8

Simple Multistate Systems: Chain Models

The single-state models that we introduced in Chapter 7 are just a starting point for a broader class of models involving simple "chains" of closely coupled states. Even the simplest such models involving only two states and unidirectional transitions are useful for representing many important forms of social dynamics. And, if these models are made slightly more complex by adding additional states and allowing flows to move in both directions among states, an even wider variety of common social processes can be represented and analyzed.

The kinds of processes that we will consider in this chapter and the next are quite straightforward extensions of the simple "transitions" models. They are more complex only because the chains of closely coupled states involve more statuses and more possible transitions. For example, a simple two-state chain of the type considered in the previous chapter might be used to theorize about transitions between working and retirement (a process that largely, though not always, goes in only one direction between two statuses). If we sought to construct more general theories of the work-career, however, we would have to consider a wider variety of statuses, and possible bidirectional movements: Individuals move among the statuses employed full time, employed part time, unemployed, and retired. While they can occupy only one status at a time (which makes the whole model a single chain of conserved states), they may move in both directions among the statuses; that is, individuals make transitions from unemployed to employed and back again, change from unemployed to part-time work, from part time to full time and back again, and so on. While this process is undeniably more complex than the simple one-way transition, it is clearly a similar type of theoretical problem.[1]

Processes that can be described by chains of closely coupled states, like the sequence of moves in the work career, are the central theoretical problems in many areas of social sciences. Some obvious applications are in building theories of the movements of persons among social statuses: the life-cycles of individual's movements through the economic market place, through levels in hierarchies such as professions or organizations, through family statuses, and from involvement to noninvolvement in voluntary organizations and social movements. But multistate transition processes are not restricted to individual persons; economic, political, educational, and religious organizations are born and die, change form, move from one ecological niche to another, merge, and separate.

Changes in the statuses of individuals, groups, organizations, and larger patterns of social organization are not the only kinds of "conserved flows" that are of interest. The movements of goods through a manufacturing or distribution process can be seen as a conserved flow, and may be of interest in itself, or as a part of a more complex model.[2] The movement of units of income and wealth among income and wealth holders, or networks of exchanges of any discrete and conserved commodities (e.g., honorific positions or network ties, if these are fixed and conserved) are also processes of multistate transitions.[3]

Like the simple one-way transition processes we examined previously, multiway, multistate transition processes are a "family" or "class" of related models, with near-infinite possible variations. Because of their generality we cannot set out general rules that will describe all of the possible dynamic behaviors of such models. Complex chains, however, are composed of simple chains coupled together in various ways, and can be partially understood by examining their structure in light of what we already know about the general behavior of simpler processes. Because of the tremendous variety of "chain" models it is useful to think about the variations in their structures as a way of approaching the understanding of their behaviors. We will spend this brief chapter on this issue before turning to some exemplary applications in the next chapter. This will help us to gain a sense of the range of possible applications and to try to grasp the ways that such systems behave.

Varieties of Chain Models

We can classify variations in the forms of chain models using the same concepts that are useful for discussing the complexity of theories in general. That is, theories are more complex than others to the extent that they involve more states (that is, have larger state spaces), to the extent that these states are connected to one another, and to the degree that the control structures governing action are themselves complex, involving many variables and forms of relations among variables and over time that require many rather than few parameters to specify.

From this general definition it follows that chains that have more states are more complex (hence having greater "degrees of freedom" of alternative possible behavior and being less easily analyzed) than those that have fewer states. Chains in which more states are more closely coupled to one another (that is, have higher connectivity) are less determinant and more flexible than those with less connectivity. Chains in which flows are governed by self-referencing, goal-referencing, and adaptive feedback display greater degrees of freedom than those governed by stimulus-response control structures. Where the control structures involve complicated interactions of many variables and are nonlinear in variables or with respect to time, behavioral possibilities of chains are greater and analyzability less.

