

Population Structure, Cultural Transmission, and Frequency Seriation

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The task of physics is not to answer a set of fixed questions about nature. . . . We do not know in advance what are the right questions to ask, and we often do not find out until we are close to an answer.

Weinberg (1997:215)

It is not that sociologists are studying the wrong things, but rather that they are studying them in the wrong ways. . . . the major reason for this appears to be the way in which sociologists have chosen to conceptualize the phenomena of interest to them.

Willer and Webster (1970: 748)

INTRODUCTION

Rather than being theory-driven, archaeological inquiry has been modeled, albeit often unconsciously, from our own social experiences. In the United States, this basis has

been augmented by ethnographic lore and anthropological theory. The Americanist archaeological literature, consequently, testifies to a long flirtation with the definition of "whole cultural" units comparable to "culture" or "society" as used by sociocultural anthropologists, units themselves not far removed from their vernacular counterparts. Variations of these units include "ethnic groupings" (e.g., Holmes 1903; Cordell and Yannie 1991), "cultures" (e.g., Rouse 1939, 1955), "phases" (e.g., Chapman 1989; Krause 1977; Lehmer 1966, 1971; McKern 1939; Phillips 1970; Phillips and Willey 1953; Williams 1954, 1980; Willey and Phillips 1955, 1958), "provinces" (e.g., Cordell and Plog 1979; Plog 1979, 1983), and "polities" (e.g., Hammond 1972; King and Freer 1995; Peregrine 1991, 1992, 1995; Upham 1982, 1983; Upham *et al.* 1981; Upham and Plog 1986). While

anthropological interpretations dominate the use of these units, all are *defined by* and rest upon similarities and differences between archaeological assemblages. What all of these formulations have in common is an attempt to capture patterns of interaction.

The Midwestern Taxonomic Method (hereafter MTM), which created a set of five scaled units (component, focus, aspect, phase, pattern, and base) on the basis of phenetic similarity (e.g., Sokal and Sneath 1963) between components (more or less homogeneous assemblages) (e.g., Dunnell 1971; Krause 1977; Trigger 1989), was an early attempt to replace ethnographic-based cultural units with archaeological ones (McKern 1939). Relations between units were ahistorical in consequence of employing an *ad hoc* set of set of "traits" to assess similarity and were so recognized by the architect (McKern 1939). As chronological data became available, the MTM was replaced by the nonhierarchical and decidedly historical system of Phillips and Willey. Of the units proposed, Phillips and Willey's phase is the most widely employed cultural unit with both spatial and temporal components (Chapman 1989; Phillips 1970; Phillips and Willey 1953; Willey and Phillips 1955, 1958; Williams 1954).

The phases of the central Mississippi river valley have their roots in the Lower Mississippi River Valley Survey conducted by Phillips, Ford, and Griffin (1951; hereafter, PFG) in the 1940s. The analytic focus of the PFG study is a series of seriations constructed by Ford. Similarity was assessed by a set of historical types based on types explicitly created by Ford (1936) to measure time. Because spatial variation in frequencies of historical types was sufficiently large that no single seriation could be constructed for the entire survey area, Ford had to divide the Mississippi river alluvial valley into a series of "local areas" (St. Francis, Memphis, Upper Sunflower, Lower Arkansas, Lower Yazoo). These local areas were analytic contrivances, not archaeological discoveries (*cf.* Ford 1952). Ford took a materialist approach

which contrasted starkly with the essentialist position of Griffin and Phillips. This position led Ford to break with his co-authors and analyze spatial variability quantitatively in the lower Mississippi valley data in a separate publication (1952).¹ Ford capitulated to his co-authors on the matter of time and broke the continuous sequence of events represented by seriation into a series of chronological periods compatible with an essentialist view. The combination of periods and local areas supplied the archetype for the phase (Phillips and Willey 1953; Willey and Phillips 1955, 1958; compare PFG and Phillips [1970] for a concrete example).

Williams (1954) was first to apply the Willey and Phillips system anywhere and did so in the Mississippi valley. Phillips' study (1970) has had the greatest impact on the area because he defined phases for the entire chronological sequence over the whole of the Mississippi river alluvial valley. Given this history it is not surprising that "phase" has been the dominant whole cultural unit used to describe the archaeology of the central Mississippi river valley (e.g., House 1991, 1993, 1995; D. Morse 1973, 1982, 1989, 1990; Morse and Morse 1983, 1996; P. Morse 1981, 1990; Smith 1990).

Although rooted strictly in measures of artifact similarity, archaeologists quickly gave phases ethnographic meanings. Even though phases, for example, are explicitly defined as "an archaeological unit possessing traits sufficiently characteristic to distinguish it from all other units similarly conceived, whether of the same or other cultures or civilizations, spatially limited to order of magnitude of a locality or region and chronologically limited to a relatively brief period of time" (Willey and Phillips 1958:22). Although it has been routinely suggested that "the equivalent of phase . . . ought to be 'society'" (Willey and Phillips 1958:49, italics ours; Rouse [1955] expresses

¹ This is why, one suspects, that Ford's types in PFG have become the standard (O'Brien 1996) instead of Phillips' (1970) more detailed types published later.

a similar view though with different terminology), early workers tended to be more cautious about the culture/phase equivalence (e.g., Abbot 1972; McKern 1939; Willey and Phillips 1953) and realized that such equivalencies were accidental rather than structural. Pressure to be "anthropological" has tended to overwhelm such wisdom in many areas, including the central Mississippi river valley. Here, many archaeologists treat archaeological phases as if they are the material manifestations of ethnic, political, or linguistic units. Recent central Mississippi River valley research has often focused on relating these phases to historical groups (e.g., Brain 1978, 1985; Hudson 1985; Morse and Morse 1983, 1990, 1996; Phillips 1970; Phillips *et al.* 1951; Rouse 1965; Phillips and Willey 1953; *cf.* Abbot 1972). Not surprisingly, there is little discussion regarding their definition (e.g., Eighmy and LaBelle 1996:56). Indeed, Phillips, one of the main proponents of the phase concept, candidly admits that the procedures for constructing phases are "regrettably non-objective" (1970: 523).

Still more recently, phase formulations and interpretations of central Mississippi river valley archaeology based on them have been criticized as too simplistic. It has been argued that neither ethnic, political, or linguistic units have straightforward analogs in artifact distributions (Fox 1992, 1998; House 1991; Mainfort 1995; O'Brien and Fox 1994). Mainfort (1995), for example, has proposed that while "some previously-defined late period phases represent relatively valid units (i.e., statistically reproducible), while others are much less robust, and some simply do not exist." Other reanalyses suggest that phases may have very little empirical basis. Fox (1998; also 1992; O'Brien and Fox 1994) have demonstrated that phases such as those created by Williams (1954) have no defining characteristics and cannot be considered classes (i.e., there are no necessary and sufficient conditions for membership). At the same time, cluster analysis of the

ceramics frequencies used to place assemblages particular phases show that phases are not groups (i.e., the members of one phase are not more similar to members of the same group than they are to members of others).

While particular formulations may be defective because of empirical mistakes (Fox 1992), a good deal of the problem arises through the grouping legacy inherited from the MTM. Indeed, outside the Mississippi valley many phases are just renamed foci. Through Ford's work (1935a, 1935b, 1936a, 1936b, 1938) the Mississippi alluvial valley already had a budding chronology by the mid-1930s and thus the ahistorical focus never opened a foothold in this region (Dunnell 1996). To the extent that phases are actually groups (instead of classes) the generation of new data (ceramic assemblages) *requires* the reassessment of similarity between all assemblages, not just the new ones. This was never done; *ad hoc* extensional definition was used to assign new data to old names (Dunnell 1971). Thus the "phases" of the Mississippi alluvial valley quickly lost their coherence and rationale, producing the mess documented by Fox and O'Brien. The degree to which such units "worked" (i.e., displayed time/space contiguity) is a function of the units used in assessing similarity (i.e., ceramic types). So long as stylistic (i.e., historical or neutral [Dunnell 1981]) traits dominated in the assessment of similarity, phases would necessarily display time/space contiguity. Because phases create boundaries regardless of the structure of the archaeological record, phases, their locations and distributions, are inappropriate descriptions of the archaeological record when our goal is to study cultural interaction in the past. We must develop new means to describe interaction between populations in space and time.

In their early formulation, cultural historical methods that used homologous similarity were materialist in perspective and thus are a suitable starting point (e.g., Lyman, *et al.* 1997). In particular, seriation measured

continuous variation (Dunnell 1986; Teltser 1995). In the Mississippi valley, Ford's work (e.g., 1935a, 1935b, 1936a, 1936b, 1938), documents the continuous evolution of neutral traits without resort to periodization schemes (e.g., foci or phases). Ford's and most subsequent worker's, interests in seriation were limited to treating it as an empirical dating method. There was no theoretical interest in seriation, i.e., why did seriations deliver chronological information? Spatial variation in class frequencies were usually seen as distortions, as noise confounding the chronological information. Now that progress has been made in understanding the theoretical basis of seriation in evolutionary theory (Dunnell 1982; Neiman 1992; Teltser 1995), the "noise" arising from differences in space becomes a potential source of information on the transmission of homologous traits through space just as its use as a dating method capitalized on the transmission of homologous traits through time.

In this paper, we review the linkage between interaction, measures of homologous similarity, space and time as a prelude to demonstrating the use of neutral traits to map patterns of interaction in the archaeological record. Because the Lower Mississippi Valley Survey data constitute the historical basis for whole cultural units in use in this region and because these data were collected (at least roughly) with the intent of studying homologous similarity, we have reanalyzed PFG's data for their St. Francis and Memphis local areas. We use a modified frequency seriation method designed to examine the effects of space on the structure of homologous similarity. Our findings demonstrate the possibility of understanding interaction history using methods like deterministic frequency seriation, thus allowing us to create group-level units of social interaction.

EVOLUTION, LINEAGES, AND CULTURAL TRANSMISSION

Although some social scientists remain as the last bastion of the pre-and non-Darwin-

ian thought, we simply assume the general applicability of scientific evolution on the basis of arguments made decades ago (e.g., Blute 1979; Dunnell 1978; 1980; Rindos 1980). Consequently, we sketch here only the essential concepts that extend the theory from its nonhuman, noncultural origins (e.g., Darwin 1859). Evolutionary theory explains the differential persistence of traits in living forms, i.e., change. Evolutionary theory is the only *scientific* theory that explains change (why rather than how), so our commitment to evolution arises from a commitment to an empirical epistemological standard, nothing more.

The principal mechanism explaining differential persistence of transmitted variation is *natural selection*. For selection to be operative, not only must variants be transmitted, but at least some of the variants must interact with the environment and do so differentially (i.e., result in difference in fitness.). Such variants are commonly referred to as functional or "adaptive," though the latter term is fraught with undesirable connotations in the human context. It is with this argument in mind that many writers talk about the use of evolutionary theory as taking a "selectionist" approach, but it is entirely inappropriate, however inadvertent, to make such an equation. For decades biologists (Crow and Kimura 1970; Kimura 1977, 1983; King and Jukes 1969) have realized that not all variation results in *differential* interaction with the environment, that viewed from a selectionist perspective, some variation is *neutral*. That does not mean, again as some writers supposed, such variation cannot be explained by evolution, only that it is not explained by selection. Such variation is explained by transmission processes alone or in combination with sampling (e.g., Gulick 1872, 1905; Wright 1931, 1932, 1940, 1948, 1949), processes that are Markovian in nature (Dunnell 1978, 1981; Gould *et al.* 1977).

The extension of evolutionary theory to archaeological phenomena required two additional steps. The first, beginning in the

1950s, was the recognition that an organism's phenotype was not limited by its skin, a view fostered by the museum rather than field study approach taken by biologists prior to this time. Behavior, just as much as bones, constituted phenotypic elements. Indeed, it is even hard to imagine evolution of morphology without behavior—giraffes could never have acquired long necks if they did not try to eat leaves (Wcislo 1989).

The second step, the recognition that culture constituted a second (in addition to genes) mechanism for trait transmission, was facilitated by the first change inasmuch as most morphological traits are transmitted genetically most of the time while many behavioral traits are transmitted culturally, even in animals (Lynch 1996; Payne 1996). Given the dominance of culture in the generation of the human phenotype, it is doubly embarrassing that biologists (e.g., Bonner 1980) were the first to work out these relations. An additional mechanism for trait transmission does not imply a need for additional selective mechanisms as some (e.g., Boone and Smith 1998; Boyd and Richerson 1985; Cavalli-Sforza and Feldman 1981; Durham 1976, 1979, 1990, 1991, 1992; Graves-Brown 1996; Soltis, *et al.* 1995) have assumed. Indeed, positing mechanisms like "cultural selection" seems to be generated by a confusion of folk explanation (our culture's "explanation" for change) with scientific causation.

Since the connection between neutral variation and the archaeological notion of type or historical types was made (Dunnell 1978, 1980, 1982), it has become possible to explain *why* seriation worked as a dating method and why spatial variation was a confounding factor in that environment of use (Dunnell 1982). If stylistic variation were neutral variation, then the temporal distribution of stylistic (historical) types would be unimodal because of the probabilistic structure of transmission (Dunnell 1982). This supposition, originally based on Gould *et al.*'s (1977) observation in biology, has been

confirmed and extended greatly by the work of Neiman (1992, 1995).

