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Constructing Dynamic Models of Social Systems: Systems Concepts

In this chapter we will discuss some of the basic concepts of systems thinking and examine how these concepts can be used in formalizing theories about continuous-state/continuous-time dynamics. The first step is to get a grasp on the general idea of a *system,* and the related notions of *subsystem, coupling,* and *complexity.* This first step is an important one because of the confusion that can arise when the ideas of abstract systems are applied to the study of human behavior.

Part of the confusion arises from the fact that the notion of systems has been used at three different levels of analysis in the social sciences. One application has been to the study of the observable behavior of individuals (as in sociometry and early small-groups and social-network analysis). At this level theories and models concern specific observable individuals who have a particular pattern of relations (the network) which, taken together, constitutes a system. A second use of the concept of systems and the tools of systems analysis has been in the analysis of relations among aggregates, and among social actors that are larger than individual persons. At this level we find formal theories of the behavior of governments, formal organizations, populations of consumers, and the like. The phenomena that are being theorized about are still quite concrete, but consist of the behavior of aggregates of individuals, or the behavior of social actors composed of many individuals and the relationships among them. There is a third way in which systems thinking has been widely used in social science thinking (particularly in sociology, anthropology, and political science). At this third level of analysis, systems are composed of abstract concepts and *general variables.* At this level of analysis we find statements about such things as the system of relations between ethnic diversity and political polycentrism, or between the latent pattern maintenance and goal attainment functions of social systems. That is, the elements of the system are not concrete, but rather are highly abstract variables and concepts.

The applications of systems thinking at these quite diverse levels of analysis are not contradictory, but they stress the necessity of being quite clear about what one means when one uses the term *system*. By rigorously applying concepts from systems analysis, and by using formal languages to state theories, it is possible to identify the nature of systems to be theorized with considerable precision. We must, however, begin with a very broad and imprecise definition.

At the most abstract level, *systems* are simply wholes composed of related things.[1] The behavior of each of the "things" (be they atoms, people, business firms, nation states, or abstract variables) in a *system* is conditioned directly and indirectly by the behavior of each of the other things. The appearance and behavior of the "whole" system is the product of both the nature of the things and of the relations among them. In theorizing about the dynamics of such structures, we need a vocabulary to describe the "things" and to describe the "relations" among them—particularly dynamic causal relations. We will devote the two major sections of this chapter to these issues. The discussion of "things" calls forth the concepts of system boundaries, states and state spaces; the analysis of dynamic relations among things requires the language of *connectivity* and *control*.

Systems Elements and Systems Boundaries

One analyst may describe the network of interlocks among directors of corporations as a "system" and theorize about the movement of information in such a network. The network in this case is clearly a type of system, as we defined the term. It has parts (the corporate directors) who stand in relations to one another (either being members of the same boards or not). Taken as a whole, the actors and their interconnectedness form a system with distinctive static and dynamic properties (e.g., centrality, connectedness, etc.). A good deal of the theory of small groups, social networks, and social exchange consists of propositions about the statics and dynamics of such systems.[2] In this case the elements of the system (the "things") are concrete individuals, and the "relations among the things" are relatively simply characterized as the presence/absence (or the strength of) a relation between each pair of individuals.

A second analyst might have an interest in the relationship between governmental policy and mass political support. Such a problem might be approached by treating the government as a unitary actor, and by dividing the population into two aggregates: supporters and opponents. The relations among these three "things" or elements might be quite complex: The level of support and opposition might change (with delay, and possibly in nonlinear fashion) in response to shifts in government policy; government policy, in turn, may shift (with delay, and possibly in a nonlinear fashion) in response to perceived shifts in mass support. The "elements" of the system in this example are quite concrete (the government, the population of supporters, the population of opponents), but are composed of aggregates (supporters and opponents) and social actors (the government, which might be thought of as a system of individuals and relations in itself for other purposes). The relations among the elements of such a system might be a good deal more complicated than in our small groups or network system, but can be specified as a set of precise rules that describe how changes in the behavior of one element of the system (e.g., shifts in government policy) affect the levels of other elements of the system (e.g., the numbers of supporters and opponents.[3]

A third analyst may wish to talk about the "system" of relations among the abstract properties of a bureaucratic organization. (S)he might define the "elements" of the system as the degree of "centralization," the degree of "formalization," the degree of "complexity," and the level of "conflict." The "relations among the parts" of the system may be stated in a set of propositions of the type: "as the degree of centralization increases by one unit (on an arbitrary metric scale), the degree of formalization increases by three-tenths of a unit, but does so with the time shape of a first-order exponential delay of five time units." (More on "delays" later.) Here the elements of the system are general variables (centralization, formalization, complexity, etc.). The relations among these system elements are stated as abstract hypotheses about statistical regularities in the relationships between one property and another.[4]

It may seem at first that these examples of types of systems theories are fundamentally different from one another. It is certainly true that they represent quite different disciplinary interests and quite different approaches to conceptualizing, as well as different levels of analysis. Despite the seeming dissimilarity, the examples are really rather alike from a "general systems" point of view. All three systems are relatively complex in that there are numerous elements and these elements are connected in rather complicated ways.