These general-systems principles applied to varieties of chain models are of some utility in understanding the range of possibilities for modeling theories and for comparing them in terms of their structures and complexity. The principles are probably too abstract and general, however, to fire the imagination. In order to illustrate the general principles, but more importantly to get a better sense of the range and kinds of problems that are usefully conceptualized as multistate chains, let's examine in more detail some of the variations on the theme of increasing complexity within the family of such models.

More States in the Chain

The first models that we examined involved a single dependent variable or state and (implicitly) a source or sink. Such models are quite common, and very useful for many problems, as we saw in the previous chapter. It is often the case that we have no immediate interest in where the quantity in a level comes from or where it goes when it leaves a level.

One might, for example, build a theory of the level of the material standard of living of a society that does not explicitly take natural resource constraints (natural resources being the "source" of material wealth), or waste disposal constraints (waste being the "sink" for material wealth) into account. Within limited ranges, at least, such a model with a single level is plausible and useful. Similarly, if we were interested in the dynamics of attitudes or beliefs, our interest focuses almost exclusively on the current "level" of the process, and we usually pay no attention to where the attitude or belief comes from (in the sense of a movement of "psychic energy" from one use to another) or where it goes when the attitude or belief is reduced or disappears. One could readily expand the list of examples of important applications of models with one active state. In all theories of this type there is a single level of interest, and the sources and sinks associated with the level play no causal role in the dynamics of the system.

Models of transitions, diffusion, bounded growth and decline, and analogous processes involve two (or sometimes more) simultaneous dependent states. In diffusion models, for example, it is common to divide the population into two groups, those who "know" of a message or have adopted an innovation and those who "don't know." It might at first seem that there is really only one level here—for if a person does not fall into one category, they must fall into the other, so that there is only one "degree of freedom." In most such theories, however, the number of knowers and the number of nonknowers play different causal roles in the theory, and hence must be considered as separate states. In our diffusion-process theories, the number of knowers has an effect on the rate of change when knowers become tellers. The number of nonknowers plays a causal role in determining the rate of change by affecting the probability that a given telling reaches a person who is still at risk of making the transition from not knowing to knowing. Where the levels of the variables enter the theory as causal factors, the process needs to be considered as a multistate process (even if some of the states are "absorbing states"), rather than as a single state with implicit sources and sinks.

One might wish to reconceptualize a theory of levels of material well-being as a three-state chain, rather than as a single state with implicit sources and sinks, in light of this discussion. Rather than thinking of the level of wealth as coming from an unspecified and unlimited source and disappearing into an unspecified and unlimited sink, a more complex theory might treat natural resources as a causal factor affecting the rate of transition from natural resources to material wealth. In this case, the level of natural resources must be treated explicitly as a state in the model. Similarly, if we supposed that the level of waste had effects on the rates of wealth creation or of wealth use, it could not be treated as a simple implicit sink. Thus, a slightly more complicated conceptualization of the problem of material wealth leads to a model with the structure of several levels linked in a simple chain (natural resources flow into material wealth flows into waste), rather than a single state model with implicit sources and sinks.

From this simple illustration, it can easily be seen how chain models with larger numbers of states develop. We might choose, for example, to create a still more complex model of material wealth by dividing resources into different kinds, identifying different production processes, different resulting products with differing survival or depreciation rates, and multiple kinds of waste. Input-output matricies, and large scale econometric models follow this line of development, often including hundreds or even thousands of different connected states to model the flows of materials through production and consumption processes.[4]

Sociologists often use models of individual's "event histories" that are quite elaborate in their numbers of closely coupled states. The movements of individuals among economic statuses, for example, could be treated with more or fewer levels. For some purposes it might be adequate to see the problem as one of flows from prelabor market status to on the labor market to postlabor market. But for other purposes more detail might be necessary. One might include educational statuses as levels in models of the work career, occupational, industrial, and sectorial distinctions of job types, and other "levels" such as unemployment, and voluntary withdrawal from the labor market. While such a model could easily include hundreds or even thousands of such statuses, its fundamental character is quite straightforward; each individual (or dollar, or resource unit, or quanta of attitudinal intensity, or whatever) may occupy one and only one of the states at a time, and must occupy one of the states at all times.

