internal interdependence is on the increase. In effect, as the complexity of a system grows, even modestly, our tools of formal description and hence prediction are subject to greatly increased error. Thus, systems analysis and planning subject us to a spurious sense of accuracy prompted by the apparent precision of their mathematical tools.

Chapter VIII breaks stride with the character and language of the others in this book. Based on an empirical field study done in England at the time of our original formulation, it is the only chapter which directly shows the research utility of our conception of complexity. It demonstrates that questions derived from the perspective of organized complexity can with considerable profit be put to organizational experience, in this case to an aspect of public education policy. It is unlikely that the insights gathered in the case examined here could have emerged had the more traditional literature of organizational analysis been the sole basis of the study. In a sense, this experience of English higher education in the recent past lends credibility to the application of the adaptive systems construct described in Chapter V. Adaptation clearly occurred in this case toward more internal complexity and greater integration among the various actors involved. We present Nias' essay as evidence that empirical research can and ought to be done as we gain more awareness of increasing organized social complexity. A host of interesting organizational and political questions emerge in such an enterprise. Some of them will be discussed in Chapter X.

Part Four begins with an attempt to refine the notion of complexity for the purpose of renewing the relevance of political theory to the present. Wilson provides an extension of the notion of organized social complexity in such a way as to allow an examination of historical writings in political, social, and organizational theory in terms of the major theorists' implicit conceptions of complex reality. Such an extension bridges the gap between problems of analysis and the challenge of action. Political and organizational theories have been the basis for conceptions of order which in turn become the foundations of programs and policy. The implicit conception of social complexity underlying manifest theorizing leads to different types of social and political prescriptions. How we come to perceive the character of present social complexity could lead dramatically to new political patterns, characterized, for example, by programs which drive toward "coercive simplicity" or "normative complexity." The implications for

the political order are most profound. Chapter X is both summary and prospective; it attempts to draw out some of the implications of the preceding work and to indicate potentially fruitful directions for the future, particularly within the ambit of organization theory and the study of public institutions.

Together these chapters move toward answers to a series of crucial questions. In so doing, they take up the task implicit in Alexander's assertion about the difficulty of conceptualizing complexity: "In a single mental act you can . . . visualize a tree. You cannot bring the semilattice structure into a visualized form for a single mental act."[28] Have we developed political and social theories only of simple systems? How appropriate are they for a society of extraordinary complexity? What intellectual and research demands are implied by the quest for organizational, political, and social theories of complex systems?

[28]Alexander, "A City," p. 60.

Appendix I-A
Matrix Form of Illustrative Structural Variations

The matrices below represent the three different forms of organized social complexity discussed early in this chapter (pages 8, 9). In that discussion the forms were represented in schematic form with indications of direction of dependence. In the form used below, the matrix format is the guiding structure and refers to the exchange dependency of only one resource $(A_{ij})_{r_1}$.

Figure 1–5. Matrices Representing Three Forms of Social Complexity

Matrix of Semilattice Dependence

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}
C_1	0	0	0	0	0	0	0	0	0	0	0	0	0
C_2	0	0	0	0	0	0	1	1	0	0	0	0	0
C_3	1	0	0	0	0	0	0	0	0	0	0	0	0
C_4	1	0	0	0	1	0	0	0	0	0	0	0	0
C_5	1	1	0	0	0	0	0	0	0	1	0	0	0
C_6	0	1	0	0	0	0	0	0	0	0	0	0	0
C_7	0	0	0	0	0	1	0	0	0	0	0	0	0
C_8	0	0	0	0	0	0	0	0	0	0	0	0	0
C_9	0	0	1	1	0	0	0	0	0	0	0	0	0
C_{10}	0	0	0	0	0	0	0	0	0	0	1	0	0
C_{11}	0	0	0	0	0	1	0	0	0	0	0	0	0
C_{12}	0	0	0	0	0	1	0	0	0	0	0	0	0
C_{13}	0	0	0	0	0	0	0	1	0	0	0	1	0

Matrix for a Tree of Dependence

	C_1	C_2	C_3	C_4	C_5	C_6	C_7
C_1	0	0	0	0	0	0	0
C_2	1	0	0	0	0	0	0
C_3	1	0	0	0	0	0	0
C_4	1	0	0	0	0	0	0
C_5	0	1	0	0	0	0	0
C_6	0	0	1	0	0	0	0
C_7	0	0	0	1	0	0	0