Theorists disagree over the "right" way to define the units of analysis appropriate for theorizing. We take no position on this particular issue, other than to suspect that there is substantial virtue in rigorous theoretical research on both concrete and abstract systems, and on systems at the "micro" and "macro" levels. The critical point is that from a systems perspective there is little practical difference between theories and models that describe patterns of relations among actors and those that describe patterns of relations among aggregates and "social actors" and those that describe relations among abstract general variables. In principle at least, the notion of a system allows the possibility of models of social action that include both multiple actors and multiple traits nested hierarchically so as to cross levels of analysis in the same theory. For example, a system might consist of a number of productive organizations (each composed of divisions, work units and individuals) interacting to form an economy, which, in turn, is in interactions with other economies. Each of these entities (individuals, work units, divisions, organizations, and economies) might be thought of as having multiple properties that affect its interaction with other actors.[5]

The capacity of a system to include both variables and actors, and to allow virtually any form of relations among variables and actors, accords a great deal of flexibility in constructing theory about social action. The available flexibility, however, should not be used as an excuse for sloppiness. The first task in any systems-based theory construction is to define with great precision its *state space*. To properly specify and formalize a model, it is an absolutely necessary first step to decide what the "things" to be theorized about are. Very simply, the list of "things" in the theory constitute the state space and define the boundaries of the system.[6] Where the theorist decides to draw the boundaries of the system is, of course, highly consequential. In the field of formal organizations, for example, many early models of the relations among organizational properties have been termed "closed systems" models because of their inclusion of only variables describing the structure of the focal organization itself. These "closed" systems models are counterpoised to "open" systems models that also include characteristics of the organization's environment.[7] The dispute here is over where the boundaries of the system are best drawn: Is only the organization to be included, or is the environment part of the system as well?

General systems theory and systems analysis methodologies offer little assistance in resolving such questions. In principle it is desirable to include all of the factors (be they actors or variables) that have effects on the phenomena of interest. That is, one makes the system a "closed" one by including everything within the theory. This injunction for greater inclusion from a formal systems analysis point of view makes a great deal of sense in principle, but not in practice. Only rarely do social scientists theorize about systems of action that are fully closed. In verbal specifications of theories, it is very common to find a number of telling phrases: "under certain conditions," "within limits," and "all other things being equal." These statements recognize that the theory in question has not attained closure and that consequently there are limits on the generalizability and applicability of the model. In statistical formalizations one can find equivalent (though often more hidden) statements about the lack of closure. The assumptions of randomly distributed residuals, uncorrelated residuals, and proper specification of multiequation structural equation models, for example, are intended to attain system closure. They are equivalent to saying that this specification of the model either includes all of the relevant variables, or if it does not, the parts that have been left out do not affect our understanding of the relationships among the variables that have been included.

In defining boundaries for social science theorizing, deciding what the system boundaries are is a pragmatic and paradigmatic question, not a technical one. Full "closure" of a theory is rarely or never possible. The drawing of system boundaries, then, remains one of the most difficult tasks of theory building, requiring creative insight and artistry.

Despite its arbitrary nature, the precise definition of the boundaries of a system and the listing of the elements (individuals, aggregates, and variables) of the state space is an essential first step to all successful formalizations. Systematic application of two systems concepts can often be very useful in dealing with this problem: the notions of *subsystems* and *connectivity.*

Subsystems

Like "system," the term "subsystem" can only be broadly and generally defined. If a system is the whole of a set of parts and relations among parts, a subsystem is a partition of that whole. It is usually most helpful to define subsystems in such a way as to partition a complex system into a series of smaller and simpler ones with less dense ties between than within partitions. If we were examining the network of treaty ties among nations in the world system, for example, we might well see the "system" as composed of two "subsystems" (one centered on the United States and the other on the USSR), with many ties within each subsystem, and few ties between the subsystems. If one were analyzing patterns of father-son intergenerational social mobility, it might prove useful to partition the patterns of relations into two subaggregates of "movers" and "stayers." If one were defining the historical process of class conflict and revolution, it might be most helpful to divide the "system" of action into subsystems of economic, political, and cultural/ideological production.

Most conceptual schemes in all of the social sciences have a great deal in common in how they go about partitioning systems into subsystems. This is not to say that the kinds of systems that different theoretical traditions examine are very similar, nor that they go about defining the state spaces or relations in similar ways. The commonalities among various approaches, however, do allow the formulation of some general rules that can be of considerable use in attempting to define the boundaries and partitions of a system of action.