For many social processes, one could create models of chains of connected states that involved very large number of levels. But most problems can also be simplified by reducing finer distinctions to coarser ones. The optimal level of complexity of this type is ultimately determined by the needs for descriptive adequacy and theoretical articulation. There is no single and final answer to this problem, but there are some general rules for deciding how much complexity, by way of additional state variables, to introduce.

Simplicity is much to be desired over complexity in deciding how many levels to use in conceptualizing chain processes. The dynamics of chain models, as simple as they are, can become quite complicated and difficult to understand if nonlinearities in the relations of either variables or time are present. Reducing the number of states in the chain to a minimum may aid the analyst both in understanding these dynamics and in communicating the results coherently to others.

Simpler models are also to be preferred over more complex ones on the grounds of parsimonious explanation. While models with more levels may appear more elegant or provide fuller descriptions of social processes, they do not necessarily represent more powerful explanations. States that play no independent causal role in determining the dynamics of systems can, and sometimes should, be eliminated from models. In the language of path analysis, for a parallel example, we do not include variables that have no unique effects on dependent variables, and may eliminate as redundant variables that have only indirect effects on others. Similarly, in the analysis of flowgraphs, "loop reduction" is commonly practiced to gather together several effects along pathways into simpler, more compact statements, where such reductions do not confound separate processes.[5] One can, however, go too far. The complex expressions resulting from completely valid reductions of systems with many states to more abstract ones with fewer states may be difficult to comprehend, and gather together factors that the theorist would rather retain as descriptively separate.

There is yet another reason for preferring chain models with fewer states over those with more states that has little to do with either the descriptive or explanatory adequacy of the models. Models with more states are simply more work to create and to analyze. If there is little to be gained in terms of describing a process more realistically or in understanding its causal texture by making the chains more elaborate, it is inefficient to spend human and machine resources in formulating and simulating more complicated models. Simulation methods for understanding theories are often quite intensive in both human and machine time; models with many additional states that contribute little to explanation or representation can be quite costly without much return.

The elaboration of theories of transitions or flows into more complex expressions often occurs by the addition of more states to the "chain." Models with single "dependent" states can effectively represent many important processes. Such models have contributed much to our understanding of social dynamics, but it is also quite reasonable to extend the modeling effort to consider, in a single integrated framework, processes that involve the movements of people, data, and things among large numbers of states.

More Connectivity Among the States

The dynamic processes that we considered in Chapter 7 were "simple" chains in a second way. In addition to having only two (or at most three) states, these states were connected in the simplest possible way: Transitions or flows occurred in only one direction, and (where there were three states, as in the model of an epidemic) in a single fixed sequence, for example from well to ill to recovered, but never from well to recovered without passing through the state of being ill. These "chains" might be termed unidirectional, and (relative to the logically possible alternatives for such systems) having low connectivity, with only one possible sequence of moves or flows. Systems of this type have structures like those of the top panel of Figure 8.1.

As the examples of diffusion processes demonstrated, even the simplest of chain models are adequate for constructing and testing theories about important social processes. Obviously, though, many other social dynamics cannot be very well approximated with such models. Bidirectionality is very common in social dynamics. Individuals move from being unemployed to employed and from employed to unemployed. People migrate from the country to the city, but many also return to the country from the city. Money flows from owners to workers in the form of wages, but returns to owners in the form of purchases of goods.