Two other components are critical. Dunnell (1970) analyzed Ford's (Phillips *et al.* 1951: 219–223) assumptions for the use of seriation, all of which were phrased as conditions that had to be met by the assemblages to be seriated. Dunnell showed that Ford's "local area" criterion, that all of the assemblages had to come from the same local area was incorrect. The problem that Ford was attempting to solve with the local area notion was an exclusion of space (as distance between assemblages) from influencing assemblage placement in a seriation. Drawing boundaries around local areas was not an appropriate solution because culture trait transmission has, necessarily, both spatial and temporal components.² While one set of stylistic classes applied to a given area might not detect spatial variation, increasing the amount of space or using another more detailed set of classes would include spatial variability even though each analysis used the same set of potsherds. Seriation was not conceived as a theory to explain neutral variations by culture historians like Ford, but as a dating method. As a theory, it was, and is, dynamically insufficient (Lewontin 1974: 6).

The second element must also be understood from this historical perspective. Ford (Phillips *et al.* 1951) also saw that assemblages to be seriated had to be drawn from the same tradition. This was correctly attributed to a condition that the assemblages had to meet but the reasons this should be so are significant. As Dunnell (1970) noted, the only way you could determine whether a group of assemblages did constitute a tradition or not was whether or not they could be seriated. What Ford meant by "tradition" (*cf.* Ford 1954) was that the assemblages being seriated had to be drawn from assemblages that were historically related. In evolutionary terms, this requirement meant that

² And probably why "local area" was never defined and why no procedures for defining such areas were given.

they assemblages must be samples of the same lineage.

Thus, why seriation works (and does not work) is explained by evolutionary theory and the appropriateness of seriation as a tool to explore interaction is clearly warranted. Appropriately expanded, seriation can be used just as easily to delineate lineages from which assemblages are drawn as it has been to arrange those assemblages in chronological order. That expansion is our task here.

To proceed much further, it is useful to start with Neiman's (1995) recent formulation of neutral trait transmission because it rests on simple, credible assumptions. In Neiman's model, all individuals in the population are considered to have equal probability of interaction with each other and the frequencies of traits should behave stochastically due to drift. If this model is translated into a spatial context, it would mean that space imposed no energy costs and that all individuals would, over the long run, interact with each other. In panmictic populations, we would expect that overall similarity between *samples* of individuals from across the space would be similar at any point in time. Such a model is clearly unrealistic, but as Neiman (1990, 1995: Fig. 2) showed, when viewed as relative frequencies, transmitted attributes form unimodal curves of the kind seen in frequency seriation. As Dunnell (1970) notes and as we would expect, this behavior is due to the absence of a spatial component to transmission between individuals in the population.

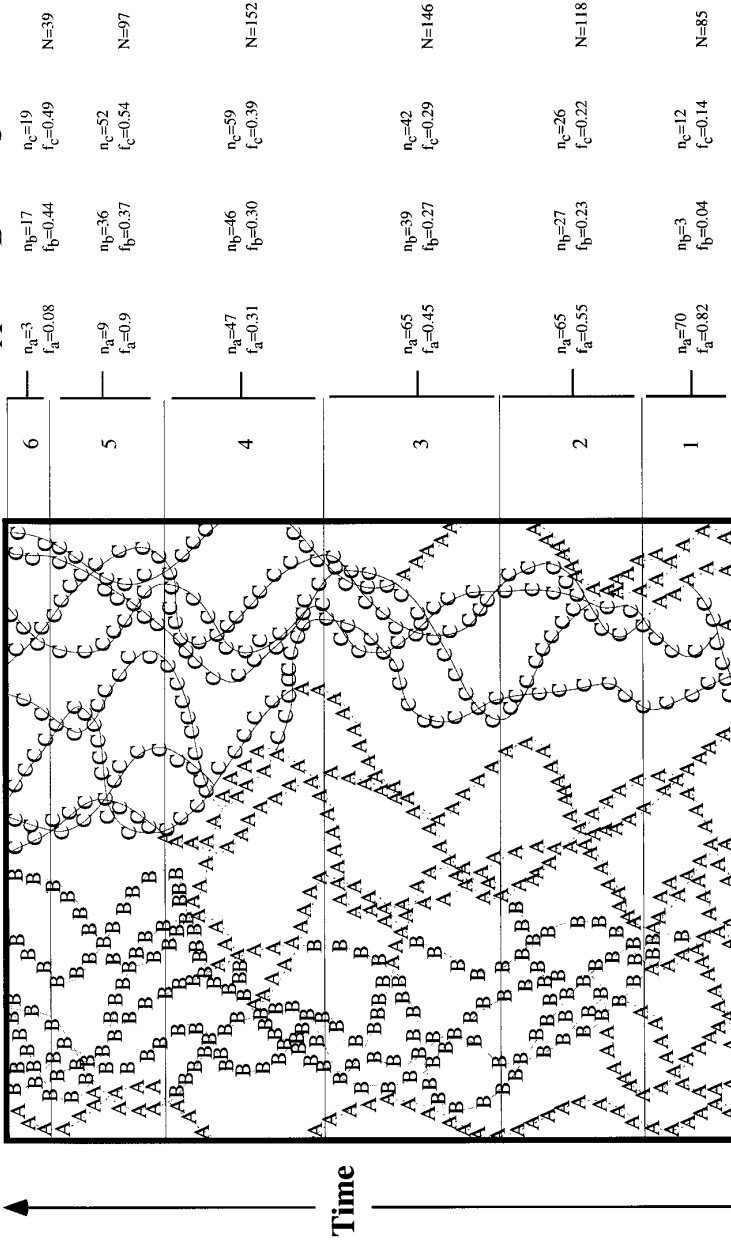
This effect can be most clearly seen by simulating interaction using Neiman's as-

sumptions, allowing individuals to interact over great distances, and accumulating many time slices of such transmission events. Taking a spatial transect through the space and time "cube" of results is illustrated schematically in Fig. 1. Time is displayed on the vertical axis, with the bottom of the figure being the start of the simulation, and space along the horizontal axis. The "threads" traveling from bottom to top are individuals, each displaying the attribute currently held along one of several dimensions such as a letter value. Intersections between threads are, when viewed at a moment in time, interactions between individuals as they move around the space and encounter one another. The result of an interaction can be a switch in traits for both individuals, one individual copies the other's trait, or neither individual changing their original phenotype. Transmission events are depicted, then, by a symbol change in a thread exiting one of these interaction "intersections." Using Neiman's assumptions of global interaction (Fig. 1), we ran a simulation and tabulated the frequencies of three variants for six durations of time, as indicated between the fine horizontal lines. As seen at the right side of the diagram, with no spatial biases on interaction, the frequencies form unimodal series.

In our experiments, we relaxed the assumption of panmixis in several ways—both homogeneously (in the form of a simple distance-decay function [Hagerstrand 1952; Renfrew 1977]) and inhomogeneously (in the form of clumped distributions of individuals in addition to transmission entail-

FIG. 1. Transmission among individuals with different phenotypic traits, labeled A, B, and C, depicted within a uniform population with no spatial restriction on interaction frequency. When individuals encounter each other there is a probability, not predicted by the form of the trait(s), that the individual takes the trait of the other individual. Although in this simulation the frequency of taking a trait was set at 50%, this frequency can also vary in relation to the frequency of the traits (i.e., density-dependent). Individual letters (A, B, C) represent discard events that are aggregated over a period of time into depositional events ("assemblages" 1–6). Trait frequencies are tabulated for each assemblage along the right-hand side. A seriation using these trait frequencies is located at the bottom of the figure. Note that in real cases errors in sampling will yield numbers that do not match the model. Consequently, error terms must be used.

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ing a distance “cost”). Figure 2 depicts a homogenous population with a strong bias towards interaction close to “home,” along with an attribute (A) diffusing through the population from left to right over an appreciable period of time. Again, frequencies are sampled at five points in time marked by horizontal lines. The global frequencies are shown at the bottom, while frequencies in three regions of the transect are shown across the top. It is notable that the regional results show different frequency histories, and different histories of class richness. While all are unimodal (or nearly so, given the effects of sampling), they display peaks and valleys offset from one another, representing the unique history of transmission in a regional population.

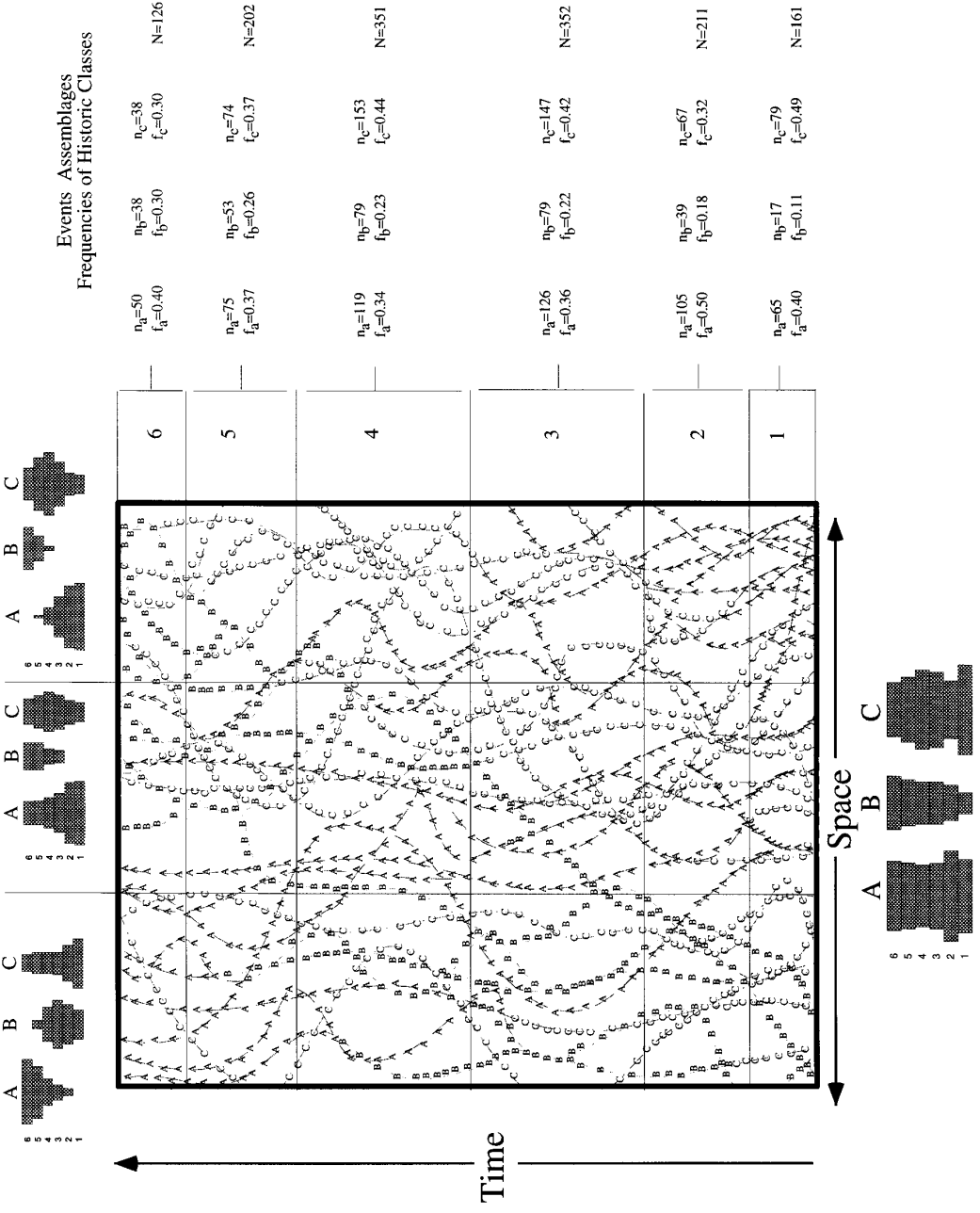
When populations interact differentially across an area and tend to interact within a short radius relative to the entire region, as in Fig. 3, real differences in the rates of interaction between areas of the space and in trait frequencies appear at any moment in time. There is a constant density of individuals in each of the panels, but they vary in the frequency of encounter with others. Even though individuals are uniformly distributed throughout the space, variants will diffuse more quickly through the left and right panels because the interaction frequency is higher, and will take longer to spread through and across the central panel. The same results are seen in Fig. 4 where individuals are unevenly distributed in space and interaction occurs in frequently between the two “clusters.” Despite the similarity of patterns of interaction, these two scenarios are archaeologically distinguishable by studies of the spatial distribution of assemblages. Simulations of Neiman’s (1990, 1995) trans-

mission model with the additions of limited interaction radii and inhomogeneous population distribution yields the kind of behavior we see in real archaeological datasets: areas within which data form unimodal curves, and larger regions of space over which unimodality breaks down because several locally interactive groups have been artificially lumped together. It is for this reason that Ford had to insert his “local area” criterion for seriation.