Social scientist's models can generally be partitioned into sets of variables characterizing actors that exist within general fields or environments. In most cases, the variables in question are nested within actors, and actors are nested within a general field or environment in a relatively simple hierarchy.[8] In some cases, the models attain true multilevel complexity in which the relations among and within actors are characterized by multivariate relations, with several levels of analysis existing in the same model (e.g., individuals within groups within organizations within societies).

It is often most helpful in beginning the construction of a theory to start with the concrete actors, if there is more than one. One of the most fundamental ways that most social science theories partition systems into subsystems is by their use of actors (though not in theories that deal with relations among properties of abstracted whole systems).[9] Many sociological theories, for example, contain a single actor, such as a composite or generalized individual, organization, or society. Other theories are about two, three, or small groups of actors. Relatively few deal with any substantial numbers of actors. With the exception of some "network" approaches, sociologists who wish to theorize about large numbers of individuals tend to theorize about single aggregates or patterns of action (e.g., "the complex organization") rather than the "individuals" (be they groups, persons, classes, or whatever) that make up the pattern. Many other disciplines have a stronger taste for concreteness, and are likely to build theories about systems composed of multiple actors (each with distinctive traits) in interaction, such as families in a village or firms in a market. In any case, it is often a good first step in identifying the elements of the system to identify actors as subsystems.

The next step is to define the characteristics of each "actor" (be it an individual, a dyad, a group, a network, an organization, nation-state, etc.). The traits or variables describing each actor can often be further partitioned into subsystems of closely connected variables. In models of single whole societies, it is quite common to partition the variables into a series of subsystems: demographic, religious, political, economic, military, and so forth. In models with several actors, each actor might be described by numerous traits that denote processes within the individual giving rise to traits that affect the interaction between individuals. Here the systems are partitioned first by actors, and then by variables. In most cases, the partitioning of variables into subsystems is not an absolute matter. Variables that are closely dependent upon one another and have direct causal relations are more usefully grouped together; variables that are theorized to be connected only tenuously or through the connections along long causal chains can be partitioned into different subsystems.

In most social science theories the actions and interactions of individuals are seen as occurring within "fields" or "environments." Environmental factors are, by definition, outside of the spaces or subsystems of actors. Such environmental factors can be either constants (i.e., exogenous, or not affected by the actors) or variables that have causal relations with actors and other variables). These "emergent" or system properties are not part of the subsystems bounded within particular actors, but are nevertheless important parts of the system as a whole.

Suppose, for a moment, that we were interested in constructing a theory about the economic interaction between two national economies. The system can be partitioned first into two subsystems on the basis of actors. The actors (the national economies) can be described in terms of a number of variables (firms, capital, raw materials, labor supply, etc.), as could the interaction between the two nations (composed of flows of the factors of production, money, and commodities).

In such a model, there are a number of implicit "constants" that do not enter the model—for example, the territory occupied by each nation might be assumed to remain fixed, so there would be no need to define this fact with variables in the "environmental" subsystem of the model. Yet the two nations might well be exposed to vagaries of weather patterns that have differential impacts on the performance of their economic systems, and hence affect the trade relation between them. The weather pattern, however operationalized, would be a necessary element of the "environmental" subsystem of each actor.

There are also a number of properties here that are characteristics of the system as a whole, but not directly part of the state spaces bounded by either nation (though these properties have effects on both actors). The "supply" and "demand" for factors of production and commodities, for example, and the transaction costs of internation transfers are characteristics of the whole system (and hence a necessary part of the theory), but are not specifically part of the state space of either economy.

While these guidelines from general systems thinking are helpful, there are no fixed rules for the definition of system boundaries and the partitioning of systems into subsystems. It is very useful, however, to approach these questions in a structured fashion. Each theoretical and research tradition carries with it a very substantial conceptual baggage that can provide much of what is needed to define the systems and subsystems. In fact, much of the value of comparative statics theories and typologies lie in their identifying the boundaries and partitions of the property-space covered by theoretical models.

Implicitly or explicitly, a major role of "conceptualization" and "definition" is to identify boundaries and subsystem partitions by providing answers to the questions Who are the actors in the system? What traits describe each actor? Can these be divided into subsets? And what are the conditions outside of each actor that influence the action?

Relations Among Things: Connectivity

The first step in thinking about a problem from the systems perspective is identifying the "things" or elements that fall within the boundaries of the system. The second step is dividing them into partitions or subsystems. The next step, following from the definition of systems as "relations among things," is to identify which of the elements are connected to which others. Systems theory and particularly the derived applied field of systems analysis have a variety of useful ways of describing the relations among elements of systems. Many of these ways of describing the coupling among elements in the theoretical model are intended to reference processes operating over time; and this makes them useful for constructing theories about social dynamics.

