Sequence Analysis: New Methods for Old Ideas

Andrew Abbott

Annual Review of Sociology, Volume 21 (1995), 93-113.

Stable URL:
http://links.jstor.org/sici?sici=0360-0572%281995%2921%3C93%3ASANMFO%3E2.0.CO%3B2-Y

Your use of the JSTOR archive indicates your acceptance of JSTOR's Terms and Conditions of Use, available at http://www.jstor.org/about/terms.html. JSTOR's Terms and Conditions of Use provides, in part, that unless you have obtained prior permission, you may not download an entire issue of a journal or multiple copies of articles, and you may use content in the JSTOR archive only for your personal, non-commercial use.

Each copy of any part of a JSTOR transmission must contain the same copyright notice that appears on the screen or printed page of such transmission.

Annual Review of Sociology is published by Annual Reviews. Please contact the publisher for further permissions regarding the use of this work. Publisher contact information may be obtained at http://www.jstor.org/journals/annrevs.html.

Annual Review of Sociology
©1995 Annual Reviews

JSTOR and the JSTOR logo are trademarks of JSTOR, and are Registered in the U.S. Patent and Trademark Office. For more information on JSTOR contact jstor-info@umich.edu.

©2002 JSTOR

http://www.jstor.org/
Wed Aug 14 18:23:59 2002

Annu. Rev. Sociol. 1995. 21:93–113
Copyright © 1995 by Annual Reviews Inc. All rights reserved

SEQUENCE ANALYSIS: New Methods for Old Ideas

Andrew Abbott
Department of Sociology, University of Chicago, Chicago, Illinois

KEYWORDS: methodology, alignment, stages

ABSTRACT

A wide variety of work in social science concerns sequences of events or phenomena. This essay reviews concepts of sequence and methods for analyzing sequences. After a brief definitional discussion, I consider sequence literatures from various areas. I then discuss recent methodologies for sequence analysis. I review stepwise approaches like Markovian and event history analysis as well as whole sequence approaches resting on new developments in biology and other fields.

INTRODUCTION

A quiet revolution is underway in social science. We are turning from units to context, from attributes to connections, from causes to events. The change has many antecedents: the exhaustion of our old paradigm, our inherent desire for change, the new powers of computers. It also has many consequences: new areas for empirical work, new methodologies, rediscovery of important old theories.

This essay concerns the temporal facet of this move toward context, a turn toward process and events that has taken shape in something called *sequence analysis*. It should be understood that sequence analysis (SA) is not a particular technique, like event history analysis. It is rather a body of questions about social processes and a collection of techniques available to answer them.

I begin with a review of the turn toward context, locating SA within a broader classification of approaches to social life. I then consider a variety of empirical literatures that raise problems appropriate for SA. This section leads

0360-0572/95/0815-0093$05.00

into a discussion of the basic questions addressable within SA and a location of these questions within a grid of methodologies applicable to sequence data. I then consider some methods for sequence analysis.

Many apparently disparate developments in current sociology are avatars of one phenomenon: an emphasis on context. By context, I mean here simply the phenomena surrounding a case. I do not invoke the connotations of reflexivity that have become customary in the postmodernist usage of "context." I mean simply that sociologists seem less willing than heretofore to detach cases from the network of other cases and prior times.

For many years, our usual approach in sociology has been to think about cases independent of one another and, often, of the past. We characterize cases by properties like gender, race, totalitarianism, or bureaucratization and then ask how these properties are connected together in something we call a causal chain. Our methods are founded almost exclusively on such a model of social reality. And they have produced much interesting knowledge.

On the other hand, this model has major problems. It doesn't do very well by its own standards: Variance explained is often small, and effects are often substantively minimal despite their statistical significance. Rather than cumulation, we see diminishing returns. Moreover, the model's assumptions are embarrassing at best (as was recognized by some of its founders, see Blau & Duncan 1967). We assume intercase independence even while our theorists focus on interaction. We talk about causality while our theorists emphasize social action. Our articles are filled with statements about race and bureaucratization "doing things," even while our theories concern people doing things. Between the two lie a cumbersome set of just-so stories specifying that if the people typically do such and such to each other, then the variables will be related as so and so (Abbott 1992b).

Meanwhile, there are areas of sociological research that clearly center on problems of events and actions in their temporal context, what we might call sequence problems. The various literatures related to the life course are probably the largest such area, but the tangle of literatures related to careers—occupational, criminal, organizational—runs a close second. Here the central problem has been reconciling the theoretical "sequentiality" of these literatures with the unrelentingly nonsequential character of sociologists' preferred methodologies.

Beyond sociology, surprisingly, the issue of sequence and temporality is much less of a problem. Sequences of events have a long research history in psychology and have enjoyed a recent renaissance in economics. Linguistics also has a tradition of sequence research, as does archaeology.

Before considering the sequence literature, I give some basic concepts to set the stage. By *sequence* I mean an ordered list of elements. In the present paper the sequence will always be temporal, but mathematically the underlying

property is order in one dimension, so spatial sequences (e.g. the arrangement of ethnic groups along transportation lines) would also fall under the term. However, there is no assumption of real time, as opposed to symbolic time, so *sequence* includes things like the order of steps in a manufacturing process or the successive parts of a ritual, where the time involved is artificial in some sense. Although the order of a sequence sometimes permits ties, as with parallel processes in a manufacturing process, most often we think of sequences as discrete, single lists, as in job careers. (To be sure, as moonlighting implies, even in careers we may not have a strong order, but rather simultaneous states.) The elements of a sequence are *events*, drawn from a set of all possible events in a set of sequences, the *universe* of events. We can conceptualize ties, in fact, as conjunctural events drawn from the power set of the current universe (which includes all combinations of basic events), so there is no real reason to worry about the idea of a single unilinear order.

A number of properties of sequences will be useful in the following discussion. First, events in a sequence can be unique or they can repeat. A sequence in which events cannot repeat, one that samples the universe without replacement, is *nonrecurrent*. The length of such a sequence cannot exceed the size of the universe; it will not equal that size if certain events do not happen. A sequence in which events can repeat—that is, a sequence that samples the universe of events with replacement—is a *recurrent sequence*. The length of a recurrent sequence has no limit but is typically set by some sampling frame—a lifetime, a wave of data collection, or something similar.

Second, sequences can have dependence between their states. The most familiar examples of this are stochastic processes, in which the $n + 1$th element of the sequence is some specified function of the nth or perhaps earlier elements. With a finite universe and a scalar probability of any given $n + 1$th state after any given nth state, we have the simplest such case, the Markov process. There are of course many more complicated arrangements, particularly when the universe is infinite or continuous, as with interval-valued variables. There we may find higher-order autoregressive schemes, moving averages schemes, schemes introducing error, and so on. By contrast, there may on the other hand be minimal inter-state dependence, as in the example of the order of prayers in the Roman, Milanese, Syriac and other rites of the various Catholic churches.

Third, there can be varying degrees of dependence between various whole sequences. As Harrison White noted in *Chains of Opportunity* (1970), we sometimes have sequences in which the occurrence of an event in any one sequence prevents that occurrence in any other; there can be only one Editor of the *American Journal of Sociology* at once, for example. This is true in a looser form for phenomena like "upper-classness" or "working in the farm

sector" where larger constraints, usually conceptualized in sociology as "constraints on the marginals," limit possibilities across sequences.