Matrix of Full Dependence

	C_1	C_2	C_3	. . . .	C_n
C_1	0	1	1	. . . .	1
C_2	1	0	1	. . . .	1
C_3	1	1	0	. . . .	1
.	.	.	.	. . . .	.
.	.	.	.	. . . .	.
.	.	.	.	. . . .	.
C_n	1	1	1	. . . .	0

Appendix I–B

A Note on Graph and Lattice Theories Applied to Organized Complexity

In constructing definitions of various types of complex structures, we sought a language that would help us to frame premises in such a way that more precise and rigorous work could be developed. Our primitive notions were essentially rooted in conceptions of the relatedness between persons in relatively highly differentiated organizations, so we needed some formal language based also upon such notions. In exploring available formulations, we ranged over several types of literature: group theory, sociometrics, set theory, and two other languages grounded in mathematics: graph theory and lattice theory. The definitions of structural arrangements presented in this chapter (pages 6ff) are rough translations from these two latter quite formal languages, developed to describe and analyze the properties of complex structures. Digraph theory, which begins with the relationships between individual elements (points and lines) provides the most intuitively useful language and method for the description of rather simple collections of elements or sets. (Cartwright, 1959; Szasz, 1963; Friedell, 1967). Quite a body of literature has resulted from its application to general and practical problems in a wide range of endeavors. This mathematical structure-language affords a potential for developing much more rigorous and efficient ways of describing complex structures. (See Selected Bibliography.)

Graph theory, however, because its point of departure is the relationships among limited numbers of elements, has advanced only a little in providing formal methods for describing larger and more differentiated complex organizations. Our explorations of another mathematical language — lattice theory — may also aid in this venture.

Lattice theory is much more developed and solidly rooted in both algebra and set theory (Szasz, 1968). Its immediate detailed applications to the analysis of organizational structure is a good deal more difficult to see, but nevertheless it appears to be useful when a language for describing whole structures is required. Beginning with a general mathematical formulation of the relation of sets to one another, it develops a series of propositions from certain restrictions on the characters of relationships.

Unfortunately for those interested in describing complex social structures, to whom the languages of graph and lattice theories appear to have

a clear intuitive utility, these languages apparently do not need to be integrated for mathematical purposes. Thus, their formal integration will have to await that unusual person who has skills both in formal languages *and* in their application to organizational structure. A step in this direction has been taken by Starbuck, Friedell, and Cartwright, but their work has simply applied one or the other to organizational questions; it has not sought to synthesize graph and lattice theories. In the process of our own development, we have become increasingly aware of potential applications and of our collective ignorance in these matters.

Metlay

Technical Note: A Quasi-Operational Definition of Complexity

By Daniel Metlay

Any formal attempt to examine complexity must begin with definition. We are not considering here that mode formulated by Weaver as disorganized complexity,[29] represented by the collection of gas molecules in a jar or by the voting behavior of the American people. Each of these forms of complexity will reveal predictable patterns of behavior when treated statistically. Nor are we dealing with that variant of complexity associated with natural systems such as the solar system or an ecological niche. Quite specifically, we shall examine that form of complexity that obtains in an *organized social system.*

Our intuitive, often vague, notion of that type of complexity suggests that it is a function of the number of units which comprise a given system, their degree of specialization, and the number of functional, causal, or dependency linkages among them.[30] Two major difficulties at least arise from this informal description: First, it leaves to the imagination ways of combining these variables to create something resembling an unambiguous measure of complexity; second, it does not allow for comparisons between two systems to determine which is the more complex.

The *ad hoc* character of our intuitive understanding here can be readily demonstrated. There is an infinite number of ways of constructing a function of the number of units (C), the degree of differentiation (D), and the number of linkages (I), subject only to the constraint that it be monotonically increasing over each of the variables. Thus one could say that complexity (Q) is equal to the sum of C, D, and I; one could just as easily argue that Q is equal to their product, or to some power expression, or to some combination of the additive, multiplicative, or power-raising operations.