Imagine that we have done the first step of creating a list of the elements of our theoretical model for a particular problem. We now sit with a list of actors and variables in front of us. The next step is to make a set of explicit hypotheses about which elements of our list are directly (that is, without any intervening steps) connected to other elements on the list. This is often best done using diagrams or matricies.[10] Two elements may be considered directly connected if a change in one element produces a change in the other without producing changes in other elements in the process. A change in one element may, of course, also produce changes in other elements as a result of the "first order" change, and may also have indirect as well as direct connections with some other element. These effects, however, are automatically specified when the full "first order" connectivity of the elements is created, and hence are not a source of immediate concern in constructing the theory.

The notion of "connectivity" in a set of theoretical elements is not unique to the systems approach. In fact, analogous concepts exist in all of the major languages commonly used by social scientists to formalize multivariate relations. In path-analytic terms, two elements are connected (at the first order) if there is a "direct effect" of one on the other.[11] In flow-graph terms, the elements are connected if a signal originating at one point reaches the other point without passing through any connecting paths.[12] In the language of directed graphs, two elements are connected if they share an "edge."[13] In the language of differential equations and "systems dynamics," two elements are connected at the first order if one element enters into an expression determining the rate of change in the other.[14]

The creation of a list of the elements of a theory and a complete specification of the connectivity of the elements is a good practice for any theory building exercise. The resulting artifact, be it a diagram, matrix, a collection of bivariate propositions, or some other form of representation of the "skeleton" can be of substantial interest in itself. When a theory is represented as a set of elements connected at the first order, it constitutes a "graph" or "network" and can be described as having certain properties. Theoretical models, as well as social networks and graphs, can thus be compared in terms of their formal properties of "density," "centrality," and so on. A good understanding of the nature of the theory itself as a structure is often helpful later in the process of analyzing models derived from it, because we can identify its most important variables and relations.

Relations Among Things: Control

Where the concepts of systems theory and systems analysis are of particular utility is in describing in greater detail the ways that elements are connected. Many of the applications of systems theory are in the area of machine processes, and the logic of describing production processes can often be generalized to other phenomena. It is often useful (though not necessary) to distinguish between direct connections among material things and linkages based on information. Linkages among material quantities can be termed *chains*. Connections among informational elements or between informational and material elements constitute the "control structures" of systems and are characterized as *loops* and *feedback*.

Most social scientist's models involve relatively few material elements and chains, but often very large numbers of informational elements and complex control structures. The material elements and chains, however, are often the central focus of the theory and are a good place to start in mapping connectivity. After the basic chains or production processes are mapped, then attention can be turned to the informational or control structures that monitor and control these chains. An example might help to clarify some of these distinctions and to illustrate the strategy for mapping connections among elements in a theory.

Suppose that we were interested in building a model of the age structure of a population in order to project the probable size of the aged population over time. As we will see in later chapters, this simple demographic example is a prototype of systems that occur with great frequency in all of the social sciences. At any one point in time, we can divide the population into groups (say, young, middle aged, and aged), with individuals moving from one category to the next one after a fixed waiting time. In this way of thinking about population dynamics, there are three material "elements" or "things" in the model: the number of the young, the number of the middle aged, and the number of the aged. (There is actually another level as well, a "sink," or "absorbing state," called "deceased.") These states—the young, the middle aged, and the old—are connected by a "chain": the same material quantity—an individual—moves from one state to another. We can draw a simple diagram describing the connectivity of these "material" quantities.

Our "simple" example, however, is not quite so simple as it seems. To discuss the dynamics of population we must specify the mechanisms and timing of the transitions from one state to another (e.g., from young to middle aged). To do this we need to specify the rate at which transitions occur. That is, we must describe the structure that controls the rates of flow between the states in the chain.

What governs or controls change in the number of young persons, the number of middle-aged persons, and the number of aged persons in our simple model? Young people are created by birth and disappear through either death or transition to the "middle aged" category (assuming no immigration or emigration). The rate at which births occur is determined by a large number of variables, including the current number of middle-aged people. That is, a variable that is later in the chain (the number of middle-aged people) is a cause of a variable that occurs earlier in the chain (the number of young). This is an example of "control" by "feedback." The number of young people who exist at any point in time is also determined by the rate of deaths among them and by the rate at which they make transitions to the "middle aged" category. The number