Fourth, sequence can be investigated either for itself or as an independent or dependent variable. Sometimes we are interested simply in the patterns in a collection of sequences. Other times we wish to know how the prior event sequence affects the immediate future, as when we try to predict joblessness given prior *sequence* of job experiences. Still other times we wish to know what accounts for different sequences of behavior—what prior variables, for example, lead to descending spirals into criminality?

These four properties form a useful framework for analysis. In looking across the various sequence literatures, we shall see that some involve recurrent, others nonrecurrent sequences. Some look for dependence within sequences, some between. Some consider sequence for itself, others for its origins, still others for its causal power.

LITERATURES

I have focused my prior reviews of sequence literatures (1983, 1990) on sociology alone. But readers have been befuddled by seeing familiar things like careers and school-to-work transitions through the unfamiliar lenses of sequence analysis. I therefore base my review on diverse sequence literatures around the social sciences, turning to sociology proper only at the end. In all areas, the review is selective, not exhaustive.

Psychology

The largest literature on sequences in social science is in psychology. This work is in three areas: cognition (broadly understood), interaction sequences, and theories of developmental stages.

The first major cognitive sequence topic is perception. Typically, sequences here are sequences of stimuli, treated as independent variables that affect level of perception or discrimination. Thus Polich (1987) studies EEG responses to tone sequences, Baird et al (1991) study verbal judgments of loudness in tone sequences, and Allik (1992) studies judgments of motion given random dot patterns with varying luminance. Occasionally this literature studies internal dependence, but only as an independent variable: French-St. George & Bregman (1989), for example, study the impact of predictability of tone sequences on ability to discriminate tones. This has been an area of considerable theoretical development, aimed at the general problem of how subjects distinguish "parameter" change from "noise" change in sequential perceptual stimuli. Treisman & Williams (1984) advanced the theory of criterion-setting for this problem, while van Leeuwen et al (1988) explain sequence influences by a more general formal theory of perception.

Another sequence literature in studies of individual cognition concerns more general topics, particularly memory and learning. Here, too, sequence is sometimes an independent variable only. Thus, Park & Tennyson (1986) examine tailoring the sequence of assistance in a computer-based learning system to patterns of student error, and Wold & Reinvang (1990) examine effects of sequence of information on the ability to recall it. Some studies focus on the effect of sequence on judgment. Thus Mullen et al (1989) and Davis et al (1989) investigate effects of polling sequences on estimates of consensus in groups, and Peake & Cervone (1989) investigate *sequence anchoring*, an extended form of primacy effect in which early judgments influence later ones. All of this work on judgment falls within the study of internal sequence dependence.

Most of the cognitive psychology literature on sequence, however, concerns sequence as itself an object of learning or perception, often integrating that with a concern for the actual sequence of learning. For reasons that become clear on reflection, sequences of learning are best investigated empirically by studying the learning of sequences. In a typical study, Winn (1988) investigates whether students can remember the order in which concepts were presented. Sometimes studies concern the relation of sequence perception to sequence production or discrimination (Terrace 1986, Grenzebach & McDonald 1992), but the more characteristic study tries to embed learning of sequences in a more general theory of learning or encoding of information (Cohen et al 1990). Another interesting literature concerns the ability to reconstruct full sequences out of partial information (Oppenheimer & Lee 1983, Oppenheimer & Groot 1985, Wyer et al 1985), a topic that has also emerged in the "script" literature spawned by the work of Schank & Abelson (1977; e.g. Hue & Erickson 1991). Read et al (1989) show nicely how reordering can radically change subjects' understanding of the meaning of particular events.

A final cognitive literature concerns sequences of action. Here again, sequence is typically an independent variable, usually in the form of sequences of reinforcement (success of some sort). A substantial literature studies the effects of the "illusion of control," artificially high reinforcement early in a given experience (Burger 1986, Fleming & Darley 1990), but there is also a longstanding and enormous literature on schedules of reinforcement (e.g. Pittenger et al 1988). There are a few studies of mechanisms for generating sequences of action (e.g. Garcia-Colera & Semjen 1987 on finger movements and Inhoff 1986 on eye movements).

Studies of individual sequences in psychology are supplemented by a second major literature, that on interaction. Once prominent in social psychology generally (e.g. in the Bales tradition), interaction sequences are now more common as topics in the therapy literature. Parker (1988) exemplifies the long-running literature on turn-taking in conversation. On a broader scale, Staw

& Ross (1989) consider escalation situations, changing the reinforcement schedule of the classical experimental paradigm into a mutual reinforcement system and examining the origins of such systems. Also common are studies of "sequence of sequences," that is, studies of the development over time of sequential interaction patterns. Mays (1986) examines this in small groups, while Ryle (1991) provides a Vygotskian theoretical analysis of counseling sequences. Ney (1987) gives a typical analysis of "the natural sequence of events" in counseling, in this case for treatment of child abuse. Mishler (e.g. 1986) has done much work on narrative sequences in counseling. Bakeman (e.g. Bakeman & Gottman 1986) has done a variety of interaction sequence studies.

Another interactional literature focuses on sequences of family interaction generally and mother-child interaction in particular. Cohn & Tronick (1987) examine developmental patterns in mother-child interaction, while Lamb & Malkin (1986) study such patterns when the child is seeking aid. Duncan & Farley (1990) consider the emergence of conventions in parent-child sequential interactions. Vucinich (1984) has looked more broadly at sequences in family conflict.

The final psychological sequence literature concerns developmental sequences. Such conceptions—known and despised in sociology as stage theories—are widespread in psychology. A good but dated review essay is Campbell & Richie (1983), which urges continuing use of developmental sequences despite arguments against them. Campbell & Richie were clearly preaching to the converted; the developmental literature continues to make sequence one of its fundamental concepts. Lister et al (1990) consider concept development in children, and Berti et al (1986) focus on acquisition of economic ideas, on which there exists a substantial literature. Another literature continues the longstanding research on moral development sequences (Vasudev & Hummel 1987, Foster & Sprinthall 1992). A final literature discusses sequences of diseases and treatments. For example, Faedda et al (1991) consider response to lithium, Deltito et al (1991) consider symptom change in panic disorder, and Ellickson et al (1992) study sequential patterns of drug use.

Overall, then, there is much writing on sequence in psychology. In most of it, however, the conceptualization of sequence is simple. Particularly when sequence is an independent variable, sequence is defined as simple reversal, or as monotonic ascent or descent, or some similarly regular pattern like alternation. Complex sequence patterns are never investigated except as tasks for tests of cognitive functioning or as linear sequences of nonrecurring states in developmental sequences. Even within the psychological literature on interaction, there is seldom a focus on serious contingency in sequence. When there is, it is usually seen in a stochastic process (usually Markovian) framework.

Economics

Economics, like psychology, features several disparate literatures on sequences. There is a longstanding literature on sequence problems in operations research proper that ties loosely to studies of sequential games. The games literature ties further to some papers on sequence problems in general economic theory. There is also a specific literature on sequences in markets. Finally, there is some writing on sequence effects in advertising and consumption, loosely related to the literature in psychology on sequence effects in perception.

The operations research literature is highly technical. Most of it concerns scheduling problems where there are one or more machines capable of performing several tasks, and the costs of setting up machines for new tasks are a function of the sequence in which the tasks are done. [A favorite example: making chocolate cake mix after white cake mix requires less set up than making white cake mix after chocolate! (Meier et al 1982 cited in Dilts & Ramsing 1989)] Exemplary papers are Chand & Chhajed (1992), Dilts & Ramsing (1989), Dobson (1992), and Gupta & Darrow (1986). Perhaps more interesting, for its practical utility, is Nakai's (1986) paper on another common problem, how to make a best selection of candidates interviewed sequentially, once known as "the classical secretary problem" (Nakai 1986:478). Although these papers seem technical, they concern problems central to daily social life and addressed by a variety of satisficing strategies. They provide important models for thinking about social processes. Because of its genesis in immediate application, operations research work on sequence and scheduling often makes a lot more practical sense than do the more arcane flights of game theory.