Combining the notion of bidirectional flows with the simplest form of multistate models (the single sequence), a variety of relatively complicated processes can be captured. A dynamic process with the structure of the figure in the second panel of Figure 8.1, for example, might be used to represent the process of career movements in a large organization. This model proposes four possible statuses: entry level management, line management, staff management, and executive. All movements originate at the entry level in this model, and movements out of the entry level are allowed only into line management. Line managers may become staff managers, but may not directly become executives, who are selected from among staff managers. Staff managers may rise to executive positions, but they can also fall back into the line management—creating a bidirectional flow among middle-level managers. This model of the mobility dynamics within organizations is, of course, still quite primitive, but serves to illustrate the point. The number of possible sequences of flows or movements in this model is much greater than in the simple chain. The levels of each of the states and the rates of transition among the states at any point in time in this model can display far more complicated over-time behavior than the simple unidirectional flow models.

Many social processes do not display simple and fixed sequences of possible moves or flows like the first two diagrams in Figure 8.1. In many cases it is possible for flows to occur from a single "origin" to many alternative "destinations"; and, for flows from many different "origins" to flow into a single "destination." One obvious example of such processes is that of career-status mobility. The mobility matrix of transitions from first job to final job, so common in studies of status attainment, is a representation of such a process. In such a matrix, flows occur over the careers of individuals in all possible directions. If we considered a status hierarchy with only three levels (for simplicity), the

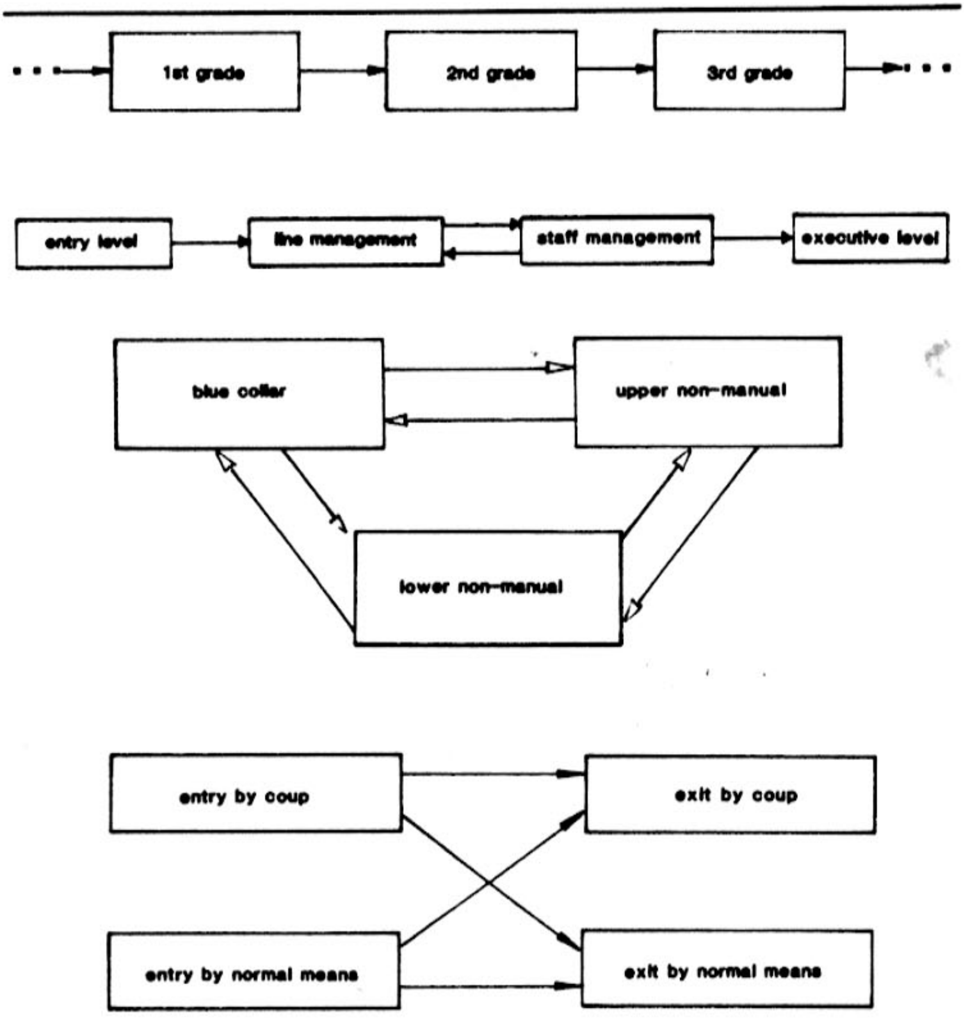

Figure 8.1: Elaborated connectedness.