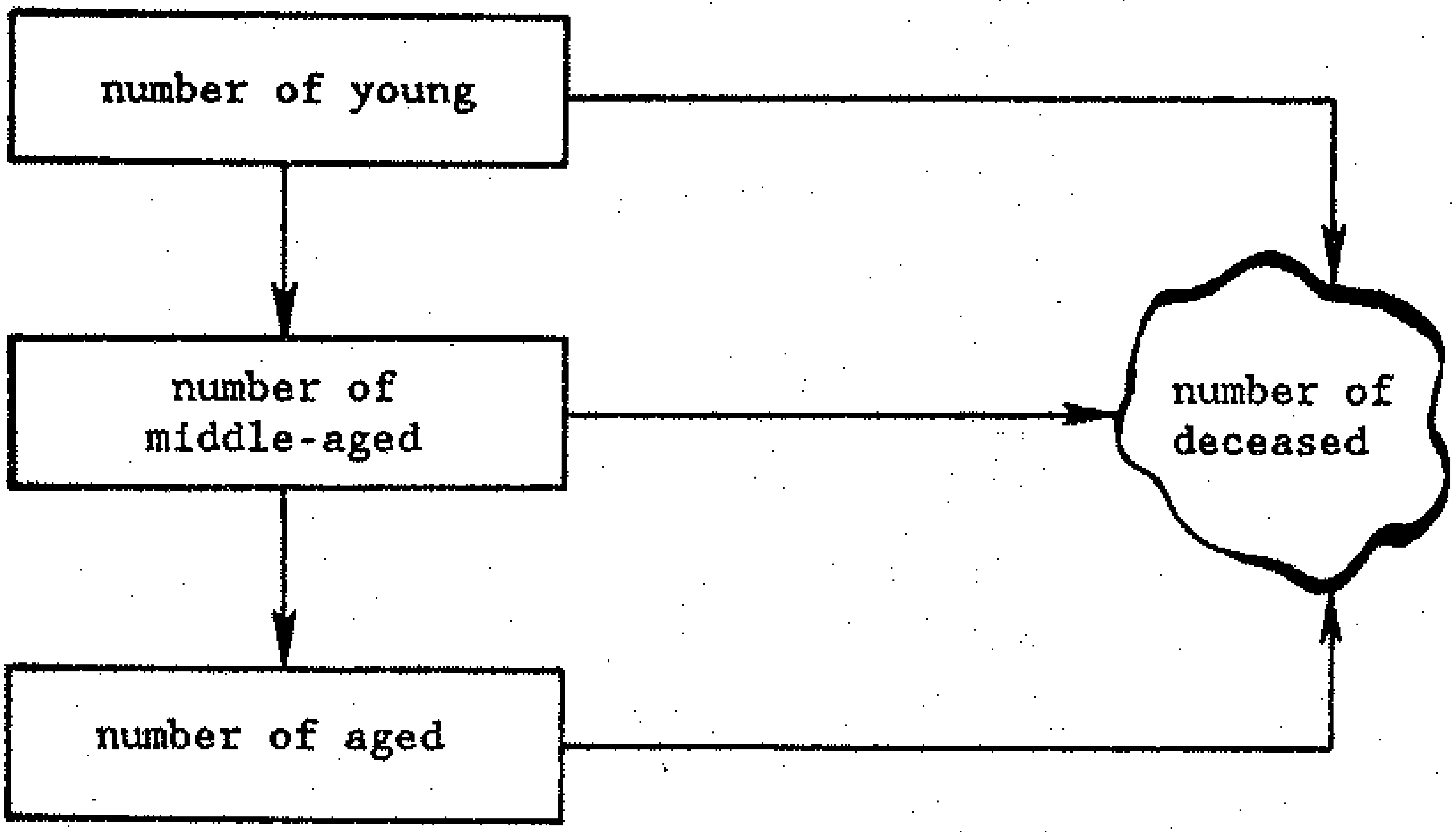

Figure 2.1: A simple chain of material states.

of deaths and the number of transitions to middle age are controlled by many factors, including the current number of young people. That is, the number of deaths among the young is a function both of external factors and the size of the population at risk. The current number of young people is a cause or part of the "control" loop governing the rate of change in the number of young people. If we continued our consideration of the dynamics of this simple chain we would see that there is a good deal more to the "control structure" of this simple model, as is shown in Figure 2.2.

The more elaborate structure of Figure 2.2, in contrast to Figure 2.1, illustrates the second step in the process of thinking about the connectivity among the elements of a theoretical model. The linkages in Figure 2.1 are the place to start in specifying the connectivity among the elements of theoretical models. These connections are of the most fundamental type, involving the actual movement of measurable quantities from one status to another. Many of the theories constructed by social scientists involve only a single chain of this type, and sometimes the chain consists of only a single element. We will examine models of this type at some length in the second section of this volume. Most other models of concern to social scientists include a relatively small number of chains that are interconnected by (often quite complicated) control mechanisms. We will examine some models of this type in the third section.