The second limitation of our intuitive approach follows directly from the first one. If we have no rigorous method of measuring the complexity of a single system, we are then unable to compare the relative complexity of two systems. Except in the case where two of the three variables are the same (a rare event), we cannot say whether or not system A is *more complex* than system B if, say, it has seven more linkages yet six fewer units. In general, we have no way of making "trade-offs" among our components of complexity. Quite clearly, we need to abandon this intuitive approach and ground our definition in organization theory.

[29]Warren Weaver, "Science and Complexity," *American Scientist*, 36 (1948), 536–544.

[30]See Herbert Simon, "The Architecture of Complexity," *General Systems Yearbook*, 10 (1965), 63–75.

Other chapters in this volume will discuss various aspects of the concept of organized social complexity. It is appropriate here to take a brief look forward into the more salient definitional ones. A method of defining the boundaries of a social system is a case in point. Two components are part of the same system if they are involved in reciprocal exchanges of resources, either directly or through some third component. A unilateral exchange between two components places the "giver" in the environment of the "receiver." Aggregating the elements within the system produces a set of exchange relations (linkages) by which any element depends for its behavior upon some particular combination of the other elements of the system, as well as upon those in the environment.[31] Clearly any measure of social complexity must not only reflect this aspect of systemic interaction, but, more specifically, must have a minimum value for a single reciprocal exchange between two members of the system.

Other commentators argue that organized complexity is inversely related to a system's redundancy.[32] They suggest that the growth of a system is a necessary, but not sufficient, cause of increased complexity. Growth will lead to a more complex structure if, and only if, the additions are differentiated from those already present. Thus, we need to construct our measure so that it is in agreement with this theoretical prescription regarding redundancy.

Finally, work which deals with decomposability of systems can be helpful in developing an operational definition of complexity. Central here is the argument that hierarchy reduces the complexity of a given system and that it is rare to find elements "linked with almost equal strength with *almost all* other parts of the system."[33] To the extent that this is true, it is possible to decompose the system into subsystems, each evincing simpler behavior. Thus, the degree to which the system can be decomposed is inversely related to its complexity, a matter we need to consider in our measure.

It is a commentary on the state of the art that we can say only that organized social complexity is a function of the three components C, D, and I, and that it must conform to the three theoretical prescriptions mentioned above. A number of measures may, in fact, satisfy these constraints. We propose one which appears to have additional analytical utility.

[31]For a discussion of political exchange theory, see Warren Ilchman and Norman Uphoff, *The Political Economy of Change* (Berkeley: University of California Press, 1969).

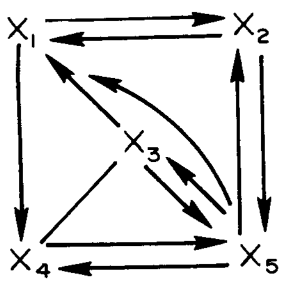
[32]Cf. Simon, "The Architecture of Complexity," p. 73.

[33]*Ibid.*, p. 70.

Complexity as Rank

The matrix notation suggested by Simon, Stinchcombe, Starbuck, La Porte, and others can be extended for analysis.[34] A matrix (A) is constructed representing the dependency or exchange relationships among the units (C). The i-jth element is either a one or a zero depending on whether or not the ith unit is linked to the jth unit. For example, a five component system $[x_1 \ldots x_5]$ can be represented by the dependence matrix in Figure 1–6. The direction of the dependence relationship is indicated both by the arrow in the diagram and by the convention to be followed throughout this book that the *row unit depends on the column units.*

Figure 1–6. Five-Member System and Its Matrix Representation



(i)	X_1	X_2	X_3	X_4	X_5 (j)
X_1	0	1	1	0	1
X_2	1	0	0	0	1
X_3	0	0	0	1	1
X_4	1	0	0	0	1
X_5	0	1	1	1	0

We can use this technique to deal with some of the limitations in our intuition discussed previously. *We define organized complexity as the rank, R, of the dependence matrix.* The term "rank" has a precise meaning mathematically.[35] We define rank (R) as the number of linearly *independent* equations which are produced if the matrix is considered to be an array of coefficients. Using the dependence matrix above as an example, we can generate this set of equations:

$$x_1 = x_2 + x_3 + x_5 \quad (1.1)$$
$$x_2 = x_1 + x_5 \quad (1.2)$$
$$x_3 = x_4 + x_5 \quad (1.3)$$
$$x_4 = x_1 + x_5 \quad (1.4)$$
$$x_5 = x_2 + x_3 + x_4. \quad (1.5)$$