Importance of Neutrality

An important point not easily captured in simulations or mathematical models of transmission is the effects of selection on the eventual distribution of traits. Most phenotypic attributes have the potential of informing on interaction (Beck 1995), but the degree to which any particular trait is useful for studying interaction at a particular spatial and temporal scale will vary depending upon the strength of evolutionary processes (other than transmission) acting upon the trait. If selection or other evolutionary mechanisms do not act to change trait frequencies, the geographic distribution of the trait through time is determined by the spatial structure of individuals in the environment and the frequency with which individuals encounter each other (which may vary among communities). In other words, under null conditions, the frequency of interaction is equivalent to the spatial structure of the population. Along a dimension of phenotypic variability, attributes that do not affect fitness, and thus whose frequencies are unaffected by selection, are neutral or stylistic (Crow and Kimura 1970; Dunnell 1978; Kimura and Ohta 1971; King and Jukes 1969).

FIG. 2. Transmission among individuals within a uniform population where the probability of interaction is strongly affected by distance. Individuals interact only with local neighbors. In this simulation, trait B moves from left to right through the population. At the bottom of the figure, a seriation that considers the entire space does not meet unimodal expectation of the model. Seriations calculated at the top for spatially limited samples indicated by the vertical lines, however, meet the expectations of the model and form perfect seriations. As mentioned in Fig. 1, real cases require the use of error terms due to the effect of sampling.



Attributes that make either a positive or a negative contribution to individual fitness (functional attributes) will be structured geographically not only by the distribution and connectivity of individuals from lineage to lineage, but by the characteristics of the selective environment. The effects of a change in selective environment on stylistic and functional attributes is depicted in Fig. 5. In the right-hand panel the distribution of two neutral traits with respect to an environmental gradient (solid line) is random; these traits have distributions that are capable of informing on interaction between transmitters. In the left-hand panel the distribution of alternatives is conditioned strongly by the environmental gradient. If we were to use these functional attributes, we might hastily conclude that there is little interaction between the two regions. Thus, in contrast to simulations, in real archaeological cases we must be careful *which* traits we use to delimit lineages.

Heritability and the Seriation Method

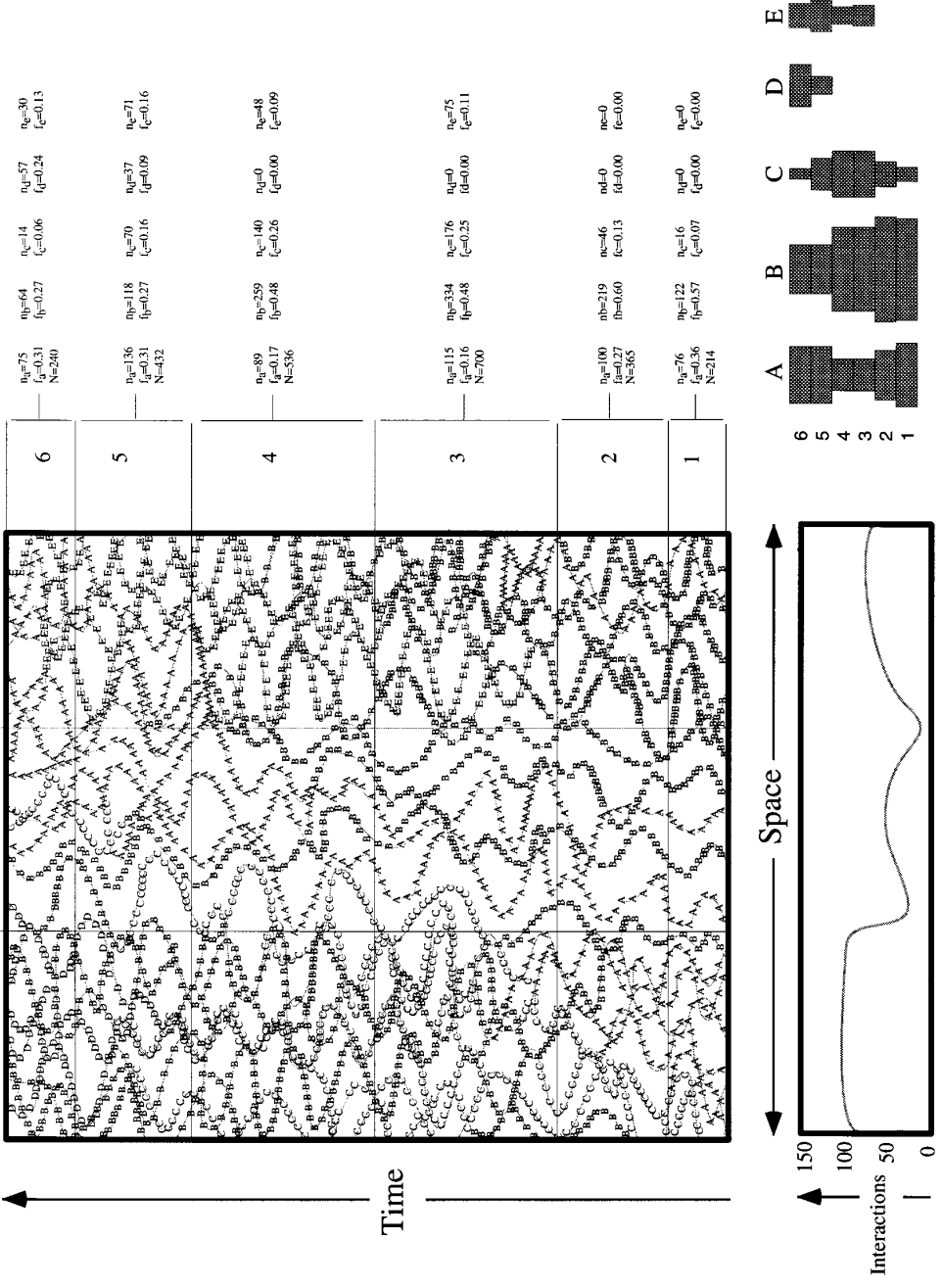
During our simulation experiments, we noted that panmictic populations whose members were free to interact equally over the entire space produced nearly perfect seriations, whereas any restrictions on the radius of interaction would destroy our ability to include the entire test population in one seriation. Frequencies of traits in one area of the simulated population were out of "sync" with frequencies in other regions, preventing any single ordering from yielding a perfect solution. In the absence of independent temporal control over a set of assemblages, we suggest that the *failure* of a set of assemblages to seriate (rather than success) might be exploited to test hypotheses about the history of interaction in a region.

The only difficulty with this notion is the

fact that frequencies of stylistic types in assemblages are more than simply the results of transmission in past populations, but derive their particular character from additional sources: duration, classification, and sampling (Dunnell 1970, 1981; Ford 1949; Phillips *et al.* 1951). As Ford was cognizant of the duration problem, conscious efforts were made in the field to eliminate long duration occupations (Phillips, *et al.* 1951: 219). Minimizing the effect of differences in duration was accomplished by eliminating mixed assemblages or assemblages that were anomalously rich compared to other assemblages that were to be seriated (*cf.* Dunnell 1970). Ford (1949, 1952; Phillips *et al.* 1951) accounted for variability in the frequencies of stylistic types caused by classification by noting that the unimodal character of historical classes when viewed in a seriation was derived from filtering a continuous stream of transmitted information through a classification so that we could count variants. Ford's explanation, however, is incomplete. Unimodality is created both by the stochastic or Markovian character of neutral trait transmission, and by confronting the frequencies of those traits with a set of classes treated as a closed array. If there are many classes forming the closed array, as in a classification with many dimensions or attribute classes per dimension, fine temporal and spatial discriminations can be made (Dunnell 1971). If there are few classes forming the closed array, the resulting discriminations will be coarse in scale. This elementary fact suggests that no single seriation can claim to yield groups of assemblages that comprise a lineage. Rather, seriation can be used to map quantitative changes in the history of regional and local interaction. The method we use involves creating seriations with a nested set of

FIG. 3. Transmission depicted within a population varying in interaction frequency across space. Two "populations" of individuals are apparent in this simulation separated by an area of less frequent interaction. A graph of the frequency of interaction is shown at the bottom.

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classes at variable levels in order to see how interaction changes with level. If interaction is conditioned solely by distance (assuming the types used are strictly stylistic) then varying classification in level should produce differences in how assemblages are group that correspond to changes in spatial "boundaries." If, on the other hand, interactions are structured by barriers (physical or social), spatial boundaries will be reflected in inflections, seemingly unrelated to distance at some classification levels while related to distance at others (Fig. 6). In the remainder of the paper, we explore this notion using data from the Lower Mississippi Valley Survey.

ANALYTIC METHODS AND TECHNIQUES

The common approach to seriation today is a probabilistic technique. In a probabilistic technique some form of matrix ordering algorithm is used to shuffle assemblages until the best fit to a unimodal curve is achieved, and the resulting order accepted as chronological (e.g., Johnson and Nelson 1990; Love 1993; Marquardt 1973). The probabilistic approach is inadequate, as it offers no means of differentiating violations of seriation principles from sampling and measurement error. Probabilistic methods uniformly reduce the frequencies present in data sets to a set of similarity measures, which are scaled according to one or another algorithm. Probabilistic techniques always produce an order, even with data of poor quality because information concerning sampling error is not used. We are particular sensitive to this issue because we are interested in using seriation not as a dating technique but as a means of explaining frequency variation. We reject the probabilistic approach. Consequently, we use a deterministic approach to seriation, accepting only those

assemblages into a particular seriation that fit the unimodal model formed by assemblages already in the seriation, with degrees of freedom in assignment dictated by sampling (Dunnell 1970, 1981, in press).

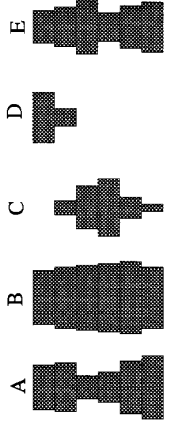
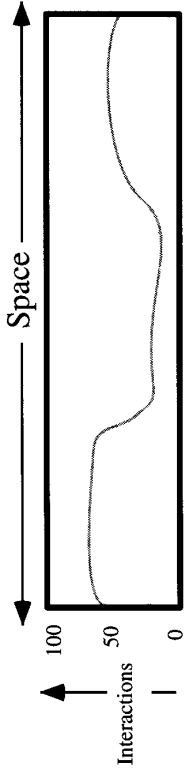
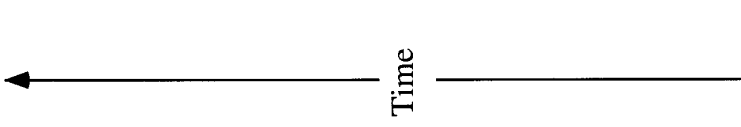
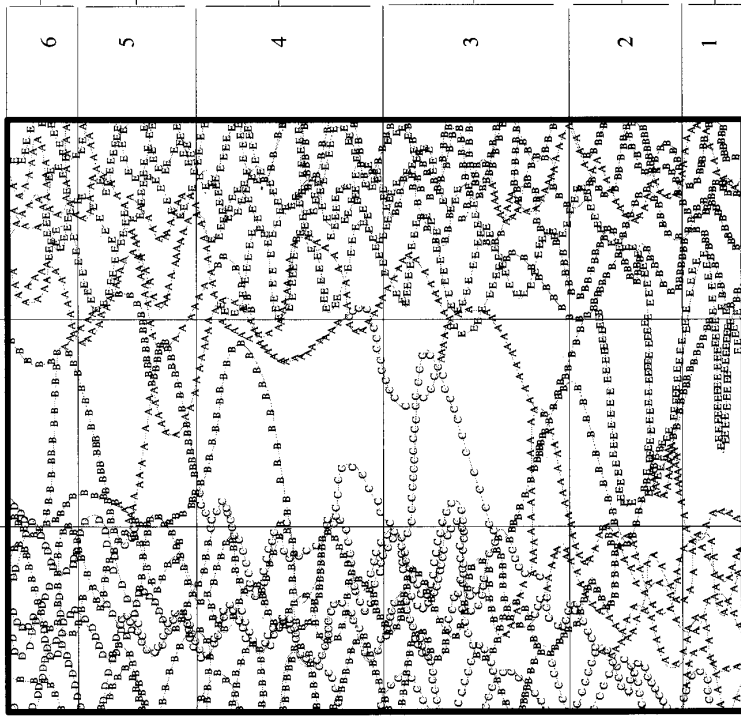
All assemblages are samples of a much larger deposit, and because of this fact comparisons between assemblages must be treated as hypotheses. Error terms are calculated on the basis of sample size. Two approaches to sampling error were used in this analysis. First, because seriation is sensitive to the number of classes present in any assemblage (richness), and it is well known that in "small" assemblages richness may be a function of sample size (Grayson 1989), we examined the effects of assemblage size on the number of classes seen in Lower Mississippi Valley Survey (PFG) assemblages. We wanted to determine whether there were assemblages that were too small to be reasonably included in seriations with the remainder of the PFG seriations (i.e., differentiate "absences" due to sample size rather than population differences). Figure 7 shows plots of assemblage richness versus assemblage size for all assemblages in our study area. This figure demonstrates that while there is the familiar trend of richness increasing as sample size increases, there is also considerable scatter. Usual practice would be to accept any assemblages that fell onto the asymptotic portion of the graph as large enough to have reasonable samples of all classes, but this assumes that all differences in richness are due to the effects of sample size, and excludes possible variation in richness through time or across space. We did not want to exclude these possibilities by concluding that all assemblages with smaller sample sizes and low richness were poor samples, so we used bootstrap methods to examine richness and sample size for each assemblage.