In general economic theory, sequence concepts are uncommon, since the characteristic move of that area is to seek asymptotic distribution theory precisely in order to ignore the sequence of intermediate states. Nonetheless, sequential equilibrium (Kreps & Wilson 1982) is an important topic in game theoretic economic writing (e.g. Besanko & Spulber 1990). In sequential equilibria, game players' strategies respond to each others' given beliefs about the rest of the game and to information sets governing their knowledge of other players' behaviors. The central empirical questions involve the game's coming to rest in one or more equilibrium points. Hoel (1987) relaxes the customary game theoretic assumption of an exact alternating sequence of offers, allowing "plays" at random times by random players. Economists, like psychologists, have often used Markovian approaches to sequences, as in Hopp's (1987) study of investment decisions.

A related literature considers sequences within specific market contexts. Here, as in the psychological literature, sequence may be either central (as in studies of interaction) or simply used as an independent variable. The most common issue is reaction to certain kinds of sequence signals, as in psy-

chology's sequence perception problem. Thus, Burgstahler & Noreen (1986) consider reactions of securities markets to sequences of related events (an independent variable model), while Vickers (1986) and later Delbono (1989) study markets where there is a sequence of innovations (that is, a sequence of opportunities to arbitrarily lower one's production costs over the next competition interval). In these two studies, the focus is on sequential decision-making. In both cases, the derived theory shows that crucial characteristics of the products, produced markets, or bidding games shape the unfolding of the observed sequence of dominance. A similar theme appears in other kinds of studies, as in Dewatripont's (1987) study of sequential models of spatial competition. Sequential game theory is related to other kinds of sequential social theories, like Fararo & Skvoretz's production theory (Fararo & Skvoretz 1984, Skvoretz & Fararo 1989). These are the coming formalizations of social action and will replace the simple exchange theories of the Homans/Blau era. [Their equivalent in the area of cognition is the Schank/Abelson (1977) script tradition.]

Also to be considered under economics are stray articles in marketing that employ sequential ideas. Sequence effects for advertisements are tested by Aaker et al (1986) and Marks & Kamins (1988). Others (Stoltman et al 1990) have tested different orders in consumption decisions—does one first choose brand, store, store type, or location? I note these papers less to draw on their scientific content than to show that interest in decision sequences extends beyond the pure psychology and economics community well into applied contexts.

Archaeology

Archaeology has long been interested in sequence analysis. The problem of ordering sequences of artifacts, using measurements provided either by resemblances between artifacts or by proximity in sites, provided the first impetus to many current methods in sequence analysis. Hodson et al's monumental collection (1971) brings many of these works together in one place and provides an entry to the field. This literature continues to grow.

Although the theoretical question is nearly always the simple stage problem of what came before what, a variety of sequence methods are used in archaeology, some reflecting modal characteristics of artifacts, some reflecting more complicated statistical analysis. For an example employing several techniques, see Tolstoy & DeBoer (1989). Typically, profiles of sites in terms of different kinds of artifacts are used to sequence sites or industry types, if that is desired (McBrearty 1988). Sometimes the methods used are extremely ingenious and rely on knowledge of complex sequential constraints, as in tree-ring dating of rooms in pueblos (Crown 1991—these are analogous, formally, to the scheduling problems of operations research). One worry in the archaeological liter-

ature is the pervasive assumption that there is a single directional sequence without cycles. Bird & Frankel (1991) raise this problem in connection with Holocene Australia, showing the difficulties of dovetailing sequences at individual sites with those elsewhere, particularly in the case of random censoring and research-induced sampling biases.

Linguistics

A variety of sequence questions have been investigated in linguistics. As in psychology, sequence is here most often a straightforward and usually simple independent variable. Generally, studies transpose words, grammatical structures, or whole parts of texts, and investigate the disturbance of comprehension. The wide range of such studies is indicated by Gisiner & Schusterman's (1992) paper, which concerns sequence effects in a language-trained sea lion. Another illustrative paper is Jonz's (1989) investigation of scrambled texts with native and non-native English speakers. A central question here—one that derives from the work of Piaget and that is central for our understanding of time more broadly—is exactly how people construct their images of and words for temporal processes and sequences. Much work concerns acquisition of such conceptions in children: Natsopoulos & Abadzi (1986) exemplify this literature. As that example suggests, the issue of linear development—the stage-theory question—is as important in linguistics as in psychology. In both cases we have sequences of sequences. Thus we find stage theory throughout language acquisition studies, not only for children, but increasingly for second language acquisition as well. Laufer (1990) studies stages in second language acquisition and illustrates a common theoretical move among stage theorists—insisting on absolutely regular gross succession, but allowing a fair amount of inversion and irregularity in the details of acquisition within stage.

Political Science

In political science, sequences have played important roles as well. The modernization tradition was anchored in a stage theory hypothesis, which spread from its application to economic change, (by scholars like Rostow), to applications to political development (in Huntington and his followers), to nationalism (in the work of Deutsch and others). More recently, stage theories have been applied to the welfare state, a problem analyzed in detail by Abbott & Deviney (1992). In some political science discussions sequence means, as it usually does in sociology, essentially a sequence of variables (e.g. Carmines & Stimson 1986). At other times, sequence is conceived essentially as some form of autoregression (Waterman et al 1991). Or again, sequence can be conceived as simple transposition in order (economic liberalization before or after political liberalization in Weintraub & Baer 1992). Auten et al (1984) present such a one-step model of budgeting. A far more sophisticated sequen-

tial model of budgeting appears in Padgett's classic 1981 article, which remains one of few really serious multilevel stochastic models of sequences of events.

The various nonsociological sequence literatures share a number of characteristics. First, the most common sequence approaches in them are two: 1. use of stage theories to comprehend patterns of development, and 2. analysis of the effects of fairly simple sequence effects (e.g. inversions) as independent variables. Stage theories with their assumption of nonrecurrence are widespread; they are central in developmental psychology, archaeology, and political science. Similarly, the limitation of sequence effects to simple reversal or, at most, variation among the order of three events is pretty universal across the psychological, political scientific, and linguistic literatures. Economics stands out for its formal approach to sequence issues, usually within a stochastic framework either in real time or in the "decision tree time" of game theory. The various Markovian studies scattered across linguistics, economics, and psychology also fit this one-step sequence format, focusing on internal interdependencies in sequences. No nonsociological work really addresses the contingencies between separable sequences, although one could think about the beliefs and strategies of participants in extensive games as separable but interdependent sequences.

Sociology

The two principal sociological literatures involving sequential conceptions have both been discussed in recent *Annual Reviews*. The life cycle literatures were reviewed by O'Rand & Krecker in 1990, and the careers literature by Rosenfeld in 1992. I have little to add to those reviews in terms of coverage of the literature.