Any two equations f_1 and f_2 are independent if there are no nonzero constants k_1 and k_2 such that

$$k_1f_1 + k_2f_2 = 0. \quad (1.6)$$

We can clearly see that the equations (1.2) and (1.4) are not independent of each other; equation (1.6) is satisfied by any set of constants $k_1 = k_2$. However, there are no constants which will satisfy equation (1.6) when equations (1.1), (1.3), or (1.5) are inserted. Thus we can isolate two sets of independent equations, (1.1, 1.2, 1.3, 1.5) and (1.1, 1.3, 1.4, 1.5). There are four members in each set; thus, the rank of the matrix is four. Consider the ranks of the dependence matrices in Figure 1–7:

Figure 1–7. Examples of Dependence Matrices

(1)
$$\begin{array}{l} 011 \\ 101 \\ 010 \end{array} \quad \begin{array}{l} C = 3 \\ D = 3 \\ R = 3 \end{array}$$

(2)
$$\begin{array}{l} 011 \\ 001 \\ 110 \end{array} \quad \begin{array}{l} C = 3 \\ D = 3 \\ R = 3 \end{array}$$

(3)
$$\begin{array}{l} 01010 \\ 10001 \\ 11000 \\ 00101 \\ 11010 \end{array} \quad \begin{array}{l} \\ \\ C = 5 \\ D = 5 \\ R = 5 \end{array}$$

(4)
$$\begin{array}{l} 011001 \\ 001110 \\ 000010 \\ 111000 \\ 101010 \end{array} \quad \begin{array}{l} \\ \\ C = 6 \\ D = 5 \\ R = 5 \end{array}$$

(5)
$$\begin{array}{l} 000000 \\ 000000 \\ 000000 \\ 000000 \\ 000000 \\ 000000 \end{array} \quad \begin{array}{l} \\ \\ \\ C = 6 \\ D = ? \\ R = 0 \end{array}$$

(6)
$$\begin{array}{l} 00 \\ 10 \\ \end{array} \quad \begin{array}{l} C = 2 \\ D = ? \\ R = 1 \end{array}$$

(7)
$$\begin{array}{l} 01101101 \\ 00111101 \\ 10011101 \\ 11101010 \\ 11010110 \\ 11001001 \\ 11001101 \\ 11101110 \end{array} \quad \begin{array}{l} \\ \\ \\ \\ \\ C = 8 \\ D = 8 \\ R = 6 \end{array}$$

(8)
$$\begin{array}{l} 01 \\ 10 \\ \end{array} \quad \begin{array}{l} C = 2 \\ D = 2 \\ R = 2 \end{array}$$

Returning to the desiderata for a measure of organized complexity, it can be easily shown that the rank (R) fulfills each of them. It should be obvious how R is related to C: R must be less than or equal to C. Examples (1), (2), (3), and (8) in Figure 1–7 provide instances where R equals C. In the remaining examples, R is less than C. The relation between R and D, the degree of specialization, is similar: R will be less than or equal to D. Example (4) shows R equal to D. Note that the third and fourth row ele-

[34] *Ibid.*, Arthur Stinchcombe, *Constructing Social Theories* (New York: Harcourt, Brace, and World, 1968), William Starbuck, "Mathematics and Organization Theory," in *Handbook of Organization*, ed. James G. March (Chicago: Rand McNally, 1965), pp. 363–379; and Todd La Porte, Chapter 1, above.