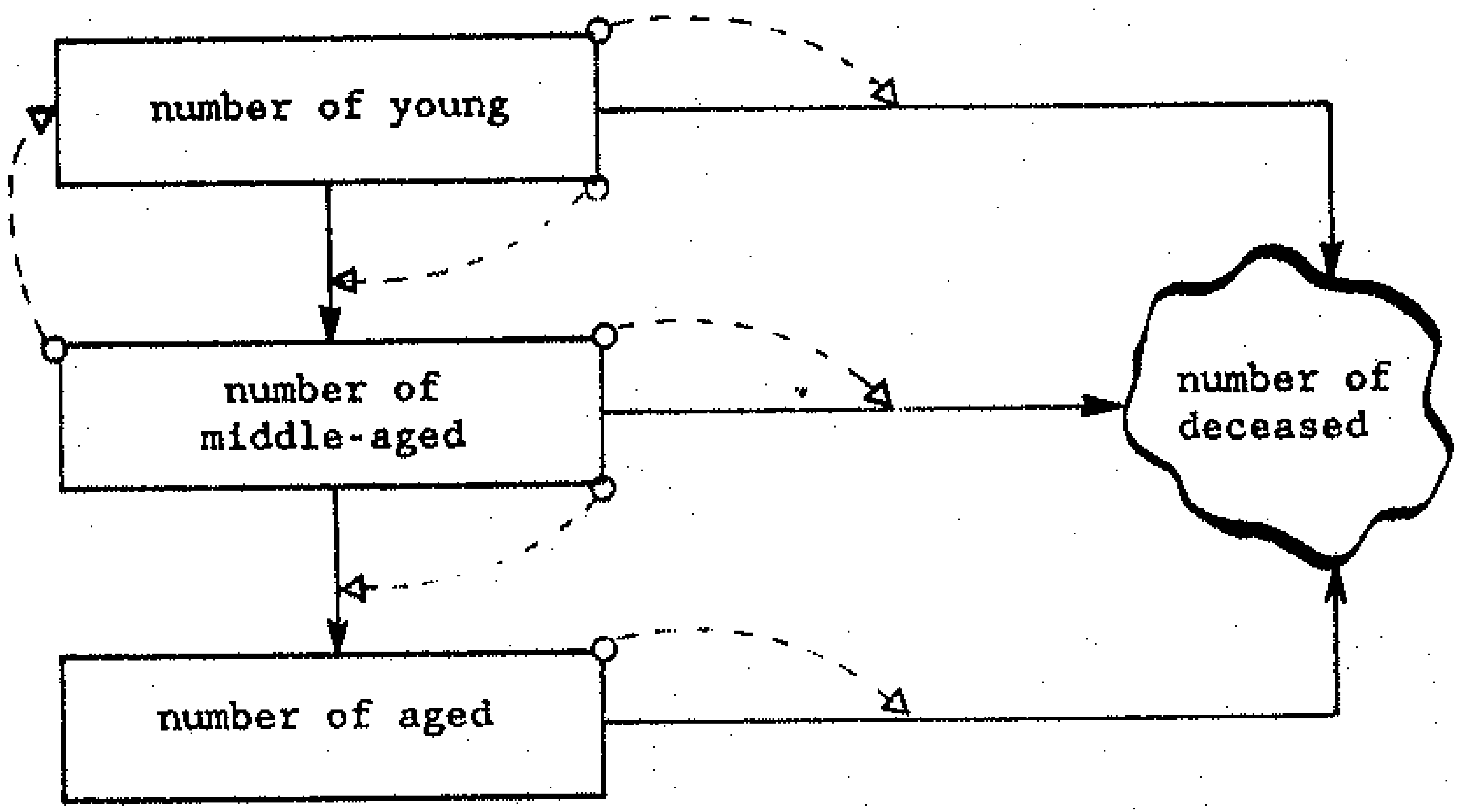

Figure 2.2: A simple chain with control structure.

The second kind of linkages among elements, the "control" or "information" systems as illustrated in Figure 2.2, is where the real action lies in most theories. Connections of this type do not involve the actual physical transition of a quantity from one state to another, but rather express effects on the rates at which flows or transitions occur. In the language of systems, "information" is "taken off" by "monitoring" and acts as input to "decisions" that govern the rates at which variables change or transitions occur. In the more common language of discourse in theory construction, connections of the control system type shown in Figure 2.2 are the "causal parameters" that describe what variables in the model have effects on the rates of change in other variables. Mapping this form of connectivity is, therefore, central to the task of building a theory.

The first step in using "systems" thinking to specify connectivity should be to find the "chains" of states that represent actual physical movements of things. The second step is to identify the causal connections among the elements of the model, so that the "informational" and "control" mechanisms can be mapped. As with the consideration of the elements of the theory, mapping the connections among the elements is made much easier by the use of formal languages designed for this purpose.

Kinds of Systems and Kinds of Formal Languages

A variety of languages can be used to perform the tasks of building formal theories within the "general systems" tradition. Different languages, however, are easier or more difficult to use to describe certain types of systems. The use of the right specialized language can contribute substantially to the ease with which a theory is specified, and can lead to many new insights in the theory building process. The use of the wrong language can obscure theoretical relations and lead to mind-numbing and arid formalisms rather than new insights. In the remainder of this volume we are going to use one particular language (DYNAMO) to express theories about continuous-state continuous-time dynamic processes. This language is closely connected to one variant of "general systems" thinking about social relations called "systems dynamics." Before we turn to the necessary details of vocabulary and syntax of this language, and to the use of simulation methods in theory building (the topics of the next three chapters), we should be a bit clearer about the strengths and weaknesses of this language.