Although sequences have made many appearances in sociology, there are few formal theoretical analyses for them. I have already noted the Fararo/Skvoretz tradition. There was also early work by Mayhew and others (Mayhew et al 1971, Mayhew & Levinger 1976), and by Abbott who (1983) attempted to characterize the theoretical and methodological literature on sequences. Beyond that, the theoretical work in sociology is minimal. By far the most important theoretical literatures for understanding sequences of social events per se are the analytical philosophy of history (reviewed in Gardiner 1959 and monumentalized in Danto 1985) and the structuralist theory of narrative (reviewed in Chatman 1978 and epitomized in the astonishingly brilliant Barthes 1974). These are large literatures, not to be summarized sketchily. Nor have they been transcended by the culturalist muddles about history that dominate debates on historiography and narrative today. An attempt to reconcile all these literatures is Ricoeur (1984–1985: definitely not for the intellectually faint at heart).

There are really three levels of sequence conceptions in sociological writing.

The simplest are linear stage theories. These are familiar not only in the life course literature, but also in the dozens of "-ization" literatures—professionalization, rationalization, modernization, and so on. In sociology, formal stage theories have long been common. One finds them in Marx, Michels, Bateson, Kuhn, Smelser, and many others. A particularly rich source are the "natural histories" of the Chicago School, whose leader Robert Park saw stage theories nearly everywhere: in revolutions (Edwards 1927), gangs (Thrasher 1927), commercial organizations (Hughes 1928), criminal careers (Shaw 1930), dancers' careers (Cressey 1932), and so on. Other versions of stage theories are theories about "short sequences" that must be negotiated in some order, typically the school-to-work transition, but often something more quirky like the transition to criminality (Sampson & Laub 1993). These are "turning points" theories.

The next level of sequence conception involves much more contingency and accident than do stage theories. Sequences here are often more subject to influence by other sequences or by marginal conditions. Most of the job careers literature takes this approach, probably because even at the simplest level—employment and unemployment—job histories are astonishingly erratic. I therefore call these "career" theories, bearing in mind that many theories about people's careers are actually stage theories, expecting regular development, usually of nonrecurrent events.

The most extreme form of sequence conception makes all sequences interdependent in a complex network. I have elsewhere (1992c) called such theories *interactional field theories*. They are quite common. White's (1970) vacancy chain model is of this kind, but so also was Abbott's theory of professions (1988a). Such theories require quite unusual methodological handling; White resorted to modeling sequences of holes in the system rather than sequences of jobs held by individuals (see Chase 1991 for a review of such models).

The sociological literature thus involves some of the same issues as do other literatures, but it has different emphases. Stage theories dominate in the life-course literature and in much of the "transitions" literature that is a part of it. But by contrast career theories dominate most job research, and the despair of discovering patterned sequences has forced that literature to focus on point outcomes or one-step stochastic models.

METHODS

Researchers with sequence data sets and sequence-related questions can follow a fairly clear decision tree in their search for methods. The first decision is whether to analyze actual data or to construct data based on parameters from actual data, that is, to simulate. The latter is the choice of game theory and its relatives, and I do not treat it extensively, as Oliver (1993) has reviewed a

related topic recently and Macy discusses such issues elsewhere in this volume. The central problem with simulation is the semantic one of justifying the application of a particular simulation to a particular body of data. Unfortunately, it is usually true that many simulations can be constructed to "fit" a body of data, given sufficient assumptions about parameters. The justification of any particular model is therefore often very weak. In general, simulation buys syntactic power—internal logical consistency and, often, a wonderfully counterintuitive unpredictability—at the price of this semantic obscurity. It is worth noting, however, that mathematical models of this type have a considerable history in sociology (e.g. Granovetter 1978), following on Rashevsky's curious work in the 1960s (Rashevsky 1968).

If one is not using simulation-based methods, the next decision, as I have made clear elsewhere (1992a), is whether one wishes to treat the sequence as a whole or step by step.

Step-by-Step Methods

The step-by-step choice leads to time series, Markovian, and event history methods. If the central interest is a fairly deep and complex dependence of an interval-measured sequence upon its own past, then one applies time series methods. These aim to find a simple stochastic generator that effectively fits an entire sequence. It may involve autoregression, moving averages, or both in combination, and may reach varying depths into the past. The basic idea of time series analysis is to write a model that is presumably causal; mechanisms must be postulated that dictate the particular model structure—lag, averaging, and so on. New developments include introduction of event-type disturbances in time series, on which see Isaac et al 1991. The definitive text is Box et al 1994.

When the variable of interest is categorical, the step-by-step analyst employs traditional Markov methods, aiming to fit sequences of categories by estimating transition probabilities step by step and perhaps invoking either deeper past dependence (higher order) or changing probabilities (nonstationarity) to account for misfit of a one-step model. Despite early widespread application in mobility studies, Markovian analysis has not flourished in sociology, probably because it delivers powerful predictions only in the case of stationary processes (which are rare) and is practical only when the models involve just one previous time period and a fairly small state space. Useful reviews of this early but lapsed literature are Boudon (1973) and Stewman (1976), although Markov models are still occasionally used (see Brent & Sykes 1979 and Manderscheid et al 1982).

Where one is interested in transitions from only one particular prior category, and the issue is time until transition (e.g. how long is it before married people get divorced), one has event history methods, known outside sociology as

duration methods, hazard methods, failure analysis, and various other names. These have begun to see very widespread application in sociology, as any perusal of the *American Sociology Review* or the *American Journal of Sociology* shows. Although I personally have reservations about these methods (Abbott 1983, 1992), they are widely used and must be understood by any serious sequence analyst. A current review is Yamaguchi (1991).

Whole Sequence Methods

If on the other hand one wishes to treat sequences as whole units, then one must have recourse to special methodologies. However, it is useful, first, to note the basic questions of interest here. The central issue in whole sequence analysis is nearly always whether there are patterns among the sequences, either over the whole sequences or within parts of them. One may wish to ask where these patterns come from (making them dependent variables), or what they mean for the future (making them independent variables), but the first problem is always to figure out whether the patterns are there.

There are two broad approaches to this question of pattern. One is algebraic, the other metric. In the algebraic approach, the aim is to reduce each sequence to some simplest form and then to gather all sequences with similar "simplest forms" under one heading. In the metric approach, the analyst develops a measure of resemblance that gives the "distance" between any pair of sequences. These distances are then subjected to some standard classification method like scaling or clustering (on which see Arabie & Hubert 1992 for a recent review).

Many people are seeking ways to code whole sequence data. Often, the coding seems obvious, as in coding careers as simple lists of jobs; a career is simply the year-by-year or month-by-month list of jobs held. But when matters are more complex—as in attempts to code interaction or stories or parallel sequence tracks—the varieties of schemes are endless and could be the subject of their own review. There is a large literature in discourse analysis and related literatures on detailed formal representations of discourse and discourse-like processes. Poole (e.g. 1989) has done much work developing multilevel coding schemes for interaction, and indeed the Balesian interaction process analysis tradition continues (Kosaka 1993, responding to Abell 1993). See also the extensive work of Bakeman & Gottman (1986). Trabasso (Trabasso & Nickels 1992) has developed a "causal network discourse analysis." Another new scheme has emerged in the sociology of science (Latour et al 1992, Scott 1992, Carlson & Gorman 1992), although it seems to this writer that the Latour et al project more or less reinvents network analysis. For yet another coding system (and software), see Carley (1991) and Carley & Palmquist (1992). Mishler (e.g. 1986, 1990) has done much work on interview coding and analysis. Franzosi (1990) and others have worked on the coding of stories from

newspapers. Indeed, much of David Heise's ETHNO program is aimed to help investigators create a formally coded narrative structure for sequence data in interactive format.