[35] See F. Bowman, *An Introduction to Determinants and Matrices* (London: The English Universities Press, 1962). An alternative way to define rank is that a matrix has a rank of R if it has a nonzero minor of order R but no nonzero minor of order R + 1; in other words, if every minor of order greater than R vanishes, but not every minor of order R. There are a number of methods which enable an investigator to determine the rank of a dependence matrix. If it is nonsingular, then the rank equals the order. Alternatively, one can construct an equivalent matrix by means of elementary operations which has every element on the leading diagonal equal to unity or zero and every element below, or above, that diagonal zero. The rank then can be determined by inspection. The manner chosen for this research was to determine the number of nonzero eigenvalues of the matrix which is also equivalent to its rank.

ments have identical dependence relations, i.e., they perform the same tasks. From the viewpoint of the system, these elements are redundant. One may be tempted to argue that R is a superfluous measure, that we could just as well use D. However, that arrangement would be insufficient, for R not only measures explicit redundancy (equal to C-D; see examples 1–4 and 8), but it also shows the implicit redundancy present in example (7) as well. By implicit redundancy we mean that a set of actors can be analyzed as if they were performing the identical task of some additional actor outside their set.[36]

The common sense analogue to implicit redundancy would be found in an organization which employed one person to fashion a component from four inputs and which also had a person to take two subcomponents each fashioned from two of the same inputs to produce the finished component. Clearly, the dependence relations of the two people are different and thereby not redundant in the same sense that x_2 and x_4 in Figure 1–6 above are. Yet they are redundant in the sense that they ultimately carry out the same function.

In addition to being a measure of redundancy, the value R conforms to the other two theoretical constraints. While the minimum value of R is not that of the simplest exchange system, it still maintains the spirit of the exchange theory. In example (5), R equals 0: that dependency matrix does not represent a system; none of the elements are linked with any of the others. In example (6), R equals 1: this array suggests a nonreciprocal relation — a circumstance ruled out by the exchange theory. Finally, in example (8), R equals 2. Here we have the *minimum* requirements for exchange. Thus, we say that when R equals 0, the system does not exist; when R equals 1, it is degenerate. When R equals 2, the system is equivalent to the *simplest possible system allowable* under the exchange theory. Clearly, as the organized complexity of a system increases, so does its rank.

We can see this more clearly by trying to apply this measure to a hypothetical organization schematically illustrated in Figure 1–8. The dependence matrix representing this system is shown in Figure 1–9. Here C and D equal 27; so does R. The number of linkages (I) equals 75. To illustrate the "sensitivity" of the measure R to a small change in organized complexity, we remove the linkage between elements 1 and 5. Recalculating R gives a value of 26. Thus, we would suggest that R fulfills all the requisites considered so far.

[36]This notion of redundancy is somewhat different from that employed by Martin Landau. It is, however, entirely compatible with his work. See Martin Landau, "Redundancy, Rationality, and the Problem of Duplication and Overlap," *Public Administration Review*, 22 (1969) 346–358.

Figure 1–8. Hypothetical Organization

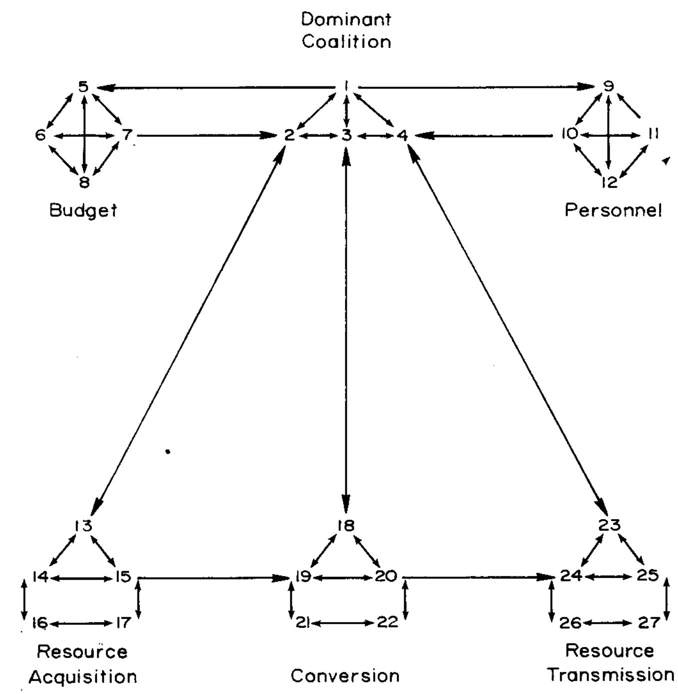


Figure 1–9. Matrix Representation of Hypothetical Organization in Figure 1–8

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
1	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1	0	1	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
4	1	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
5	1	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	1	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	1	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0
18	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	1	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	1	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0
23	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	1	0
25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	1
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0