processes involved could be represented by a chain model like that in the third panel of Figure 8.1. In this model, moves are possible back and forth between each pair of states, giving rise to an unlimited number of possible careers. This model has the maximum possible connectivity for three states.

Complex transition processes not involving bidirectionality can also be seen as generalizations of the simple chain model. In the last panel of Figure 8.1, for example, a simple model of a multistate survival process is shown. In this model there are two origin states (regimes come to power either by legal-normative means or by military coup) and two "destinations" (regimes leave power either by legal normative means or by coup).[6] Flows, by definition, do not occur between the two origin states or between the two destinations, nor are flows bidirectional. Regimes that enter by coup, however, may exit by either coup or legal-normative means; as may regimes that came to power by legal-normative means. Interest here focus on the rates of transition—that is, the probability that a movement will occur in a period of time from a given origin to a given destination. This model is a simpler one than the full mobility matrix (though it has been simplified by the way that the problem has been defined; just as the mobility matrix problem can be simplified by not allowing bidirectional movements—as in "father-son" models). Because the connectivity of the system is considerably less, the number of possible sequences and number of rates of transition that are occurring are less. It is, nonetheless, a very useful device for theorizing about survival or transition processes that have multiple "hazards" (for example, the risk of exiting power by normal means and the risk of exiting power by coup) that apply differentially to different populations (for example, those regimes that came to power by coup versus those that came to power by normal means).

The notion of modeling "event histories" of transitions among statuses can be extended to virtually any degree of complexity, depending on the descriptive and theoretical objectives. The mobility matrix, with its complete connectivity, and the two-state absorbing process of regime survival with more limited and unidirectional flows, are only two of the more interesting possibilities. Each of the social-science disciplines have many major substantive problems that can be viewed usefully as models with relatively few states but extensive connectivity. A few more possibilities, drawn from the author's "home" discipline of sociology may suggest, by analogy, some further possibilities.

Individual's economic careers and the structuring of labor markets are central topics in contemporary studies of organizations, work, and both micro and macro class stratification research. The representation of quite complex opportunity structures and rates of movements across positions in these structures are quite straightforward extensions of the chains that we have examined above. An example of an elementary map for such a model is shown in Figure 8.2, and could profitably be elaborated still further. Such chains could easily be used to represent and experiment with the effects of "internal versus external labor markets," "sectorial segmentation," the "social distribution of employment and unemployment" and other phenomena of interest. Realistic models of processes of these types are impressive in their bulk, but relatively simple in their basic structure as chains of connected states where most states display bidirectional movements.