What to do with the data once coded is another matter. In the one specific case of nonrecurrent sequences with complete data (each event observed once and only once in each sequence), there are a broad variety of permutational techniques available. These follow the metric approach above. They produce measures of resemblance between sequences, which the analyst may then scale or cluster in order to create categories that can in turn serve as dependent or independent variables. Spearman correlation is such a measure of resemblance. Where one has nonrecurrent sequences with missing data (through time frame censoring or simple nonoccurrence), the problem can be treated as a seriation or one-dimensional scaling problem, provided there are measures of distance or resemblance between sequence elements. (For an example, see Abbott 1991.) Arabie & Hubert (1992), however, warn of difficulties in such applications.

Once one moves to recurrent events, there are three explicit methodologies for considering sequence regularities of some complexity, all products of extensive theoretical and research programs. Two are algebraic in approach (David Heise and Peter Abell), and one is metric (Andrew Abbott). If the data involve branching and merging sequence lines, that is, if they involve separable but simultaneous events that the analyst does not wish to treat as combination events, the only possible choices at present are the methods of David Heise and Peter Abell. In the case of unilinear sequences, Abbott's methods are available and probably preferable. In reality, the three methods are aimed at different parts of the overall task of sequence analysis. Heise's methods are chiefly aimed at a rigorous and fully justified coding. (See his comments on Abell 1993.) Abell's methods are chiefly aimed at algebraic classification of already coded narratives. Abbott's methods are aimed at metric classification of coded narratives and, while much more flexible than Abell's, are presently available only for the case of unilinear sequences.

David Heise's ETHNO system arose out of his work coding extended action and interaction patterns, and looks to the theories of Fararo & Skvoretz (1984). It is embodied in an interactive software system (ETHNO: see Heise 1989, 1991) [available from WC Brown publishers in Dubuque, IA for $50]. For reviews, see Griffin (1993) and Barnes (1993). ETHNO presumes that the analyst has a data set composed of more or less extended narratives of particular stories that must be reduced to bare bones structures by creating a lexicon of actions and events and then formalizing the ways in which these actions and events proceed from one another. The formalization encodes the analyst's understanding of necessary relationships among the events to be placed in the narrative structure. ETHNO is well illustrated in Griffin's (1991) piece on

lynching and Eder & Enke's (1991) equally challenging analysis of gossip. See also Heise's own applications, especially Corsaro & Heise (1990).

Far more than Abell and Abbott, Heise has focused on problems of semantic definition in sequence analysis. The end result is an exceptionally clear and empirically justified coding of the narrative, combined with the idea that generalization entails finding other narratives that "collapse" into the same primitive structure when the various narrative lines are simplified. (This is more or less the narrative homomorphism criterion of Abell, which Heise, in commenting on Abell 1993, argues is the best criterion for sequence resemblance.)

Abell's homomorphism approach to sequence resemblance grew out of his own research on cooperatives and his extensive critique of standard methodologies (Abell 1987). The best recent exposition is Abell 1993, which has the advantage of being followed by lengthy responses from Heise, Fararo, Skvoretz, Abbott, and other analysts of social sequence data. Like Heise's methods, Abell's are applicable to complex, network narratives. [They should ultimately be available (in late 1995) in the UCNET system of programs, but at present are available from Martin Everett in the Department of Mathematics, Greenwich (England) University.] Abell's methods presume, like Heise's, a data set comprising various narratives of various degrees of complexity, but they focus more on the formal graphical structure of these narratives. They contain routines for reducing any coded narrative to a minimal homomorphic representation, which effectively allows one to further classify a set of Heise codings once they are developed within ETHNO. Abell (1993) has done a detailed analysis of narrative data on consumer cooperatives.

Abbott's strategy for sequence analysis—optimal matching or optimal alignment as it is usually called—derives from a broad movement in the hard sciences, although it was stimulated by his work as a historical sociologist of occupations (Abbott 1988a) and his critique (similar to Abell's) of general linear models (Abbott 1983, 1988b). The methods Abbott has adapted derive from biology and from the pattern resemblance community in computer science. The classic text on these methods is Sankoff & Kruskal (1983). Recent primers are Heijne (1987) and Gribskov & Devereux (1992). Some recent developments are discussed in Abbott (1993).

The principal practical difference between Abbott's methods and Heise's or Abell's is that Abbott's are limited to unilinear sequences and proceed by metric means. They presume a data set made up of sequential lists of events, like job careers or criminal careers. Under more or less parametric assumptions about the resemblance of individual events (jobs or crimes), the methods allow one to find resemblances between either entire sequences or subsequences within them. As with other metric techniques of sequence analysis, these resemblances are then input to scaling, clustering, and other categorization methods to uncover actual categories of patterns. Abbott's techniques are

available in simple form in his OPTIMIZE program [from him, $20], although any publicly available biological sequence alignment program will do the same things, after some modification of its IO facilities.

Optimal matching has begun to see substantial use in social science. Abbott's own published analyses include papers on dances (Abbott & Forrest 1986), on careers (Abbott & Hrycak 1990), and on welfare states (Abbott & Deviney 1992). He has tested reliability in Forrest & Abbott (1990). Jones & Brain (1985) utilize the event distance coding characteristics of optimal matching. Coxon (1988) reports both an elaborate coding scheme and application of matching methods to sexual behavior. (There may be more complete publications from this study that I have not been able to find.) Miller & Roid (1993) apply optimal alignment to movement patterns in infants, while Levitt & Nass (1989) nicely use optimal matching to demonstrate consistency among physics and sociology textbooks. Saberwahl & Robey (1993) apply the techniques to find regularities in innovation processes, as does Poole (1993). Chan (1994) has used optimal matching to analyze mobility paths, as has Carpenter (1994). Stovell (1994) uses the methods in an insightful analysis of county lynching patterns in the US South.

One of the advantages of optimal matching/alignment as a sequence technique is that analysts whose theories predict different forms of resemblance can vary the algorithms to suit them. Thus, stage theories with some local disorder—a common position among stage theorists—can be sought using variants of the cellar algorithm (Wagner 1983). Theories implying the unimportance of minor shifts in duration of runs can be handled with variants of the affine gap-cost algorithm (Sankoff & Kruskal 1983:296ff). "Subsequence problems" across large data sets (the "turning point question" in life cycle data) can be handled with new local alignment algorithms using Gibbs samplers and expectation maximization (Lawrence et al 1993). More important, the unilinearity constraint is slowly being lifted. Even game theoretic sequences (which branch at each decision point) will probably be analyzable using the tree resemblance algorithms of Shasha and others (Zhang & Shasha 1989, see also Sankoff & Kruskal 1983: 265ff).

At present the measure theory of whole sequence data is preliminary indeed. In the highly specialized but fairly common situation of sequences embodying stages that all cases traverse in the same order, the methods of Collins et al (1988: a kind of generalized Guttmann methodology) may prove to be generalizable from their original of use as a generator of scaling items. But much depends on formal models of sequence generation and, probably more importantly, on the actual methodology chosen. Abbott (1984) raises a number of general measurement issues. Another extraordinarily interesting area is scheduling theory; for example, Birch (1984) has an extremely interesting paper on sequences generated by simple activation time models. Scheduling

models such as the Fararo/Skvoretz production scheme may prove crucial to developing serious measurement analysis for sequence data. Sequence-guessing programs created by artificial intelligence may also be important. For an example, see Dietterich & Michalski 1985.