We must still consider the remaining two desiderata for any measure of the complexity of a system — behavior under a condition of decomposition and its relation to the number of linkages (I). Consider the dependency matrices appearing in Figure 1–10:

Figure 1–10. Dependency Matrices

$$\left[\begin{array}{cccccc|cccc}
0&1&1&0&1&1&0&0&0&0\\
0&0&1&1&0&0&0&0&0&0\\
1&1&0&0&1&1&0&0&0&0\\
0&1&1&0&0&0&0&0&0&0\\
0&0&0&0&0&1&0&0&0&0\\
1&1&1&1&1&0&0&0&0&0\\ \hline
0&0&0&0&0&0&0&1&1&1\\
0&0&0&0&0&0&1&0&0&0\\
0&0&0&0&0&0&1&1&0&1\\
0&0&0&0&0&0&0&1&1&0
\end{array}\right]$$

SYSTEM A

$R = 9$
$I = 27$

$$\left[\begin{array}{cccccc|cccc}
0&1&1&0&1&1&0&0&0&0\\
0&0&1&1&0&0&0&1&0&0\\
1&1&0&0&1&1&0&0&0&0\\
0&1&1&0&0&0&0&0&0&0\\
0&0&0&0&0&1&0&0&0&0\\
1&1&1&1&1&0&0&0&0&0\\ \hline
0&0&0&0&0&0&0&1&1&1\\
0&0&0&0&0&0&1&0&0&0\\
0&0&0&0&0&0&1&1&0&1\\
0&0&0&0&0&0&0&1&1&0
\end{array}\right]$$

SYSTEM B

$R = 9$
$I = 28$

$$\left[\begin{array}{cccccc|cccc}
0&1&1&0&1&1&0&0&0&0\\
0&0&1&1&0&0&0&1&0&0\\
1&1&0&0&1&1&0&0&0&0\\
0&1&1&0&0&0&0&0&0&0\\
0&0&0&0&0&1&0&0&0&0\\
1&1&1&1&1&0&0&0&0&0\\ \hline
0&0&0&0&0&0&0&1&1&1\\
0&0&0&0&0&0&1&0&0&0\\
0&0&0&0&1&0&1&1&0&1\\
0&0&0&0&0&0&0&1&1&0
\end{array}\right]$$

SYSTEM C

$R = 9$
$I = 29$

For each of the three systems R equals 9. Considering that System A differs from System B in only the (2, 8) element and that B differs from C only in the (9, 5) element, it is not particularly surprising that they have the same complexity measure. Yet system A is clearly less complex than is system B. The former can be *completely decomposed* into two subsystems each having no effect upon the other. Elements 1–6 form one subunit; elements 7–10 are similarly joined. System A then is really not a single system at all. It can be analyzed *equally well* by considering the two subsystems separately. Thus, decomposition yields a system of rank 5 and one of rank 4. The existence of the (2, 8) element in system B prevents the decomposition of that matrix. To make explicit this difference we need to modify our definition slightly by using R as a measure of systems *which cannot be further decomposed.*[37]

The partitioning of complex systems into simpler subsystems is a mode of planning behavior designed to reduce organized social complexity. One way systems may achieve this simplification is through coalition formation. Formal treatments of coalitions stress external behavior rather than the internal behavior of those groups.[38] Thus, while payoffs to individuals are important in determining which coalitions will form, those groups, once in existence, are analyzed *as if they were a single unit.*

This aspect of system behavior is subsumed in our measure of organized complexity — R. Consider the following example of ten actors whose initial dependencies are represented by a matrix having 0's along the diagonal and 1's everywhere else:

[37]Some aspects of this definition must remain unsettled at this point. First, the use of zeros and ones in the matrix is strictly arbitrary. There is no reason to believe that a member of a social system is equally influenced by all members upon whom he depends. If the ones in the matrix are replaced by numbers representing, in some sense, the *weight* of influence, then the rank will either increase or remain the same. Thus our definition will, if anything, tend to underestimate the degree of complexity. It is not clear that this needs to be pursued any further if only because, as we will argue later, we may never be able to determine those weights. Second, we are assuming that only a single resource is being exchanged and that each individual's "behavioral production function," i.e., the manner in which he converts factor inputs into outputs, is the same. Clearly there are social systems which do not correspond to those assumptions; it would be a point for further research to extend this definition to cover those particular instances.