Some of the issues of interest to researchers and theorists in the

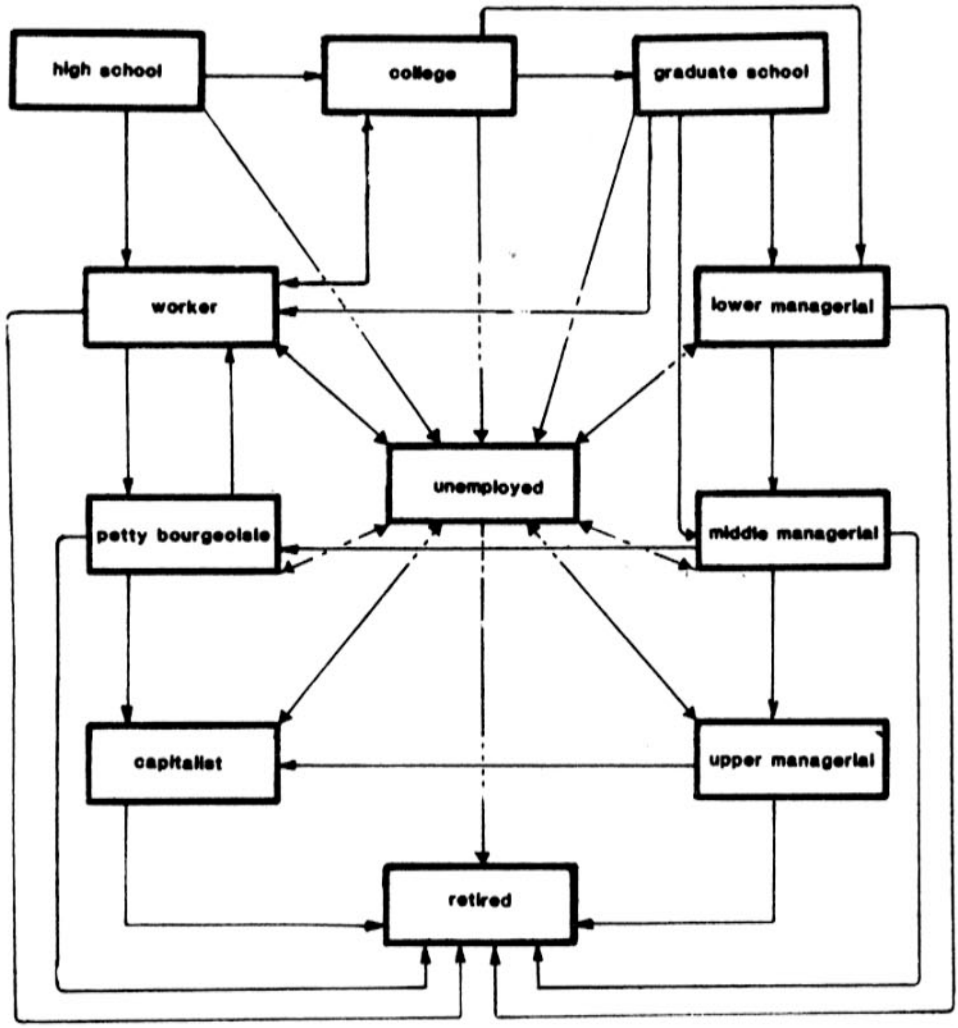

Figure 8.2: Class-career flows.

"social networks" tradition can also be cast as questions of the dynamics of chains of various degrees of connectivity.[7] Rates of exchange, sending and receiving of social ties, the diffusion of information, and other processes can be conceived as chains in which the actors are seen as levels or states, and the relationships of connectivity, exchange, or whatever among them are seen as flows. A simple schematic of one possible network is shown as Figure 8.3, purely as an illustration of the possibilities. Approached in this way, some of the classic questions of sociometry—and their revised versions in "social networks"—can be examined by means of formal models and simulation. "Structures" of higher or lower degrees of connectivity, of any size (up to the limits of