In summary, sequence methods seem to be poised at a point of major development. Once the vast array of biological algorithms can be harnessed to a reasonable sociological IO system, Abbott's empiricist sequence resemblance techniques should become a reasonable tool. The major problem then will be to think through ways of combining Heise's elegance of description, Abell's rigor of homomorphic classification, and Abbott's empirically practical use of metric techniques. Unsolved even in computer science, however, is the combination of the last two (analysis of network-structured sequence data with metric resemblance techniques), although see Abbott (1993) for speculations on this matter. Unsolved too are the great difficulties of developing a serious measurement and statistical theory for sequence analysis. All these methods at present are largely heuristic. Only now are the biologists really facing the problems of statistical inference with sequences, problems that differ in many ways from the kinds of inferences sociologists may wish to draw. (For the biological literature, see Karlin et al 1991 and Vingron & Waterman 1994.)

Sequence analysis holds great promise for sociology. Most of our classic theories are sequential or interactional theories. The new methods address those theories directly. What the field needs now are junior scholars committed to exploring what sequence regularities can tell us about social life. The methods will not, to be sure, solve the great problems represented by interactional fields—where all sequences are mutually dependent and the data bewilderingly complex. But the methods will provide us with far more effective ways of analyzing life courses, careers, and other such relatively independent and regular sequences, ways of analyzing that accord directly with the canonical theoretical apparatus of the discipline.

Any *Annual Review* chapter, as well as any article cited in an *Annual Review* chapter, may be purchased from the Annual Reviews Preprints and Reprints service. 1-800-347-8007; 415-259-5017; email: arpr@class.org

Literature Cited

Aaker DA, Stayman DM, Hagerty MR. 1986. Warmth in advertising. *J. Consum. Res.* 12:365–81

Abbott A. 1983. Sequences of social events. *Hist. Methods* 16:129–47

Abbott A. 1984. Event sequence and event duration. *Hist. Meth.* 17:192–204

Abbott A. 1988a. *The System of Professions.* Chicago: Univ. Chicago Press

Abbott A. 1988b. Transcending general linear reality. *Sociol. Theory* 6:169–86

Abbott A. 1990. Primer on sequence methods. *Organ. Sci.* 1:373–92

Abbott A. 1991. The order of professionalization. *Work Occup.* 18:355–84

Abbott A. 1992a. From causes to events. *Sociol. Methods Res.* 20:428–55

Abbott A. 1992b. What do cases do? In *What*

Is a Case?, ed. CC Ragin, HS Becker, pp. 53–82. Cambridge: Cambridge Univ. Press. 242 pp.
Abbott A. 1992c. Of time and space. Sorokin Lecture, Southern Sociol. Soc., New Orleans. 10 April 1992
Abbott A. 1993. Measure for measure. *J. Mat. Sociol.* 18:203–14
Abbott A, Deviney S. 1992. The welfare state as transnational event. *Sociol. Sci. Hist.* 16: 245–74
Abbott A, Forrest J. 1986. Optimal matching methods for historical sequences. *J. Interdiscip. Hist.* 16:471–94
Abbott A, Hrycak AM. 1990. Measuring resemblance in sequence data. *Am. J. SOciol.* 96:144–85
Abell P. 1987. *The Syntax of Social Life*. Oxford: Oxford Univ. Press
Abell P. 1993. Some aspects of narrative method. *J. Mat. Sociol* 18:93–134
Allik J. 1992. Competing motion paths in sequence of random dot patterns. *Vision* 32: 157–65
Arabie P, Hubert LJ. 1992. Combinatorial data analysis. *Annu. Rev. Psychol.* 43:169–203
Auten G, Bozeman B, Cline R. 1984. A sequential model of congressional appropriations. *Am. J. Polit. Sci.* 28:503–23
Baird JC, Berglund B, Berglund U, Lindberg S. 1991. Stimulus sequence and the exponent of the power function for loudness. *Perception Motor Skills* 73:3–17
Bakeman R, Gottman JM. 1986. *Observing Interaction*. Cambridge: Cambridge Univ. Press
Barnes JH. 1993. ETHNO. *Advan. Consumer Res.* 20:63–69
Barthes R. *S/Z*. 1974. New York: Hill & Wang
Berti AE, Bombi AS, de Beni R. 1986. The development of economic notions. *J. Econ. Psychol.* 7:415–24
Besanko D, Spulber DF. 1990. Are treble damages neutral? *Am. Econ. Rev.* 80:870–87
Birch D. 1984. A model of fixed activation time scheduling. *J. Math. Psychol.* 28:121–59
Bird CFM, Frankel D. 1991. Problems in constructing a prehistoric regional sequence. *World Archeol.* 23:179–92
Blau PM, Duncan OD. 1967. *The American Occupational Structure*. New York: Free
Boudon R. 1973. *Mathematical Structures of Social Mobility*. San Francisco: Jossey Bass
Box GED, Jenkins GM, Reisel GC. 1994. *Time Series Analysis*. Englewood Cliffs NJ: Prentice Hall
Brent EE, Sykes RE. 1979. A mathematical model of symbolic interaction between police and suspects. *Behav. Sci.* 24:388–402
Burger JM. 1986. Desire for control and the illusion of control. *J. Res. Pers.* 20:66–76
Burgstahler D, Noreen EW. 1986. Detecting contemporaneous security market reactions to a sequence of related events. *J. Acct. Res.* 24:170–86
Campbell RL, Richie DM. 1983. Problems in the theory of developmental sequences. *Hum. Dev.* 26:156–72
Carley K. 1991. Textual analysis using maps. Unpublished paper, Carnegie Mellon Univ.
Carley K, Palmquist M. 1992. Extracting, representing, and analyzing mental models. *Soc. Forc.* 70:601–36
Carlson WB, Gorman ME. 1992. Socio-technical graphs and cognitive maps. *Soc. Stud. Sci.* 22:81–89
Carmines EG, Stimson JA. 1986. On the structure and sequence of issue evolution. *Am. Polit. Sci. Rev.* 80:901–20
Carpenter DP. 1994. The structural and institutional foundations of bureaucratic culture. Ms. Brookings Inst.
Chan TW. 1994. Tracing typical mobility paths. Ms. Nuffield Coll. Oxford
Chand S, Chhajed D. 1992. A single machine model for determination of optimal due dates and sequence. *Op. Res.* 40:596–602
Chase I. 1991. Vacancy chains. *Annu. Rev. Sociol.* 17:133–54
Chateau-Raynaud F. 1990. Une machine interpretative. Unpublished. Centre d'Etudes de l'emploi. Noisy-le-Champs, France
Chatman S. 1978. *Story and Discourse*. Ithaca: Cornell Univ. Press
Cohen A, Ivry RI, Keele SW. 1990. Attention and structure in sequence learning. *J. Exp. Psychol. LMC* 16:17–30
Cohn JF, Tronick EZ. 1987. Mother-infant face-to-face interaction. *Dev. Psychol.* 23: 68–77
Collins LM, Cliff N, Dent CW. 1988. The longitudinal Guttman simplex. *Appl. Psychol. Meas.* 12:217–30
Corsaro WA, Heise DR. 1990. Event structures from ethnographic data. In *Sociological Methodology 1990*, ed. C Clogg, pp. 1–57. Oxford: Basil Blackwell
Coxon APM. 1988. Something sensational. *Sociol. Rev.* 36:353–67
Cressey PG. 1932. *The Taxi Dance Hall*. Chicago: Univ. Chicago Press
Crown PL. 1991. Evaluating the construction sequence and population of Pot Creek pueblo, northern New Mexico. *Am. Antiq.* 56:291–314
Danto AC. 1985. *Narration and Knowledge*. New York: Columbia Univ. Press
Davis JH, Kameda T, Parks C, Stasson M, Zimmerman S. 1989. Some social mechanics of group decision-making. *J. Pers. Soc Psychol.* 57:1000–12
Delbono, F. 1989. Market leadership with a sequence of history dependent patent races. *J. Indust. Econ.* 38:95–101
Deltito JA, Argyle N, Buller R, Nutzinger D, Ottosson J-O, et al. 1991. The sequence of