Bootstrapping is a method for evaluating the degree to which a test statistic calculated

FIG. 4. Transmission depicted within a population of varying density across space. Note that the frequency of interaction is the same as in Fig. 5. Archaeologically these scenarios (shown in Figs. 3 and 4) can be distinguished through the study of spatial distributions of assemblages.

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$n_d=49$ $f_d=0.26$ N=192	$n_f=57$ $f_f=0.30$	$n_c=0$ $f_c=0.00$	$n_g=54$ $f_g=0.28$	$n_e=32$ $f_e=0.17$
$n_d=88$ $f_d=0.31$ N=279	$n_f=112$ $f_f=0.27$	$n_c=26$ $f_c=0.16$	$n_g=32$ $f_g=0.09$	$n_e=71$ $f_e=0.16$
$n_d=67$ $f_d=0.13$ N=524	$n_f=182$ $f_f=0.35$	$n_c=24$ $f_c=0.24$	$n_g=0$ $f_g=0.00$	$n_e=151$ $f_e=0.29$
$n_d=84$ $f_d=0.15$ N=548	$n_f=207$ $f_f=0.38$	$n_c=170$ $f_c=0.31$	$n_g=0$ $f_g=0.00$	$n_e=87$ $f_e=0.16$
$n_d=100$ $f_d=0.28$ N=365	$n_f=141$ $f_f=0.29$	$n_c=37$ $f_c=0.10$	$n_g=0$ $f_g=0.00$	$n_e=81$ $f_e=0.23$
$n_d=65$ $f_d=0.34$ N=189	$n_f=64$ $f_f=0.34$	$n_c=7$ $f_c=0.04$	$n_g=0$ $f_g=0.00$	$n_e=53$ $f_e=0.28$



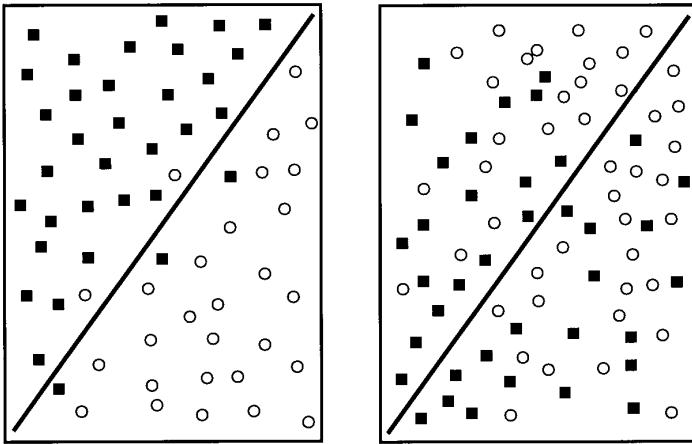
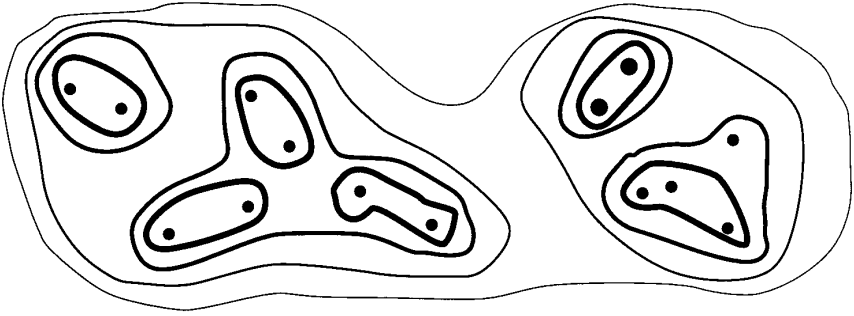


FIG. 5. The effects of a change in selective environment on stylistic and functional attributes. In the right-hand panel, the distribution of two neutral traits with respect to an environmental gradient (solid line) is random; these traits have distributions that are capable of informing on interaction between transmitters. In the left-hand panel, the distribution of alternatives is conditioned strongly by the environmental gradient. Failure to distinguish functional attributes from neutral attributes in the case of the left hand panel indicates that there is little interaction between the two regions. Care must be given when choosing the traits to be used to delimit lineages.

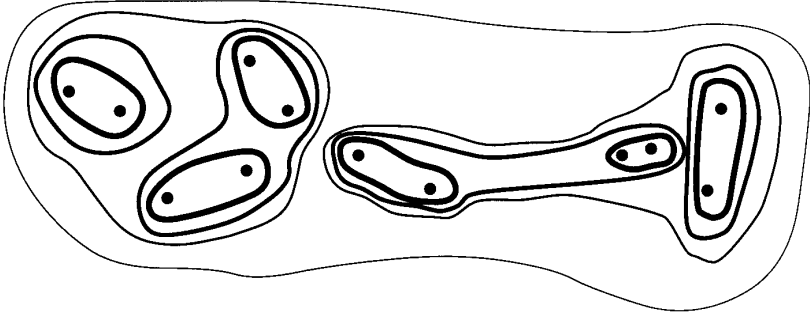
for a particular sample is an estimator of the unknown, underlying population (Berry *et al.* 1980, 1983; Efron 1982, 1983; Efron and Tibshirani 1993; Fisher 1936; Good 1994; Mooney and Duval 1993; Noreen 1989; Simon 1990; Simon and Bruce 1991). The method relies on the creation of a bootstrap distribution of values for the test statistic created by repeatedly resampling from the original data. In our evaluation of richness and sample size, we created a series of richness distributions constructed of randomly drawn resamples that we systematically increased in sample size. For example, with an assemblage of original sample size of 300 we randomly drew 10 sherds with replacement from the original sample and calculated richness. This procedure was repeated 1000 times and a distribution of richness calculated. We then resampled 20 sherds from the original sample and calculated a richness distribution. This process continued with increasing resample sizes until the original sample size was reached. Significant changes in the richness distribution as sample size increased were caused by differ-

ences in sample evenness and hence require greater sample sizes to confidently assess richness. By plotting the mean and variances of the richness distributions, we were able to evaluate the degree to which assemblages had a sufficient sample size to confidently estimate the population richness. We divided the assemblages into three groups (Fig. 8). The first group contained those assemblages that had richness mean and variance values that reached an asymptote with the original sample richness prior to the final sample size. The second group included assemblages that had mean resample richnesses or variances (but not both) that did not approach an asymptote as sample size was increased. Finally, the third group consisted of assemblages that had neither asymptotic mean richness or variance but suggested that increased sampling from the archaeological record would result in significant increases in the number of artifact classes represented.

Finally, when making each seriation attempt, assemblages were added in an iterative fashion, and various orderings treated as a hy-



A: Interaction is biased solely by distance.



B: Interaction is biased by physical or social boundaries.

Similar Assemblage Groups As Measured by:

- 1 Dimension ● Assemblages
- 2 Dimensions
- 3 Dimensions
- 4 Dimensions

FIG. 6. Describing assemblages with a nested set of stylistic classes at variable classification levels permits the examination of how interaction changes with classification level. If interaction is conditioned solely by distance (assuming the types used are strictly stylistic) then varying classification in level corresponds to changes in spatial “boundaries.” Interactions that are structured by physical or social barriers produce spatial boundaries that are detected by inflections in the relationship between distance to classification level. In this hypothetical example, as the number of dimensions in the classification are decreased from four to one, the spatial scales of the resulting groups increase uniformly and are correlated with distance. Using a classification of two or three dimensions, however, consistently produces two spatially coherent groups of assemblages. The disjunction in the measurement of these two assemblage sets cannot be explained by distance and, therefore, may (once sampling and differences in deposition are considered) represent interaction structured by physical or social barriers.

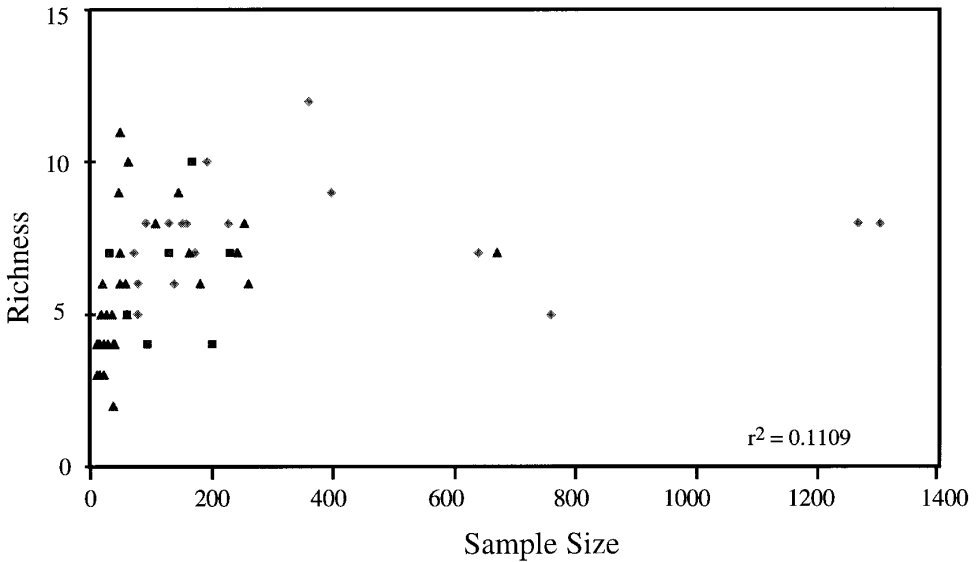


FIG. 7. Relationship of richness and sample size for all PFG assemblages, St. Francis and Memphis area data. The diamond (\blacklozenge), square (\blacksquare), and triangle (\blacktriangle) symbols refer to bootstrap assessed types I, II, and II, respectively.

pothesis test concerning fit to unimodality. Testing the fit involved pairwise comparison of assemblage frequencies using confidence intervals for class frequencies calculated on the basis of sample size following Beals, *et al.*

(1945) method: a normal approximation to a confidence interval for a binomial variable was calculated using a type I error rate of 0.005 (modified from Cochran 1975:57). Assemblages that fit the increasing or decreasing ex-

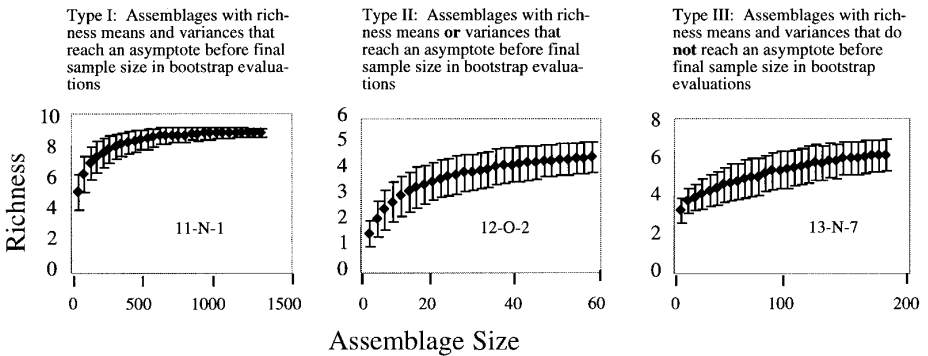


FIG. 8. Bootstrap richness and sample size relationship examples, St. Francis and Memphis area data. Assemblages have been split into three types: Type I, assemblages with richness means and variances that reach an asymptote before final sample size in bootstrap evaluations; Type II, assemblages with richness means or variances that reach an asymptote before final sample size in bootstrap evaluations, and; Type III, assemblages with richness means and variances that do not reach an asymptote before final sample size in bootstrap evaluations. Examining the distribution of the bootstrap assessed types in a standard richness and sample size plot (Fig. 7) demonstrates the limitations of these plots; Type I and Type II assemblages are mixed even at "large" sample sizes. Minimum sample sizes, therefore, must be determined for each sample and a "global" sample size may not necessarily be reliably set.