Systems Dynamics and DYNAMO

One of the most widely used languages for formalization of systems theories of continuous-state continuous-time dynamics in the social sciences was developed by Jay W. Forrester and his colleagues at MIT. The "systems dynamics" approach to thinking about problems of this type was developed by these scholars in direct connection with a computer language called DYNAMO. DYNAMO has been used in the social and physical sciences to construct simulation models to study a wide array of substantive problems.[15] The computer language is available for both mainframe and micro systems, and can be implemented under most major operating systems.[16] All of the applications in this volume were prepared on DOS type personal computers, operating under the UCSD Pascal system.

The "systems dynamics" approach to thinking about continuous-state continuous-time dynamics provides one very powerful way of applying the "general systems" concepts that we have been discussing above to particular social science problems. It is not, however, necessary that one accept all of the peculiarities of the conceptual baggage of "systems dynamics" in order to apply systems thinking or the DYNAMO language. In the next chapter we will examine in some detail both the strengths and the weaknesses of the systems dynamics approach, along with the basics of DYNAMO.

The main ideas of the systems dynamics method are embodied in the DYNAMO language, which acts as a "translator" between the everyday language used by the theorist and the mathematics of nonlinear difference and differential equations that are calculated by the computer. Computers, by and large, are quite unable to understand everyday language (though the problem is being worked on); social science theorists, by and large, are quite unable to understand simultaneous nonlinear differential equation systems (and this is, perhaps, a problem that we should be working on). The role of DYNAMO is to allow the theorist to state ideas about social dynamics in a language that is close to everyday use (though it is different enough that we need to spend some time on its vocabulary and syntax) and to convert these statements into mathematical systems that can be simulated by the computer and understood by experimentation. With a little practice and persistence, the DYNAMO language can be used to state almost any well-specified theory about social dynamics. The chapters in the second and third parts of this volume provide a number of examples that can act as starting points for others.

When Not to Use DYNAMO

The systems dynamics method of thinking about dynamic systems and the DYNAMO language have been and can be very widely applied to social science problems. This particular approach to thinking about theory building and this particular language, however, are not the right choice for all classes of problems of interest to social science theorists.

Social science theorists are rightly concerned with the study of statics as well as dynamics. There are a number of specialized languages that are more useful for the study of statics than DYNAMO. Where the concern is primarily with discrete-state statics (as, for example, in the study of the structure of networks), a powerful array of specialized concepts, language, and tools have been developed for formal representation based on graph theory, smallest space analysis and the like. There are also well-developed languages for the analysis of continuous-state statics that should be used in preference to DYNAMO for problems of that type. The most powerful and familiar of such formalisms for dealing with continuous-state statics are "structural equations," and their implementation into "path analysis." More powerful extensions of these languages—particularly "flow graphs"—based on linear programing, electrical and hydraulic engineering have also been advocated for complex feedback systems.

There are also well-developed alternative languages for the formalization and analysis of dynamic systems that may be of greater utility than DYNAMO in some circumstances. Where the phenomenon to be understood is most easily thought of in discrete state/discrete time terms, queuing theory and event analysis provide tools. Applications of "game theory" thinking and language are perhaps the most familiar examples of such systems in the social sciences. Several computer simulation languages (e.g., SIMULA) are much easier to adapt to problems of this type than is DYNAMO. Where the focus is on phenomena most usefully conceived of as having discrete states but with continuous time dynamics, event-history methods based on Markov processes can provide a very powerful complement to simulation analysis using DYNAMO. Several other simulation languages designed for the modeling of "mixed" categorical and continuous systems (e.g., GASP, SLAM) may also be usefully applied.

There are also alternatives to DYNAMO for the analysis of continuous-state, continuous-time dynamics. By far the most common language for formalizing theories of continuous-state, continuous-time dynamics (i.e., systems in which continuously occurring change in some variables have effects on the rates of change in other variables) is differential equations. Differential equations and the calculus provide very powerful tools for concisely describing and making deductions from statements about rates of change in continuous variables. As briefly discussed in the previous chapter, there are some limitations on the types of systems to which differential equation mathematics can be usefully applied. There are also several competing alternative simulation languages for continuous-state, continuous-time or mixed discrete and continuous state systems, including CSSL and GASP/SLAM. These languages are equally powerful, but are less grounded in general systems theory (which may be regarded by some as an advantage, by others as a disadvantage).

Conclusions

Many of the basic ideas of general systems theory and systems analysis provide useful ways of approaching the task of building theories about social dynamics. In this chapter we have examined the notion of systems and examined some ways of identifying and partitioning the state spaces of systems and mapping the connectivity and forms of dynamic relationships among state space elements.