improvement of the symptoms encountered in patients with panic disorder. *Compr. Psychiatry* 32:120–29
Dewatripont M. 1987. The role of indifference in sequential models of spatial competition. *Econ. Letters* 23:323–28
Dietterich TG, Michalski RS. 1985. Discovering patterns in sequences of events. *Artific. Intell.* 25:187–232
Dilts DM, Ramsing KD. 1989. Joint lot sizing and scheduling of multiple items with sequence-dependent setup costs. *Decision Sci.* 20:120–33
Dobson G. 1992. The cyclic lot scheduling problem with sequence-dependent setups. *Op. Res.* 40:736–49
Duncan S, Farley AM. 1990. Achieving parent-child coordination through convention. *Child Dev.* 61:742–53
Eder D, Enke JL. 1991. The structure of gossip. *Am. Sociol. Rev.* 46:494–508.
Edwards L. 1927. *The Natural History of Revolutions*. Chicago: Univ. Chicago Press
Ellickson PL, Hays RD, Bell RM. 1992. Stepping through the drug use sequence. *J. Abnorm. Psychol.* 101:441–51
Faedda GL, Baldessarini RJ, Tohen M, Strakowski SM, Waternaux C. 1991. Episode sequence in dipolar disorder and response to lithium treatment. *Am. J. Psychiatr.* 148:1237–39
Fararo TJ. 1993. Generating narrative forms. *J. Math. Sociol.* 18:153–81
Fararo TJ, Skvoretz J. 1984. Institutions as production systems. *J. Math. Sociol.* 10:117–82
Fleming JH, Darley JM. 1990. The purposeful-action sequence and the "illusion of control."*Pers. Soc. Psychol. Bull.* 16:346–57
Forrest J, Abbott A. 1990. The optimal matching method for anthropological data. *J. Quant. Anthropol.* 2:151–70
Foster V, Sprinthall NA. 1992. Developmental profiles of adolescents and young adults choosing abortion. *Adolescence* 27:655–73
Franzosi R. 1990. Computer-assisted coding of textual data. *Soc. Meth. Res.* 19:225–57
French-St.George M, Bregman AS. 1989. Role of predictability of sequence in auditory stream segregation. *Percept. Psychophysics* 46:384–86
Garcia-Colera A, Semjen A. 1987. The organization of rapid movement sequences as a function of sequence length. *Acta Psychol.* 66:237–50
Gardiner P. 1959. *Theories of History*. Glencoe IL: Free Press
Gisiner R, Schusterman RJ. 1992. Sequence, syntax and semantics. *J. Compar. Psychol.* 106:78–91
Grenzebach AP, McDonald JE. 1992. Alphabetic sequence decisions for letter pairs with separations of one to three letters. *J. Exp. Psychol. LMC* 18:865–72
Gribskov M, Devereux J. 1992. *Sequence Analysis Primer*. New York: Freeman
Griffin L. 1993. Narrative, event structure analysis and causal interpretation in historical sociology. *Am. J. Sociol.* 98:1094–133
Griffin LJ. 1993. Introduction to ETHNO. *Contemp. Sociol.* 22:295–96
Gupta JND, Darrow WP. 1986. The two-machine sequence dependent flowshop problem. *Eur. J. Op. Res.* 24:437–46
von Heijne G. 1987. *Sequence Analysis in Molecular Biology*. San Diego: Academic
Heise D. 1989. Modeling event structures. *J. Math. Sociol.* 14:139–69
Heise D. 1991. Event structure analysis. In *Using Computers in Qualitative Research*, ed. N Fielding, R Lee, pp. 136–63. Newbury Park CA: Sage
Hodson FR, Kendall DG, Tautu P, eds. 1971. *Mathematics in the Archeological and Historical Sciences*. Edinburgh: Univ. Edinburgh
Hoel M. 1987. Bargaining games with a random sequence of who makes the offers. *Econ. Letters* 24:5–9
Hopp WJ. 1987. A sequential model of R&D investment over an unbounded time horizon. *Manage. Sci.* 33:500–8
Hue C-W, Erickson JR. 1991. Normative studies of sequence strength and scene structure of 30 scripts. *Am. J. Psychol.* 104:229–40
Hughes E. 1928. *The Growth of an Institution*. PhD thesis, Univ. Chicago
Inhoff AW. 1986. Preparing sequences of saccades under choice reaction conditions. *Acta Psychol.* 61:211–28
Isaac L, Carlson SM, Mathis MP. 1991. *Quality of quantity in comparative historical time series analysis*. Presented at Soc. Sci. Hist. Assoc., New Orleans, 2 Nov 1991
Jones SE, Brain PF. 1985. An illustration of a simple sequence analysis with reference to the agonistic behavior of four strains of laboratory mice. *Behav. Proc.* 11:365–88
Jonz J. 1989. Textual sequence and second-language comprehension. *Lang. Learning* 39: 207–49
Karlin S, Bucher P, Brendel V, Altschul SF. 1991. Statistical methods and insights for protein and DNA sequences. *Annu. Rev. Biophys. Biophys. Chem.* 20:175–203
Kosaka K. 1993. Toward a further analysis of narratives. *J. Math. Sociol.* 18:141–51
Kreps DM, Wilson R. 1982. Sequential equilibria. *Econometrica* 50:863–94
Lamb ME, Malkin CM. 1986. The development of social expectations in distress-relief sequences. *Int. J. Behav. Dev.* 9: 235–49
Latour B, Mauguin P, Teil G. 1992. A note on sociotechnical graphs. *Sociol. Stud. Sci.* 22: 33–57
Laufer B. 1990. Sequence and order in the de-