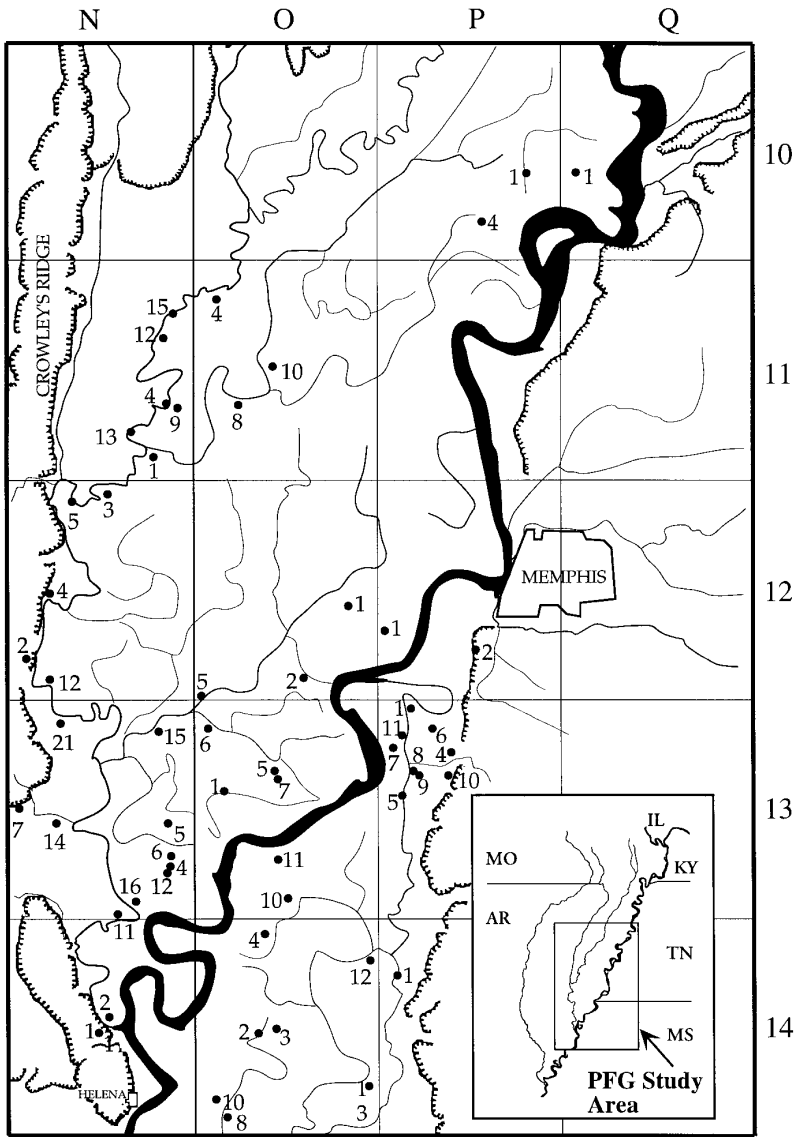


FIG. 9. Map of Lower Mississippi Valley Survey: Assemblages from the St. Francis and Memphis regions from Phillips *et al.* (1951).

peceptions of the unimodal curve model were accepted into a given seriation group and assemblages that did not fit, within calculated confidence limits, were rejected and placed in different groups. Obviously, this technique is not a mechanical algorithm in the spirit of multidimensional scaling but an iterative, operator intensive technique closer to Ford's (1962) approach. We have built a visual interface that allows one to order and reorder assemblages

into various groups while displaying confidence intervals and testing hypotheses of fit to the model.³ All of the seriation results presented here were done using this tool.

³ The program used to perform iterative seriations was written by Tim Hunt as a Visual Basic front-end to Microsoft Excel v.5.0. A version of this program is available at our WWW site: <http://www.emergentmedia.com/archy>.

SOCIAL ORGANIZATION IN THE CENTRAL MISSISSIPPI VALLEY: PFG REVISITED

During the course of Lower Mississippi Valley survey, PFG collected 346,099 sherds from 383 localities. Each of the sherds were tabulated according to culture-historical types that passed the test of historical significance.⁴ Using these tabulated data, Ford constructed five seriations for the study area in order to minimize the effects of geography that were readily apparent in the latest time horizons (Phillips *et al.* 1951: 224). Figure 9 shows the survey area and the location of sites included in these seriations and in our reanalysis. Sites are numbered sequentially on the basis of the 15 minute quadrangle in which they are located.

We were fortunate to be able to examine the original data for the Memphis and St. Francis seriations.⁵ Coded on worksheets in Ford's own hand, the original data are invaluable for modern analyses of these data, containing as they do the actual sherd counts and assemblage sizes. The data included frequencies for both shell- and clay-tempered ceramics, usually interpreted as Mississippian and Woodland, respectively. Woodland materials were not the focus of fieldwork by Phillips and colleagues and were recorded only when found underlying or mixed with the shell-tempered ceramics. Thus, the sample of Woodland materials is problematic even given the actual sherd counts, and in this paper we restrict our analysis to the shell-tempered ceramics.

We excluded plain ceramics from the tabulations (e.g., Neeley's Ferry, Belltown Plain) because the frequency of plain ceramics are biased in three ways. First, seriation measures relative frequency of historical types. The frequency of plain ceramics, on

the other hand, is partly a measure of the *amount* of decoration present in an assemblage. Since in general the level of investment in style must be driven by selection (through differential cost), the spatial and temporal distribution of plain ceramics will be responsive to external conditions, rather than being determined purely by the structure of transmission networks. Second, because decoration is not evenly distributed across individual vessels, the abundance of plain sherds will also be related to the amount of decoration on vessels, and thus breakage will differentially affect the frequency of plain ceramics derived from different vessels. Third, variability in biases between collectors also produces non-comparable assemblages in the frequency of decorated sherds.

We also excluded types that were present in only one assemblage since they do not inform on interaction frequency. In addition, we eliminated excavated assemblages from our analysis. These assemblages typically have idiosyncratic compositions depending upon the particular excavation location due to spatial autocorrelation effects arising from related fragments (Dunnell and Dancey 1983). Since archaeological deposits are rarely, if ever, spatially homogenous, even if described with stylistic (neutral) types (Dunnell 1981), frequencies calculated from spatially limited samples will differ, often greatly, from the frequencies in the assemblage as a whole. As a result, unless refitted (e.g., Newell and Krieger 1949) they cannot be considered to be representative of the entire deposit. Ceramics obtained from the surface, on the other hand, have a greater chance to exhibit representative frequencies due to post-depositional processes, such as plowing, that produce a sample of the entire deposit for inspection by archaeologists.

We began our analyses of the PFG data by examining the solutions produced by Ford for the St. Francis and Memphis areas using only assemblages collected from the surface and tabulating just the decorated, shell-tempered types. These seriations are

⁴ See Krieger (1944), strictly speaking, PFG types are not quite this consistent; Ford types approach this condition.

⁵ The late J. B. Griffin kindly supplied the data sheets to R. C. Dunnell for which we are most grateful.

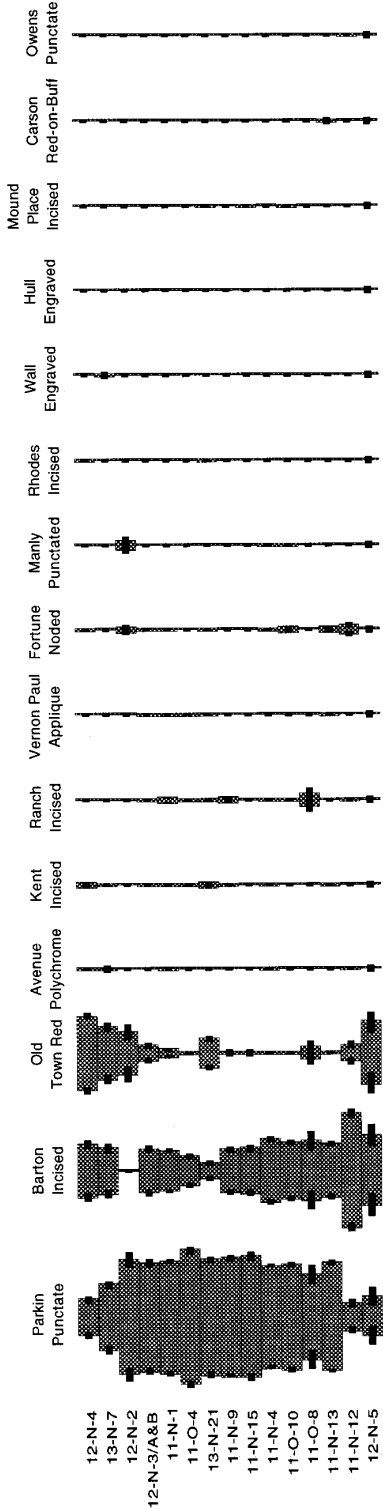


FIG. 10. Ford's seriation of the St. Francis area data using only assemblages collected from the surface and decorated, shell tempered ceramic types.

shown in Figs. 10 and 11. Clearly, there are numerous departures from strict unimodality, some probably caused by sampling error, others from the effects of space or assemblage duration (Dunnell 1970). In the remainder of our analysis, we explore the degree to which these potential effects produce deviations from the expected seriation model.

Seriation and Spatial Structure

Instead of discarding assemblages on the basis of sample size, we broke the assemblages into three groups based on the character of the bootstrap analysis. In Fig. 8, we illustrate each of these groups with a representative bootstrap sampling graph. Conclusions based on the assemblages that meet both the mean and variance criteria thus should be relatively meaningful (all other things being equal), while conclusions based uncritically on all of the assemblages (including the assemblages that met neither the mean nor the variance criteria) should be treated with extreme caution.

We began with all of PFG assemblages and seriated the assemblages into the largest groups possible without allowing violations of unimodality within calculated confidence intervals ($\alpha = 0.05$). If a seriation containing a group of assemblages displayed significant departures from unimodality, the group was broken into two groups each of which was unimodal. Obtaining seriation solutions in this way is an iterative process, involving series of hypothesis tests about particular orderings, and we show only the resulting seriation groups in Fig. 12. The groups shown in Fig. 12 are the largest possible to make within the restriction that departures from unimodality do not occur.

If one maps the assemblages comprising each group, a strong spatial pattern emerges (Fig. 13).⁶ The groups within which assem-

⁶ We can calculate the probability of randomly drawing a spatial cohesive set of assemblages by chance alone as the product of series of combinatorial probabilities where

blages seriate without violations of unimodality are spatially cohesive sets; no seriation sets are comprised of assemblages that are scattered randomly across the region as one might expect if the PFG assemblages were a random sample of a single large interacting population. Neither do many assemblages seem to belong reasonably to more than one group, with the exception Groups 2A and 2B (Fig. 13). Assemblages that belong to more than one seriation set will occur whenever these assemblages are ancestors to other assemblages which have split into two or more distinct lineages or are the product of "hybridization," i.e., coalescence of formerly distinct lineages. The spatial groups of assemblages, to a rough approximation, also resemble the general shapes and positions of culture historical phases, as one might expect. Parkin phase (P. Morse 1981, 1990) corresponds to Groups 2A and 2B, Nodena (D. Morse 1973, 1990) to Group 1, Walls phase (Smith 1990) to Group 5, Kent (House 1991; Smith 1990) to Group 7, and Commerce phase (Smith 1990) to Group 8.

That some correspondence to culture historical phases exists is not surprising, since culture historians were generally interested in delineating populations related by homologous similarity. On the basis of transmission theory as outlined above, however, cul-

ture-historical phases bear a partial relationship to lineages. Some of the spatial cohesion of a phase, in our view, comes from real structure to the interaction history of populations, with the remaining contribution to frequency variation coming from several sources: sampling error (which must be controlled), and the effects of viewing continuous variation through the "filter" of a classification. The ethnographic "groups" of the early historic period, to the extent they have a basis in social interactions are just a fleeting configuration known to us by the virtue of historical accident. As investigative units they lack any theoretical or empirical warrant.

Returning to the seriation groups obtained from using PFG classes with all of the available assemblages (Fig. 13), the question arises, are these groups representations of true discontinuities in interaction frequency, and thus "lineages," or are the groups merely artifacts of sampling and other problems with the PFG data? What are the sources of variability that contribute to the frequencies and spatial patterns seen in the PFG data? We must be able to discount all other sources of variability before we can conclude securely that the groups seen in Fig. 13 might represent the structure of population interaction in the past. If transmission through the region is basically continuous but variable across space, several factors could account for the clumped appearance of assemblages that seriate well together. The first and foremost of these is sampling error. To assess the possibility that sampling error, and in particular changes in richness due to sample size, are affecting the size, position, and inclusiveness of seriated groups, we performed iterative seriations with only those assemblages marked as "good" in bootstrap analysis. These assemblages each have sample sizes at which no new types are found if additional samples are taken, and thus are reliable in their frequency characteristics. The seriation results are presented in Fig. 14 and the geographic distribution of the seriation groups in Fig. 15.

$$p = \frac{1}{\frac{N!}{n_1!(N-n_1)!} * \frac{(N-n_1)!}{n_2!(N-(n_1+n_2))!}} \cdot$$

$$\times \frac{(N-(n_1+n_2))!}{n_1!(N-(n_1+n_2+n_3))!} \dots$$

$$\times \frac{N - \sum_{i=1}^{n-1} n_i!}{n_1!(N - \sum_{i=1}^n n_i!)}$$

N = total number of assemblages, n_i = number of assemblages in the i th group. Using the PFG assemblages that meet the mean and variance criteria, we can calculate that the probability of arriving at this spatially contiguous pattern by chance alone is very small. ($p = 4.011 \times 10^{-12}$).