[38]The fundamental work on coalition behavior is James von Neumann and Oscar Morgenstern, *Theory of Games and Economic Behavior* (Princeton: Princeton University Press 1944). See also, R. Duncan Luce and Howard Raifa, *Games and Decisions* (New York: Wiley, 1957) and A. Downs, *An Economic Theory of Democracy* (New York: Harper & Row, 1957).

$$\begin{matrix}0111111111\\1011111111\\1101111111\\1110111111\\1111011111\\1111101111\\1111110111\\1111111011\\1111111101\\1111111110\end{matrix}$$

The rank of this system is 10.

After a period of interaction, assume that two coalitions arise having seven and three members respectively. Since the order in which the actors appear in the matrix is arbitrary, we can rearrange them without loss of generality. Assuming internal dependencies to have been eliminated by virtue of the coalition formation, the newly structured system can be represented by

$$\begin{matrix}0000000111\\0000000111\\0000000111\\0000000111\\0000000111\\0000000111\\0000000111\\1111111000\\1111111000\\1111111000\end{matrix}$$

The rank of this system is 2. This can better be seen by partitioning the matrix into a "supermatrix of matrices":

$$\begin{matrix}0^{(1)} & 1^{(1)}\\1^{(2)} & 0^{(2)}\end{matrix}$$

where $0^{(1)}$ is a 7 x 7 matrix with all zero elements, $1^{(1)}$ is a 7 x 3 matrix with all elements equal to one, $1^{(2)}$ is a 3 x 7 matrix with all one elements, and $0^{(2)}$ is a 3 x 3 matrix with all elements equal to 0. This partitioned matrix clearly has a rank of 2. This method, of course, can be extended to any number of coalitions or actors. Thus, the social phenomena of

decreased complexity arising from coalition formation may be understood as being equivalent to a reduction in rank arising from a partitioned matrix.

We may wish to refine our measure even more to account for comparison between system *B* and system *C* as shown in Figure 1–9. While they have the same rank, the former is marginally less complex than the latter, i.e., system *B* has a single linkage between the two sets of elements (2, 8), while system *C* has two linkages (2, 8) and (9, 5). Thus, we can extend our definition to say that for a given rank, the system with the greater number of dependence linkages is the more complex. (It may be possible that a system with a rank R will be more complex than one with a rank $R + 1$ if the difference in their linkages exceeds a certain level. This is analogous to an electron which has more energy in the 4's quantum level than in the 3*d*. At this stage of research into complex systems, however, such "fine structure" gains very little.)

Recapitulating, we have considered the intuitive and theoretical desiderata which must be fulfilled to derive a measure of a system's complexity which is not simply an *ad hoc* value. We have shown how our definition of organized complexity as the *rank* of the dependence matrix does conform to those intuitive and theoretical constraints. We believe that a researcher will find it of use in discussing complex systems.[39]

Selected Bibliography on Organized Social Complexity

This bibliography is presented here so that others who become interested in the problems of organized social complexity may see the initial basis for our efforts in this field. It is a combination of materials gathered during 1969–1970 by Garry Brewer when he was at Yale University and by Todd La Porte. We collaborated briefly during that time in thinking through some of the problems to be faced in beginning an examination of organized complexity. Brewer's contribution of a preliminary bibliography proved to be that bit of push which made further work here on the West Coast seem sensible. In addition Chapter VI in the present volume, Brewer's subsequent treatment of the problems related to organized complexity can be found in his (with Ronald D. Brunner) *Organized Complexity: Empirical Theories of Political Development* (New York: Free Press, 1970), esp. Part IV, and *Politicians, Bureaucrats, and the Consultant: A Critique of Urban Problem Solving* (New York: Basic Books, 1973), esp. Part II.

[39]See, for example, Jennifer Nias, Chapter VIII, below.

Materials are presented below by substantive categories. These represent our way of sorting the literature such as there was (and which had not escaped our notice) at the beginning of this decade. A comparison of this kernel bibliography with the comprehensive one for this volume is a kind of commentary on our interim growth, on the "state of the art" generally, and on the relevant work in social complexity studies yet to be undertaken.

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