velopment of the L2 Lexis. *Appl. Linguist.* 11:281–96
Lawrence CE, Altschul SF, Boguski MS, Liu JS, Neuwald AF, Wootton JC. 1993. Detecting subtle sequence signals. *Science* 262: 208–14
Levitt B, Nass C. 1989. The lid on the garbage can. *Admin. Sci. Q.* 34:190–207
Lister C, Leach C, Hill J. 1990. Sequence and structure in the concept development of children with emotional and behavioral difficulties. *J. Genet. Psychol.* 151:287–300
Manderscheid RW, Rae DS, McKarrick AK, Silbergeld S. 1982. A stochastic model of relational control in dyadic interaction. *Am. Sociol. Rev.* 47:62–75
Marks LJ, Kamine MA. 1988. The use of product sampling and advertising. *J. Market. Res.* 25:266–81
Marks LJ, Kamins MA. 1990. The use of product sampling and advertising. *J. Market. Res.* 25:266–81
Mayhew BH, Gray LN, Mayhew ML. 1971. Behavior in interactional systems. *Gen. Syst.* 16:13–29
Mayhew BH, Levinger RL. 1976. On the frequency of oligarchy in human interaction. *Am. J. Sociol.* 81:1017–49
Mays VM. 1986. Developmental sequence in black women's small groups. *Int. J. Small Group Res.* 2:94–99
McBrearty S. 1988. The Sangoan-:upemban and Middle Stone Age sequence at the Muguruk Site, Western Kenya. *World Archeol.* 19:389–420
Meier RC, Johnson RA, Newell WT, Schreiber AN. 1982. Midcentral foods. In *Cases in Production and Operations Management.* Englewood Cliffs NJ: Prentice Hall
Miller LJ, Roid GH. 1993. Sequence comparison methodology for the analysis of movement patterns in infants and toddlers with and without motor delays. *Am. J. Occup. Ther.* 47:339–47
Mishler EG. 1986. The analysis of interview-narratives. In *Narrative Psychology,* ed. TR Sarbin, pp. 233–55. New York: Praeger
Mishler EG. 1990. Validation in inquiry-guided research. *Harv. Educ. Rev.* 60:415–42
Mullen B, Driskell JE, Smith C. 1989. Availability and social projection. *Pers. Soc. Psychol. Bull.* 15:84–90
Nakai T. 1986. An optimal selection problem for a sequence with a random number of applicants per period. *Op. Res.* 34:478–85
Natsopoulos D, Abadzi H. 1986. Understanding linguistic time sequence and simultaneity. *J. Psycholinguist. Res.* 15:243–73
Ney PG. 1987. The treatment of abused children. *Am. J. Psychother.* 41:391–401
Oliver PE. 1993. Formal models of collective action. *Annu. Rev. Sociol.* 19:271–300
Oppenheimer L, DeGroot M. 1985. Construction and reconstruction of social event sequences. *Psychol. Rep.* 56:511–18
Oppenheimer L, Lee HVD. 1983. Social perspective taking and event sequences. *Psychol. Rep.* 53:683–90
O'Rand AM, Krecker ML. 1990. Concepts of the life cycle. *Annu. Rev. Sociol.* 16:241–62
Padgett J. 1981. Heirarchy and ecological control in federal budgetary decision making. *Am. J. Sociol.* 87:75–129
Park O-C, Tennyson RD. 1986. Computer-based response-sensitive design strategies for selecting presentation form and sequence of examples in learning of coordinate concepts. *J. Educ. Psychol.* 78:153–58
Parker KCH. 1988. Speaking turns in small group interaction. *J. Pers. Soc. Psychol.* 54: 965–71
Peake PK, Cervone D. 1989. Sequence anchoring and self-efficacy. *Soc. Cognition* 7:31–50
Pittenger DJ, Pavlik WB, Flora SR, Kontos J. 1988. Analysis of the partial reinforcement extinction effect in humans as a function of sequence of reinforcement schedules. *Am. J. Psychol.* 101:371–82.
Polich J. 1987. Comparison of P300 from a passive tone sequence and an active discrimination task. *Psychophysiology* 24:41–46
Poole MS. 1989. Decision development in small groups. *Hum. Commun. Res.* 15:549–89
Poole MS. 1993. Sequences in decision groups. Ms. Dep. Speech & Commun., Univ. Minn. Minneaplis
Rashevsky N. 1968. *Looking at History through Mathematics.* Cambridge, MA: MIT Press
Read SJ, Druian PR, Miller LC. 1989. The role of causal sequence in the meaning of actions. *Br. J. Soc. Psychol.* 28:341–51
Ricoeur P. 1984–1985. *Time and Narrative.* Chicago: Univ. Chicago Press
Rosenfeld RA. 1992. Job mobility and career processes. *Annu. Rev. Sociol.* 18:39–61
Ryle A. 1991. Object relations theory and activity theory. *Br. J. Med. Psychol.* 64:307–16
Saberwahl R, Robey D. 1993. An empirical taxonomy of implementation processes based on sequences of events in information system development. *Org. Sci.* 4:548–76
Sampson RJ, Laub JH. 1993. *Crime in the Making.* Cambridge: Harvard Univ. Press
Sankoff D, Kruskal JB. 1983. *Time Warps. String Edits, and Macromolecules.* Reading MA: Addison-Wesley
Schank R, Abelson R. 1977. *Scripts Plans, Goals and Understanding.* Hillsdale NJ: Lawrence Erlbaum
Scott JK. 1992. Exploring socio-technical analysis. *Soc. Stud. Sci.* 22:59–80
Shaw C. 1930. *The Jackroller.* Chicago: Univ. Chicago Press

Skvoretz J, Fararo TJ. 1989. Action structures and sociological action theory. *J. Math. Sociol.* 14:111–37

Staw BM, Ross J. 1989. Understanding behavior in escalation situations. *Science* 246:216–20

Stewman S. 1976. Markov models of occupational mobility. *J. Math. Soc.* 4:201–45, 247–78

Stoltman JJ, Gentry JW, Anglin KA, Burns AC. 1990. Situational influences on the consumer decision sequence. *J. Bus. Res.* 21:195–207

Stovel K. 1994. The structure of lynching. Ms. Dep. Sociol. Univ. N. Carolina, Chapel Hill

Terrace HS. 1986. Positive transfer from sequence production to sequence discrimination in a nonverbal organism. *J. Exp. Psychol. ABP* 12:215–34

Thrasher FM. 1927. *The Gang*. Chicago: Univ. Chicago Press

Tolstoy P, DeBoer WR. 1989. An archeological sequence for the Santiago-Cayapas River basin, Esmeraldas, Ecuador. *J. Field Archeol.* 16:295–308

Trabasso T, Nickels M. 1992. The development of goal plans of action in the narration of a picture story. *Discourse Proc.* 15:249–75

Treisman M, Williams TC. 1984. A theory of criterion setting with an application to sequential dependencies. *Psychol. Rev.* 91:68–111

van Leeuwen C, Bufart H, van der Vegt J. 1988. Sequence effects on the organization of meaningless serial stimuli. *J. Exp. Psychol.* 14:481–502

Vasudev J, Hummel RC. 1987. Moral stage sequences and principled reasoning in an Indian sample. *Hum. Dev.* 30:105–118

Vickers J. 1986. The evolution of market structure when there is a sequence of innovations. *J. Indust. Econ.* 35:1–12

Vingron M, Waterman MS. 1994. Sequence alignment and penalty choice. *J. Mol. Biol.* 235:1–12

Vucinich S. 1984. Sequencing and social structure in family conflict. *Soc. Psychol. Q.* 47: 217–34

Wagner RA. 1983. On the complexity of the extended string-to-string correction problem. In Sankoff & Kruskal 1983, pp. 215–35

Waterman RW, Oppenheimer BI, Stimson JA. 1991. Sequence and equilibrium in congressional elections. *J. Polit.* 53:372–93

Weintraub S, Baer MD. 1992. The interplay beween economic and political opening. *Wash. Q.* 15:187–201

White HC. 1970. *Chains of Opportunity*. Cambridge: Harvard Univ. Press

Winn W. 1988. Recall of the pattern, sequence, and names of concepts presented in instructional diagrams. *J. Res. Sci. Teach.* 25:375–86

Wold AH, Reinvang I. 1990. The relation between integration, sequence of information, short-term memory and token test performance of aphasic subjects. *J. Commun. Disord.* 23:31–59

Wyer RS, Shoben EJ, Fuhrman RW, Bodenhausen GV. 1985. Event memory. *J. Pers. Soc. Psychol.* 49:857–77

Yamaguchi K. 1991. *Event History Analysis*. Newbury Park CA: Sage

Zhang K, Shasha D. 1989. Simple fast algorithms for the editing distance between trees and related problems. *SIAM J. Comput.* 18: 1245–62