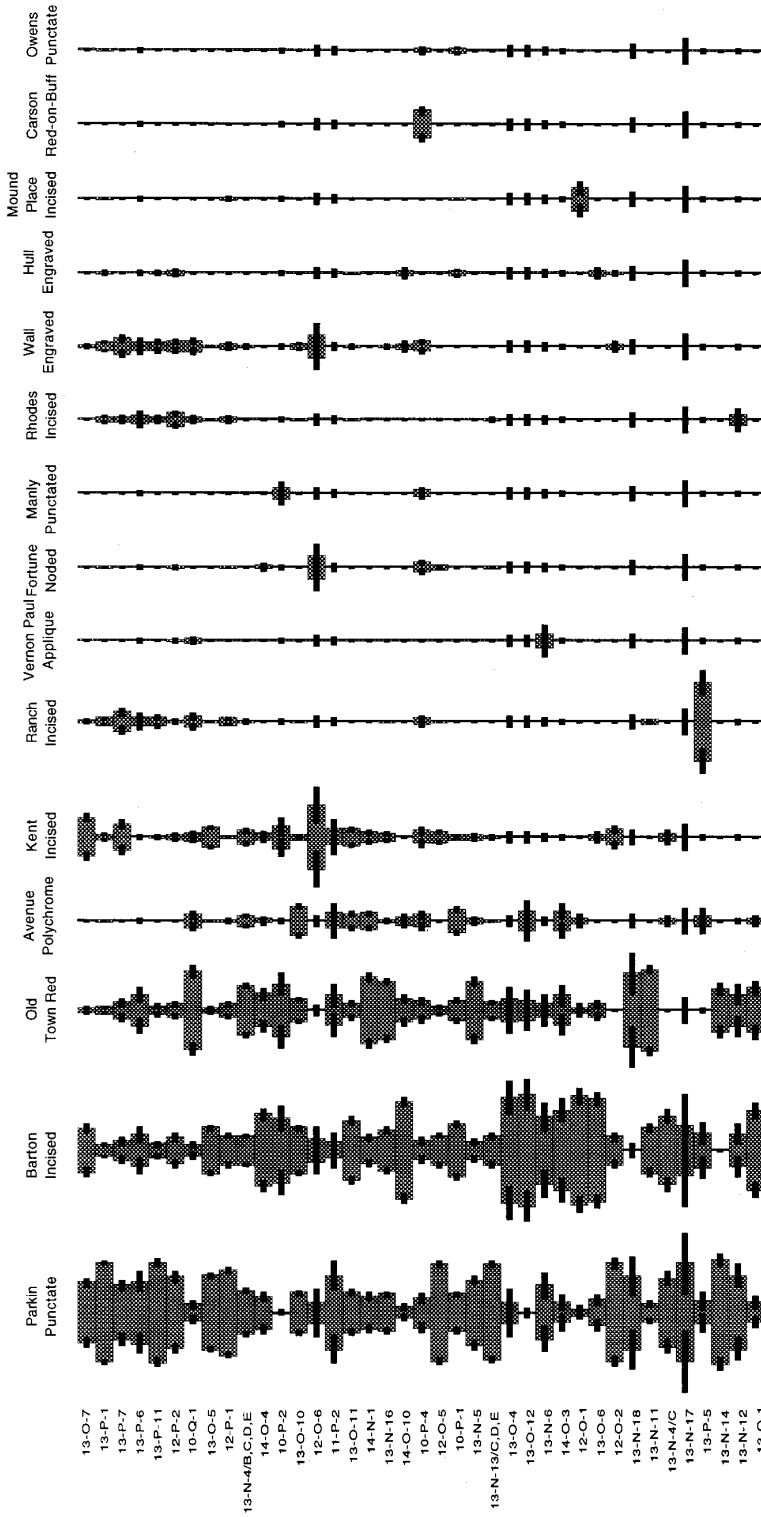


FIG. 11. Ford's seriation of the Memphis area data using only assemblages collected from the surface and decorated, shell tempered ceramic types. It is clear, that the neither the seriations in Fig. 10 nor Fig. 11 meet the expectations of the model.

What is notable about the clusters depicted in Fig. 15 is that the groups are remarkably similar to those presented in the map with all assemblages (Figure 13). Many assemblages were dropped, however, due to sample size problems, making exact comparisons of relationships difficult. Walls Phase (Group 5) sites, for example, show up as a cohesive group that seriate well together, although the relationships between seriation groups and phases becomes less clear in the area traditionally considered to be the Kent (Group 3) and southern Parkin Phase (Group 2) areas. In these areas, the small number of available assemblages may have artificially grouped assemblages from these separate seriation sets together. On the other hand, the phases themselves might be simply arbitrary spatial and temporal slices of an interacting population that is much larger in size (e.g., covering all of 11-N, 12-N, and 13-N, along with some of 13-O). Distinguishing these possibilities, and understanding the relationship of the groups mapped in Fig. 15 to the underlying interaction history of the region, requires that we examine how the groups and seriations viewed thus far are artifacts of the classificatory scheme used in Phillips *et al.* (1951).

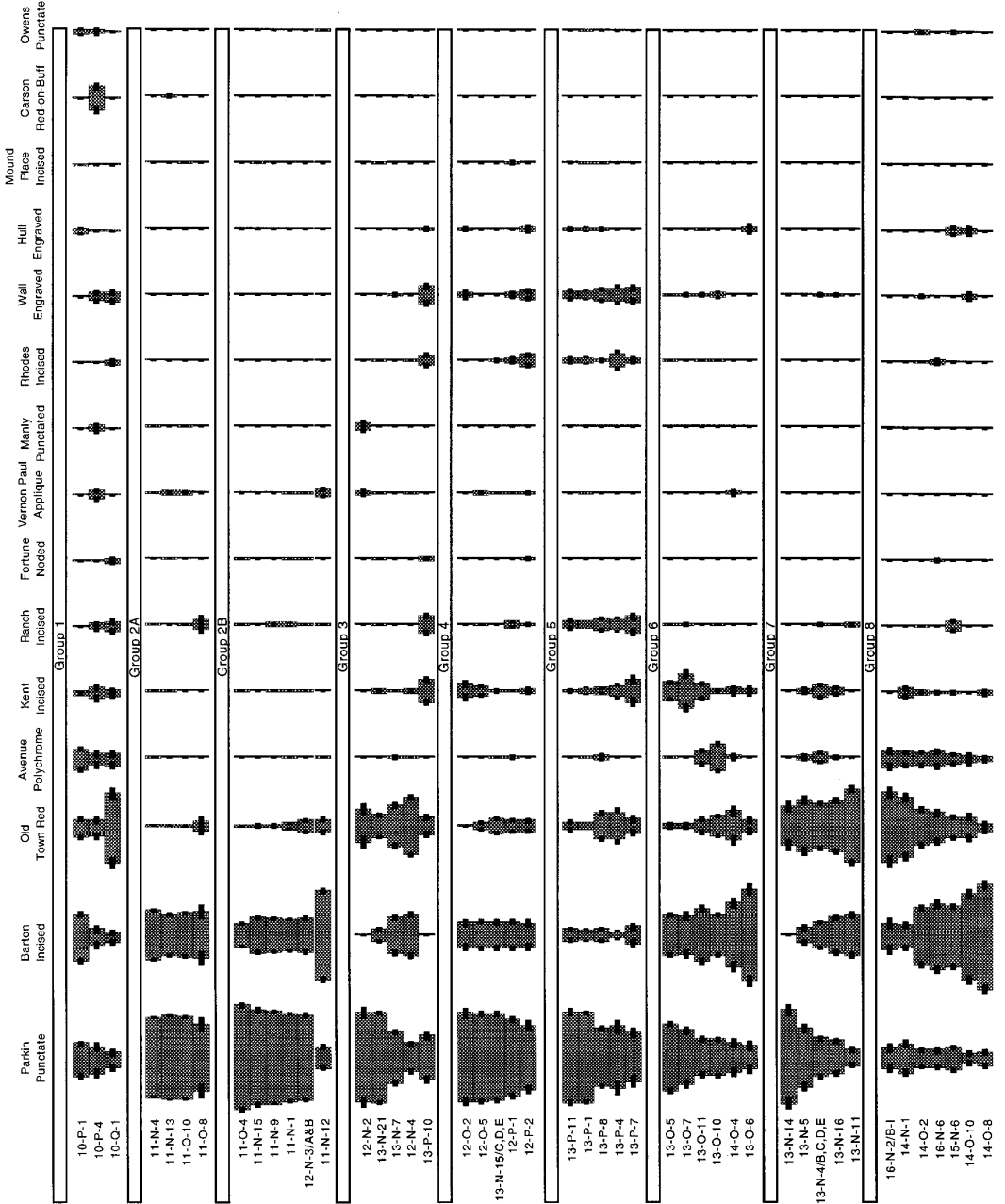
Seriations at Multiple Scales

To understand the effects that classification, and in particular the number of dimensions, has on the size, position, and inclusiveness of seriated groups, it is necessary to perform seriation analyses using a hierarchical series of classifications and, if possible, multiple independent classifications (Dunnell 1970). Ideally, the classifications used will be hybrids and rigorously dimensional in nature (Dunnell 1971), in order that

systematic differences in level can be achieved by simply collapsing dimensions of variability in an orthogonal manner. We were able to only approximate this ideal with the PFG classification. Figure 16 depicts the relationship between the original PFG types, along the top, and two successive levels of collapsing based on ever-more inclusive categories of surface decoration attribute classes. For each set of newly collapsed classes, frequencies for each assemblage were recalculated, and seriations were then done with the two collapsed sets of classes. The spatial distribution of seriations are depicted in Fig. 17.

The effects of changing the level of classification for the PFG assemblages in the direction of coarser classes (fewer dimensions) is to simply create larger groups of assemblages, and in some cases allowing coalescence of formerly separate assemblages into more inclusive groups. The groups formed, however, still retain a great deal of spatial contiguity, suggesting that the possibility exists that the seriations performed here may reflect structure in the interaction history of the region, and thus may map the approximate location of lineages. Should this conclusion turn out to be true, the relationship between "filters" of successive sizes suggests that there are not clear social interaction boundaries in the area but that interaction is widespread and continuous, and that the appearance of discrete communities comes from slicing a continuous range of interaction frequencies using an arbitrary measuring unit for interaction. If social boundaries existed in the patterns of interaction, these should be visible as discontinuities in the relationship between the numbers of dimensions and number of groups as the level of classifica-

FIG. 12. Iterative deterministic seriation solution groups for all PFG assemblages. The eight solutions (1–8) are the largest seriation groups that can be formed and still statistically meet the expectations of the model.



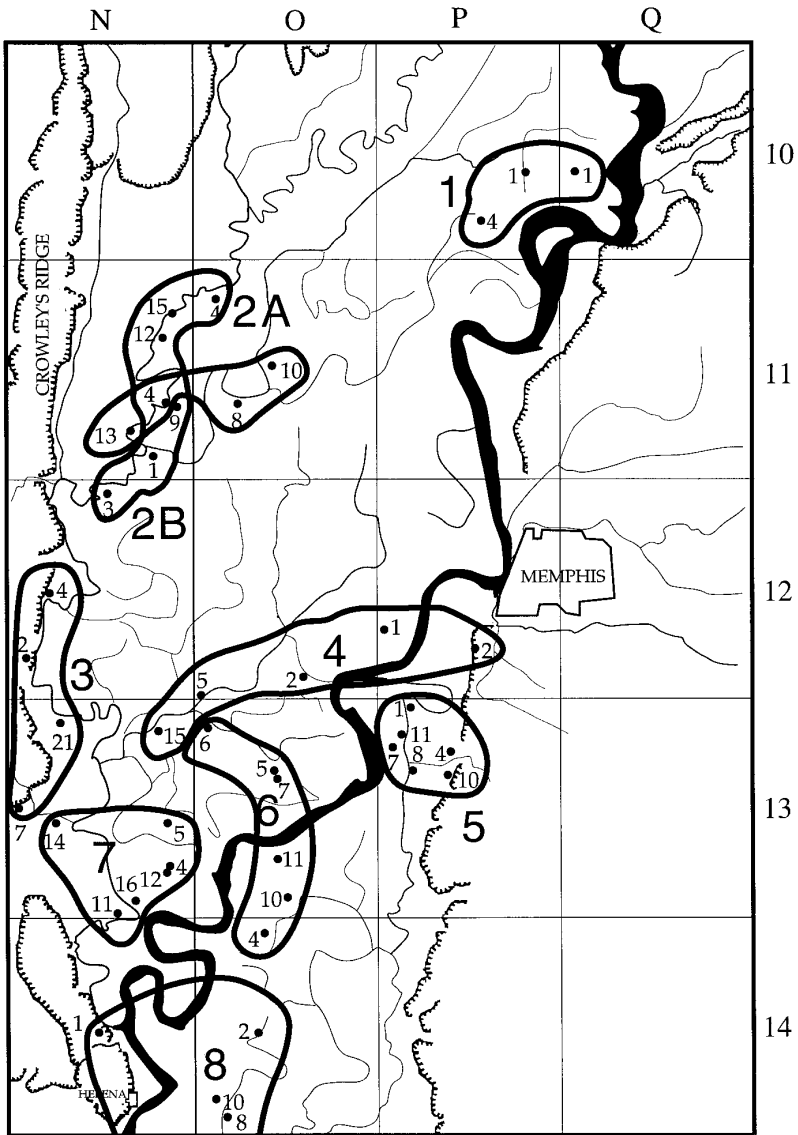


FIG. 13. Geographic distribution of solution clusters of all PFG assemblages. Numbers (1–8) refer to the seriation solutions from Fig. 12.

tion is changed. Differentiating these alternatives will require new, more complex classifications, and much larger sample sizes (Lipo and Madsen 1996) to support the use of such a classification.