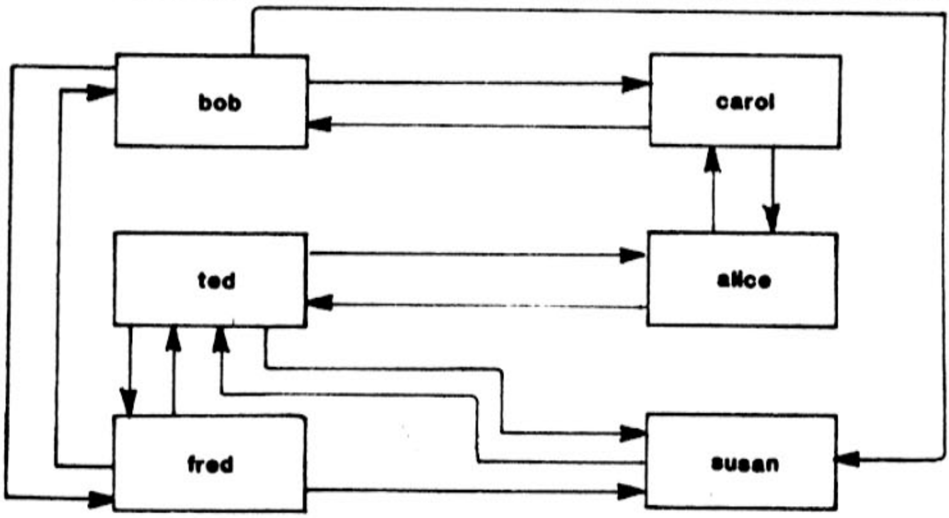

Figure 8.3: Network connectedness.

the software and hardware available), and of any configuration (e.g., wheels, stars, branching trees, etc.) can be represented and simulated. The "systems" of interest in social network applications are thus representable as chain models of flows (relations) among states (actors) in many cases; many of the questions of interest to network analysts, such as the implications of the degree and form of connectivity in a network are, when seen in this light, exactly the same issues as those of the implications of increasing the "complexity" of systems by increasing their "connectivity."

More Complex Control

The dynamic behavior of chain systems depends not only on the number of states and their connectivity but also on the control structures that govern the rates of flow among the states. These control structures can be thought of as varying in complexity by the same definition of "complexity" as do the state spaces of models. Two theories with the same number of states and degree of connectivity among the states may still differ greatly in the range of behavior they produce if they differ in the complexity of their control structures.

The simplest of chain-model control structures of any interest are processes governed by constant rates or by control structures referencing either the origin state or the destination state. For example, a model embodying the logic of a Markov process suggests that the probability of a transition from an origin to a destination is a constant. Consequently, the number of transitions that occur in a period of time (for example, the rate of flow from an origin to a destination) is equal to the transition probability times the number of cases "at risk" (for example, in the origin status). This process is a simple "feed-forward" one that references the origin state. Similarly, but at a somewhat higher level of control structure complexity the rate of movement between an origin and a destination might be seen as a constant function of the destination state. In a vacancy chain model, for example, the rate of movement from origin to destination is governed by the discrepancy between the level of the destination state and a goal state (for example, the number of unfilled positions at the destination status).

There is no necessity, of course, that the control structures governing the rate of flow along a particular link in a chain model make reference only to the states at the origin and/or destination. In our elementary sketch of class-career flows (Figure 8.2), for example, the rate of movements from midmanagerial positions to petty bourgeoisie might very well be conditioned on the level of unemployment—as many such moves are thought to be voluntary and are more likely to be undertaken in "good times" than in bad.

By extension, we can see that some chains may have quite complex control structures that may even approach attempts at full-information monitoring and control. The production processes of continuous-flow manufacturing can be seen as (usually) relatively simple chains of states coupled by control structures that take into account information about all other states in the system (or attempt to).[8] Other highly rationalized planning processes, such as personnel, money, and information flows in bureaucracies may have the same flavor of relatively simple chains governed by control structures that attempt full information monitoring and rationalization. The "complexity" of a chain depends not only on the numbers of states and their degree of direct connectedness but primarily on the complexity of the information and control system. Many systems representable as chains may be of relatively low complexity in terms of the numbers of states and flows among them, but be of considerable complexity in terms of the control structures governing those flows.

Additional Complexities of Control

The behavioral tendencies of relatively complex chain models depend most importantly on the considerations of the number of states and their connectedness by means of direct flows and by information flows (i.e., their control structures). In attempting to mimic the behavior of real social action systems, however, even further complexity is usually called for. Real systems usually involve considerable delay in the movement of both material and informational quantities; signals are often "noisy" or distorted; the production of a behavior by signals is probabilistic rather than certain; and, there may be thresholds, resistances, ceilings, and other nonlinearities in the flows of both the material and informational quantities in chains.