With these somewhat lengthy, but necessary, basic ideas that help to organize thinking about dynamic systems in hand, we can turn our attention to the mechanics of building theories of social dynamics in the systems dynamics tradition using DYNAMO.

Notes

1. The concept of "system" has been widely discussed in the social and physical sciences. Some general introductions to systems thinking and systems concepts across a variety of disciplines are provided by Ashby (1958, 1962), Bertalanffy (1968), Buckley (1967, 1968), essays in Demerath and Peterson (eds., 1967), Emery (ed., 1969), Grinker (1965), Hall (1962), Hare (1967), Klir (1971), Kremyansky (1960), Kuhn (1963, 1975), Lange (1965), Luenberger (1979), Mesarovic (1961, 1964, 1968), Sommerhoff (1969), and Weiner (1948).

2. To get a flavor of the breadth and variety of systems types of theorizing about microdynamics in the social sciences, the reader might look up Barnes (1972), Berger et al. (1966), Bonini (1963), Brams (1975), Caplow (1968), Cohen (1962), Coleman (1972), Davis and Leinhardt (1972), Neumann and Morgenstern (1947), Rapoport (1960, 1966), Shubik (ed., 1964), White (1963), and Whitten and Wolfe (1973).

3. Applications of systems thinking to aggregates and "social actors" composed of networks of individuals are very common. A flavor of the diversity of problems and approaches can be had from Boulding (1978), Bremer (1977), Buckley (ed., 1968), Cole et al. (1973), Cyert and March (1963), Dutton and Starbuck (1971), Guetzkow et al. (eds., 1972), Meadows et al. (1974), Patten (ed., 1971), Perrow (1984), and White (1963, 1965).

4. Some examples of the more abstracted use of "systems" concepts and tools in various social sciences can be seen in Bayless (1966), Bellman (1961), Burns et al. (1985), Burns and Buckley (1976), Deutsch (1963), Easton (1958, 1965), Emery and Trist (1960), Kennedy (1962), and Parsons (1937, 1957, 1966). The particular example used here is derived from Hage (1972).

5. Complex hierarchical and elaborately partitioned systems of both actors and variables are discussed in particular by Pattee (1973) and Baumgartner et al. (1976). Two particular multilevel models are quite interesting in the current context. One, by Kochen and Deutsch (1980) deals with the statics of formal organization; the other is a dynamic model of the world system by Mesarovic and Pestel (1974).

6. The question of closing systems by including all relevant elements is discussed at some length by Forrester (1968). Foster et al. (1957) offer some provocative comments on the question of indeterminancy in systems resulting from lack of closure.

7. There are a number of interesting discussion of the boundary problem. In the sociology of formal organizations, for example, the question of "What is an organization?" is frequently and variously addressed. Interesting discussions are offered by Hage (1980) and Perrow (1979) on this particular version of the more general boundary question.

8. The notion of multilevel processes is one of the most exciting areas of development in general systems theory. Some of the most interesting social science essays on this subject can be found in Baumgartner et al. (1976) and Burns et al. (1985).

9. Models of theories that involve only relations among abstract properties of a system or "general variables" are the exception to the rule of partitioning state spaces first by actors. Such models have only a single actor: the system.

10. An excellent illustration of the application of matrix methods for analyzing connectedness is contained in Brunner and Brewer (1971).

11. Excellent introductions to structural equations and path analysis are now quite numerous. Still, two of the originals are among the best: Blalock (1971) and Duncan (1975).

12. See, for an introduction to flowgraph analysis in the social sciences, Heise (1975). A more general and mathematical treatment can be found in Lorens 1964.

13. Many of the basic methods of directed graphs and network analysis are described in Barnes (1972), Berge (1962), Busacker and Saaty (1965), and Knoke and Kuklinski (1984).

14. See, for discussions of the idea of connectivity within the systems dynamics tradition: Forrester (1968), Pugh (1980), Roberts et al. (1983), and Richardson and Pugh (1981).

15. A partial list of work utilizing systems dynamics methods and the DYNAMO language shows the wide array of substantive problems that the language can be used to address: Alfeld and Graham (1976), Cole et al. (eds., 1973), Coyle (1977), J. W. Forrester (1961, 1968, 1969, 1973), N. B. Forrester (1973), Hamilton et al. (1969), Jarmain (1963), Levin et al. (1975), Levin et al. (1976), Lyneis (1980), Mass (1975), Mass (ed., 1974), Meadows (1970), Meadows et al. (1974), Meadows and Meadows (eds., 1973), Meadows et al. (1973), Randers (1980), Richardson and Pugh (1981), Roberts (1978), Roberts et al. (1983), Schroeder et al. (eds., 1975), and Weymar (1968).

16. Information on DYNAMO software is available from Addison-Wesley Publishers of Reading, Massachusetts (who carry some PC versions), and from Pugh-Roberts Associates of Cambridge, Massachusetts (who carry a full line of mainframe and micro applications).