SUMMARY

Before we can conclude that the groups of assemblages formed throughout this

analysis reflect interaction history and thus community structure, we must consider less easily controlled sources of variation. For example, we know that Phillips and colleagues (1951) attempted to gain uniform coverage of the study area, but there is a strong possibility given their focus on large, mound sites that a bias exists in the survey data. We cannot, from the PFG data alone, determine whether the seriation groups we

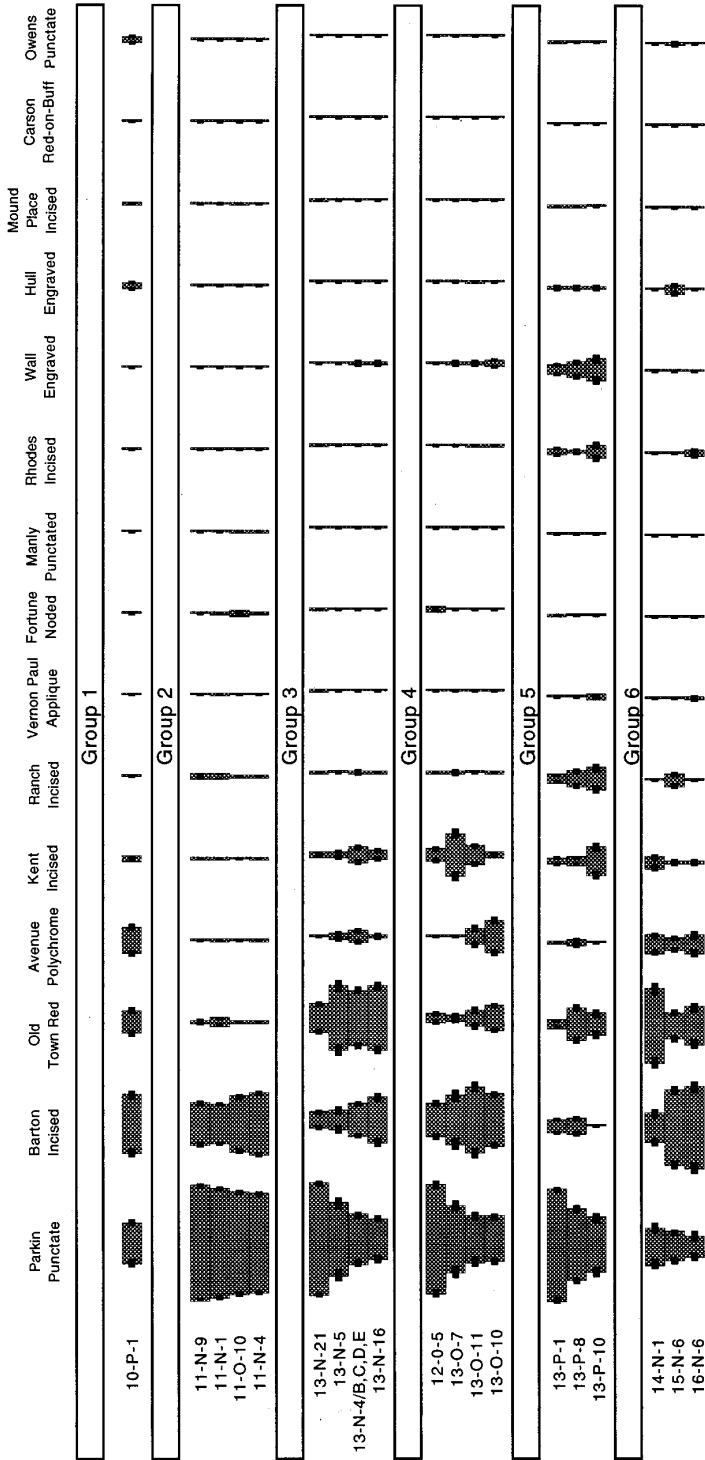


FIG. 14. Seriation solutions of PFG assemblages with sample sizes that meet asymptotic means and variance criteria (Type I) as measured by bootstrap assessment. Six solutions were created (1-6).

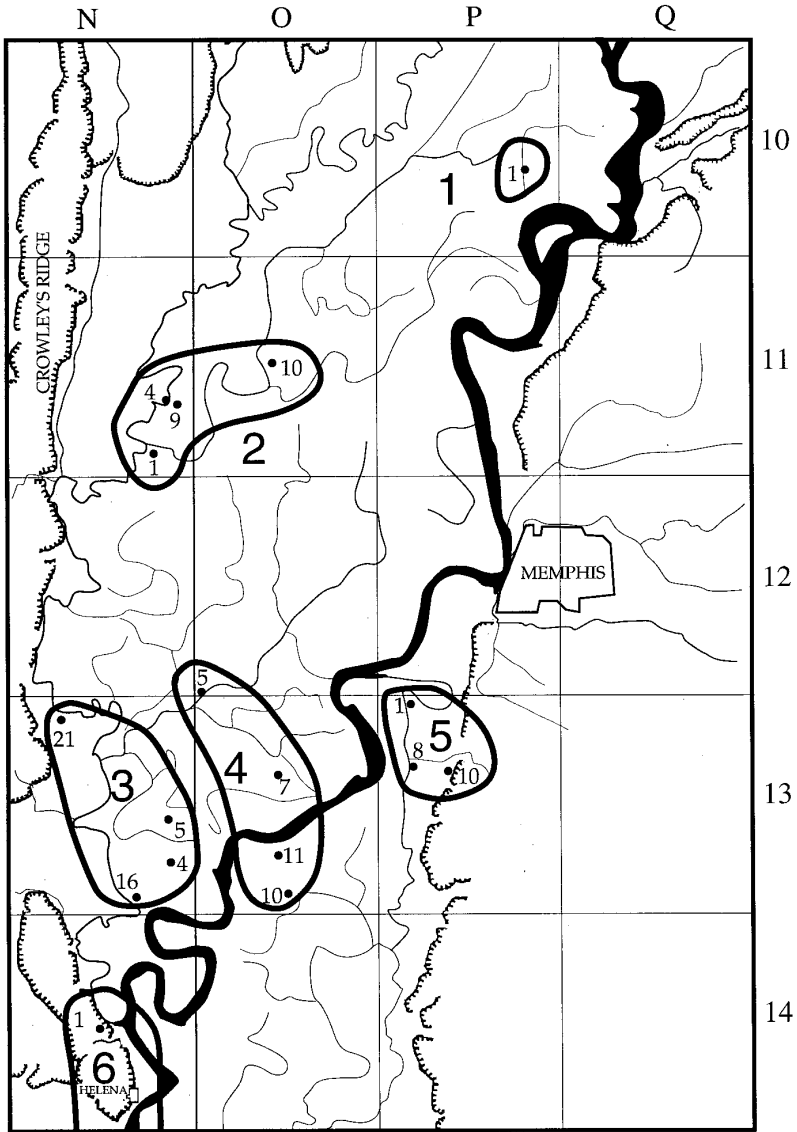


FIG. 15. Geographic distribution of seriation clusters of PFG assemblages that meet the asymptotic means and variance criteria (Type I) as measured by bootstrap assessment.

detected are a reflection of past interaction history or the consequence of simply “missing” assemblages intermediate in space (and in class frequencies) between those analyzed here.

Given the ways in which the fieldwork was done and samples collected, there are also a host of issues concerning comparabil-

ity between PFG assemblages that could explain portions of the variability we see, and thus nullify an interpretation that seriation groups represent lineages intersected by an arbitrary measure of interaction density. Any factor that creates differential representation of ceramic types across several assemblages will potentially structure the distribu-

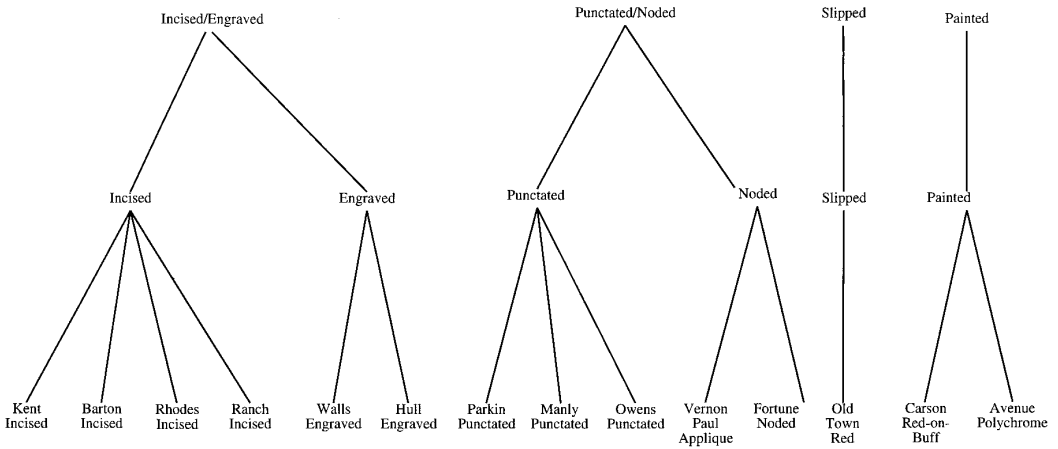


FIG. 16. Three hierarchical levels of classification used to assess effects of classification level on group membership. Here we have aggregated the original PFG types (the bottom level) to create two coarser classification levels.

tion of assemblages across a seriation independently of space or time and thus yield either systematic or random errors in mapped representations of communities. If, for example, assemblages differ in the overall frequency decorated of ceramics (a factor almost certainly under the control of selection), or if differences in settlement patterns or geomorphology create differences in the kinds of sites available in the surface record, some of the variability in class frequencies between assemblages will be due to these factors rather than transmission. Solving these issues requires additional fieldwork in the study area.

Nevertheless, if we can measure the effects of such possibilities using newly collected data to calibrate existing assemblages, we can finally test the hypothesis that the seriation groups discussed here represent lineages or communities measured indirectly via the frequency of interaction. Even if there are serious problems with the comparability of PFG assemblages and frequencies (and there almost certainly are), the fact that the groups outlined here match culture historical phases closely suggests that both culture historical methods and our approach to seriation are measuring interaction intensity at least indirectly.

Our goal has been to examine ways in which archaeologists can create population-scale descriptions of the kind needed for evolutionary explanations. Starting with a simple theory of cultural transmission, we rationalized deterministic frequency seriation as the best method for examining interaction history in the archaeological record. The nature of cultural transmission leads us to expect that lineages will not be discrete bounded entities but anomalously dense clouds of interaction within a background of continuous transmission. As suggested throughout this paper, this fact places enormous data requirements on efforts to detect lineage structure from aggregate frequency data. We found, looking at the large dataset offered by Phillips *et al.*'s Lower Mississippi Valley Survey, that seriation detected clear clusters of assemblages that are spatially coherent, but that explanation of these clusters required many sources of data simply not available from their information. Solving the problems inherent in traditionally collected data such as PFG's is a task that will take many years of dedicated and rigorous work. Our preliminary analyses, however, suggest strongly that the effort will yield val-

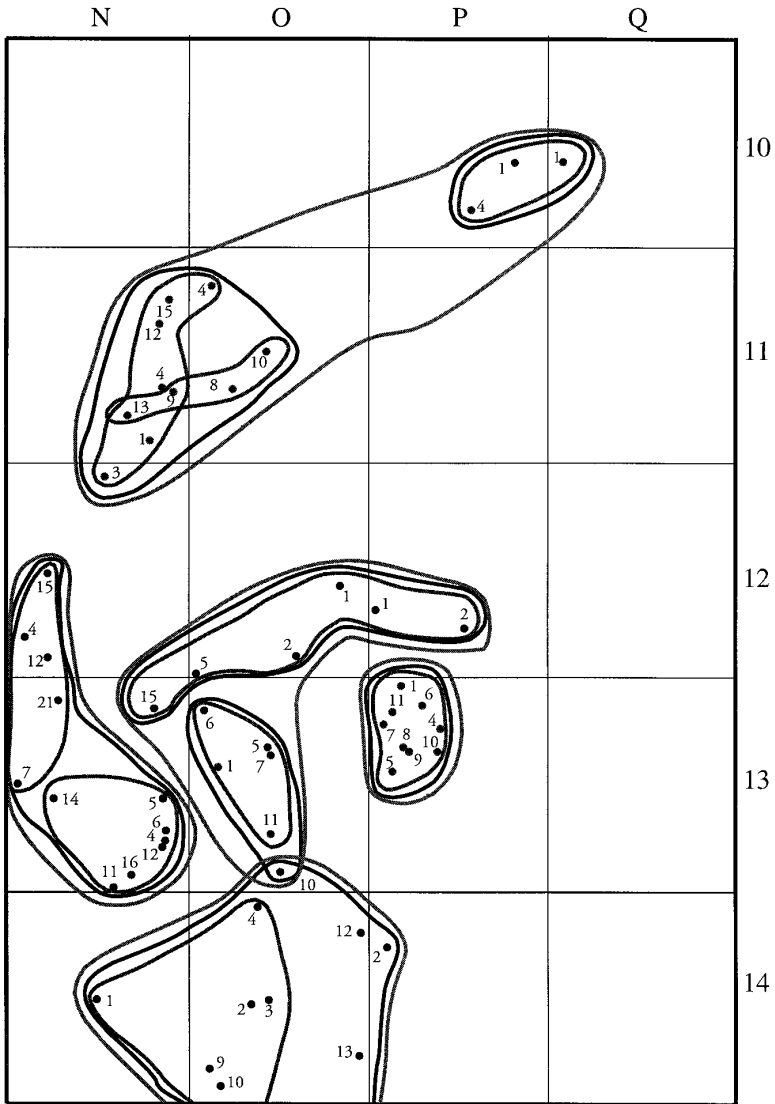


FIG. 17. Geographic distribution of maximal seriation solution clusters of PFG assemblages that meet asymptotic means and variance criteria as measured by bootstrap assessment using three different classification levels specified in Fig. 16. The geographic background has been removed for clarity. The effects of changing the level of classification for the PFG assemblages in the direction of coarser classes (fewer dimensions) is to simply create larger groups of assemblages, and in some cases allowing coalescence of formerly separate assemblages into more inclusive groups. The groups formed retain a great deal of spatial contiguity. This result suggests that the seriations performed here may reflect structure in the interaction history of the region and thus may map the approximate location of lineages. More detailed classifications and larger sample size, however, are needed to confirm this conclusion.

uable results. Although the task is difficult, we are now in a position to see the shape of methods and techniques for de-

fining population-scale units, a critical step in formulating rigorous evolutionary explanations.