Delay, distortion, and nonlinearity of flows of both material and informational quantities interact with the structure of chains and their control structures to produce even greater behavioral possibilities. By their very nature as connected "systems," the effects of noise, delay, and nonlinearity multiply through the system over time. Errors in perception in one part of a behavioral chain may result in inappropriate responses in connected parts of the system that result in complete destabilization. Small distortions of information or of material flows may prove to be the "straw that breaks the camel's back" in systems where responses are nonlinear, resulting in "disaster" or in overresponse that further destabilizes systems. Perhaps more commonly in many systems of social action, responses to signals in chains are partial and delayed in such ways that there is very little response to even rather great stimulus, or strong stimuli produce outcomes other than those intended. Increasing pressure for higher production, for example, may yield less production and higher turnover, requiring new hiring of untrained personnel that lowers productivity still further. The important point in these examples is that noise, nonlinearity, and delay in "chains" multiply through the system over time due to the interconnectedness of the system, producing (potentially) very complex behavioral responses to rather simple stimuli.

Conclusions

In this short chapter we have explored some of the ways that the very simple systems considered previously can be expanded to represent more complicated processes. Our primary concern has been with increasing the complexity of the basic model by the addition of more states. Rather than thinking about social action as a series of singular changes from one state to another, the models we have considered in the current chapter allow for multiple outcomes from multiple origins, movements of people, information, and material quantities back and forth between states all occurring simultaneously. While it is often analytically useful to think about social dynamics in terms of single dependent variables or single states as in the previous chapters, there is also a good bit to be gained by creating more elaborate dynamic theories as sets of interconnected effects or transitions.

Models of single chains of states can be made more complex in a variety of ways that serve to increase the range of phenomena that they describe and increase the "degrees of freedom" in the behavior that they can display. In this chapter, we have categorized these possibilities as increasing the number of states, increasing the connectivity of the states, and increasing the complexity of control systems governing rates of change. In identifying chain models that display these forms of increased system complexity, it has been our intent to show that many of the core theoretical models in various areas of social science research can be represented by such models.

To illustrate the utility of the strategy of formulating theories of the dynamics of action in such structures, and to show how such formulations can raise further questions for theoretical research, it is now time to build and examine the behavior of a few such (slightly) elaborated chain models.

Notes

1. Work in statistical and mathematical approaches to multistate transition models has grown very rapidly in the social sciences in the past several years, after a lengthy period in which only single-state models were considered. For some introductions to mathematical and statistical approaches to models with multiple qualitative outcomes, readers may wish to examine Coleman (1981), Tuma and Hannan (1984), and Allison (1984).

2. Jay W. Forrester's (1961) classic DYNAMO model of a business firm is an excellent example of a very powerful model developed from a few simple chains.

3. The movements of discrete quantities among discrete states (usually actors) is clearly one of the kinds of processes that we are considering in this chapter. Say, for example, the moves of armies across territories. Such models could be developed within DYNAMO, but the language is relatively inefficient for such purposes, and more event-oriented languages would be more appropriate.

4. For an interesting comparison of economic growth models that is sensitive to the conceptual distinctions we are using in this volume, see Meadows and Robinson (1985).

5. On the problems attendant upon inclusion or exclusion of "redundant" variables in structural equation models, any multivariate statistics text in the social sciences can be consulted. Heise (1975) discusses the logic and techniques of loop reduction methods in flow diagram analysis.

6. For an example of the application of statistical methods to the regime transition problem, see an example reported in Tuma and Hannan (1984, Ch. 10).

7. Though languages other than DYNAMO may be preferable for building models of such phenomena.

8. See particularly Perrow (1984) on the complexity of control structures.