REFERENCES CITED

- Abbott, D. N.
1972 The utility of the concept of phase in the archaeology of the southern northwest coast. *Syesis* 5:267-278.
- Beals, R. L., G. W. Brainerd, and W. Smith
1945 Archaeological studies in Northeast Arizona. *University of California Publications in American Archaeology and Ethnology* 44(1).
- Beck, C.
1995 *Style, function, technology, and chronological units*. Paper presented at the 60th Annual Meeting of the Society for American Archaeology, Minneapolis, MN.
- Berry, K. J., K. L. Kvamme, and P. W. J. Mielke
1980 Permutation techniques for the spatial analysis of the distribution of artifacts into classes. *American Antiquity* 45:55-59.
1983 Improvements in the permutation test for the spatial analysis of the distribution of artifacts into classes. *American Antiquity* 48:547-553.
- Blute, M.
1979 Sociocultural evolutionism. *Behavioral Science* 24:46-59.
- Bonner, J. T.
1980 *The evolution of culture in animals*. Princeton University Press, Princeton.
- Boone, J., and E. A. Smith
1998 Is it evolution yet? A critique of evolutionary archaeology. *Current Anthropology* 39(1).
- Boyd, R., and P. J. Richerson
1985 *Culture and the evolutionary process*. University of Chicago Press, Chicago.
- Brain, J. P.
1978 The archaeological phase: Ethnographic fact or fancy? In *Archaeological essays in honor of Irving B. Rouse*, edited by R. C. Dunnell and E. S. Hall, pp. 311-318. Mouton, New York.
1985 Introduction: Update of De Soto studies since the United States De Soto Expedition Commission Report. In *Final report of the United States De Soto Commission*, edited by R. Swanton, pp. xi-xlix. Smithsonian Institution Press, Washington.
- Cavalli-Sforza, L. L., and M. W. Feldman
1981 *Cultural transmission and evolution*. Princeton University Press, Princeton.
- Chapman, C. H.
1989 *The archaeology of Missouri, volume II*. University of Missouri Press, Columbia.
- Cochran, W. G.
1975 *Sampling techniques*. Wiley, New York.
- Cordell, L., and F. Plag
1979 Escaping the confines of normative thought: A reevaluation of Puebloan prehistory. *American Antiquity* 44:405-429.
- Cordell, L. S., and V. J. Yannie
1991 Ethnicity, ethnogenesis, and the individual: A processual approach toward dialogue. In *Processual and postprocessual archaeologies: Multiple ways of knowing the past*, edited by R. Preucel, pp. 96-107. University of Southern Illinois Press, Carbondale.
- Crow, J. F., and M. Kimura
1970 *An introduction to population genetics theory*. Harper Row, New York.
- Darwin, C.
1859 *On the origin of species by means of natural selection, or the preservation of favoured races in the struggle for life*. John Murray, London.
- Dunnell, R. C.
1970 Seriation method and its evaluation. *American Antiquity* 35:305-319.
1971 *Systematics in prehistory*. Free Press, New York.
1978a Archaeological potential of anthropological and scientific models of function. In *Archaeological essays in honor of Irving Benjamin Rouse*, edited by R. C. Dunnell and E. S. Hall. Mouton, The Hague.
1978b *Natural selection, scale, and cultural evolution: Some preliminary considerations*. Paper presented at the 77th Annual Meeting of the American Anthropological Association., Los Angeles, California.
1978c Style and function: A fundamental dichotomy. *American Antiquity* 43:192-202.
1980 Evolutionary theory and archaeology. In *Advances in archaeological method and theory*, edited by M. B. Schiffer, pp. 35-99. vol. 3. Academic Press, New York.
1981 Seriation, groups, and measurement. In *Manejos de Datos Y Methods Matematicos de Arqueologia*, edited by G. L. Cowgill, R. Whallon and B. S. Ottaway. Union Internacional de Ciencias Prehistoricas y Protohistoricas, Mexico DF.
1982 Science, social science and common sense: The agonizing dilemma of modern archaeology. *Journal of Anthropological Research* 38:1-25.
1986 Five decades of American archaeology. In *American archaeology past and future*, edited by D. Meltzer, D. Fowler and J. Sabloff, pp. 23-49. Smithsonian Institution, Washington, D.C.
1996 *Griffin's 'cultural change and continuity': the synthesis of time and space*. Paper presented at the Paper presented at the First Annual G. R. Willey Symposium on the History of Archaeology, 61st Annual Meeting of the Society for American Archaeology, April 1996., New Orleans.

- Dunnell, R. C., and W. S. Dancey
 1983 The siteless survey: A regional scale data collection strategy. In *Advances in archaeological method and theory*, vol. 6, edited by M. B. Schiffer, pp. 267–287. vol. 6. Academic Press, New York.
- Durham, W. H.
 1976 The adaptive significance of cultural behavior. *Human Ecology* 4:89–121.
 1979 Toward a coevolutionary theory of human biology and culture. In *Evolutionary biology and human social behavior: an anthropological perspective*, edited by N. Chagnon and W. Irons, pp. 39–58. Duxbury Press, North Scituate, MA.
 1990 Advances in evolutionary culture theory. *Annual Review Of Anthropology* 19(V19):187–210.
 1991 *Coevolution: Genes, culture, and human diversity*. Stanford University Press, Stanford, Calif.
 1992 Applications of evolutionary culture theory. *Annual Review Of Anthropology* 21(V21):331–355.
- Efron, B.
 1982 *The jackknife, the bootstrap and other resampling plans*. SIAM, New York.
 1983 Computer-intensive methods in statistics. *Scientific American* May:116–130.
- Efron, B., and R. Tibshirani
 1993 *An introduction to the bootstrap*. Chapman and Hall, New York.
- Eighmy, J. L., and J. M. LaBelle
 1996 Radio carbon dating of twenty-seven plains complexes and phases. *Plains Anthropologist* 41(155):53–69.
- Fisher, R. A.
 1936 *Statistical methods for research workers*. Oliver and Boyd, Edinburgh.
- Ford, J.
 1935a Ceramic decoration sequence at an old Indian village site, near Sicily Island, Louisiana. *Louisiana State Geological Survey, Department of Conservation, Anthropological Study* 1.
 1935b An introduction to Louisiana archaeology. *Louisiana Conservation Review* 4(5):8–11.
 1936a Archaeological methods applicable to Louisiana. *Proceedings of the Louisiana Academy of Sciences* 3:102–105.
 1936b *Analysis of Indian village site collections from Louisiana and Mississippi*. Department of Conservation, Louisiana State Geological Survey, Anthropological Study, 2. New Orleans.
 1938 A chronological method applicable to the Southeast. *American Antiquity* 3:260–264.
 1949 Cultural dating of prehistoric sites in Virú Valley Peru. *American Museum of Natural History, Anthropological Papers* 5: 263–266.
- 1952 *Measurements of some prehistoric design elements in the southeastern states* 44. Anthropological Papers of the American Museum of Natural History, New York.
- 1954 The type concept revisited. *American Anthropologist* 56: 42–54.
- 1962 *A quantitative method for deriving cultural chronology*. Technical Manual, No. 1. Pan American Union.
- Ford, J. A., and G. R. Willey
 1941 An interpretation of the prehistory of the Eastern United States. *American Anthropologist* 43: 325–363.
- Fox, G. L.
 1992 *A critical evaluation of the interpretive framework of the Mississippi period in Southeast Missouri*. Unpublished Ph.D. dissertation, Department of Anthropology, University of Missouri-Columbia.
 1998 An examination of Mississippian-period phases in Southeastern Missouri. In *The archaeology of the Central Mississippi River Valley*, edited by R. C. Dunnell and M. J. O'Brien, University of Alabama Press, Tuscaloosa.
- Good, P.
 1994 *Permutation test: A practical guide to resampling methods for testing hypotheses*. Springer-Verlag, New York.
- Gould, S. J., D. M. Raup, J. J. Sepkoski, T. J. M. Schopf, and D. S. Simberloff
 1977 The shape of evolution: A comparison of real and random clades. *Paleobiology* 3(1):23–40.
- Graves-Brown, P.
 1996 In search of the watchmaker: Attribution of agency in natural and cultural selection. In *Darwinian archaeologies*, edited by H. D. G. Maschner, pp. 165–179. Plenum Press, New York.
- Grayson, D. K.
 1989 Sample size and relative abundance in archaeological analysis: Illustrations from spiral fractures and seriation. In *Quantifying diversity in archaeology*, edited by R. D. Leonard and G. T. Jones, pp. 79–84. Cambridge University Press, Cambridge.
- Gulick, J. T.
 1872 On diversity of evolution under one set of external conditions. *Journal of the Linnean Society of Zoology* 11: 496–505.
 1905 *Evolution, racial and habitual*. Carnegie Institution of Washington, Washington, D.C.
- Hägerstrand, T.
 1952 *The propagation of innovation waves*. Royal University of Lund, Dept. of Geography, London.

- Hammond, N.
1972 Location models and the site of Lubaantun: A classic Maya center. In *Models in Archaeology*, edited by D. L. Clarke, pp. 757–300. Methuen, London.
- Holmes, W. H.
1903 *Aboriginal pottery of the Eastern United States*. Bureau of American Ethnology, 20th Annual Report., Washington, D.C.
- House, J.
1991 *Monitoring Mississippian dynamics: Time, settlement, and ceramic variation in the Kent Phase, Eastern Arkansas*. Unpublished Ph.D. dissertation, Department of Anthropology, Southern Illinois University, Carbondale.
1993 Dating the Kent Phase. *Southeastern Archaeology* 12(1):21–32.
1995 *Investigating Mississippian settlement variability in the Lower St. Francis Basin, Eastern Arkansas*. Paper presented at the 52nd Southeastern Archaeological Conference, Knoxville, Tennessee, November 9, 1995.
- Hudson, C.
1985 De Soto in Arkansas: A brief synopsis. *Arkansas Archeological Society Field Notes* 205:3–12.
- Johnson, K. W., and B. C. Nelson
1990 The Utina: Seriations and chronology. *The Florida Anthropologist* 43(1):48–62.
- Kimura, M.
1977 Preponderance of synonymous changes as evidence for the neutral theory of evolution. *Nature* 267:275–276.
1983 *The neutral theory of molecular evolution*. Cambridge University Press, Cambridge.
- Kimura, M., and T. Ohta
1971 *Theoretical aspects of population genetics*. University of Princeton Press, Princeton, New Jersey.
- King, A., and J. Freer
1995 The Mississippian Southeast: A world-systems perspective. In *Native American interactions: Multiscalar analyses and interpretations in the Eastern Woodlands*, edited by M. S. Nassaney and K. E. Sassaman, pp. 266–288. The University of Tennessee Press, Knoxville.
- King, J. L., and T. H. Jukes
1969 Non-Darwinian evolution: Random fixation of selectively neutral mutations. *Science* 164:788–798.
- Krause, R. A.
1977 Taxonomic practice and Middle Missouri Prehistory: A perspective on Donald J. Lehmer's contributions. *Plains Anthropologist, Memoir* 13:5–13.
- Lehmer, D. J.
1966 *Fire Heart Creek site*. Publications in Salvage Archaeology 1. Smithsonian Institution, River Basin Surveys, Lincoln, NE.
- 1971 *Introduction to Middle Missouri Archeology*. Anthropological Papers 1. National Park Service, Washington.
- Lewontin, R. C.
1974 *The genetic basis of evolutionary change*. Columbia University Press, New York.
- Lipo, C. P., and M. E. Madsen
1996 *Problems and solutions in the study of social organization*. Paper presented at the Society for American Archaeology, New Orleans, LA.
- Love, M. W.
1993 Ceramic chronology and chronometric dating: Stratigraphy and seriation at La Blanca Guatemala. *Ancient Mesoamerica* 4:17–29.
- Lyman, R. L., M. J. O'Brien, and R. C. Dunnell
1997 *The rise and fall of culture history*. Plenum Press, New York.
- Lynch, A.
1996 The population memetics of birdsong. In *Ecology and evolution of acoustic communication in birds*, edited by D. E. Kroodsmma and E. H. Miller, pp. 181–197. Cornell University Press, Ithaca, New York.
- Mainfort, R. C.
1995 Cluster analysis and archaeological phases: An example from the Central Mississippi Valley. Paper presented to the Midwest Archaeological Conference, Beloit, Wisconsin, 1995.
- Marquardt, W. H.
1973 Advances in archaeological seriation. *Advances in Archaeological Method and Theory* 1:257–314.
- McKern, W. C.
1939 The mid-western taxonomic method as an aid to archaeological study. *American Antiquity* 4:301–313.
- Mooney, C. Z., and R. D. Duval
1993 *Bootstrapping: A nonparametric approach to statistical inference*. Quantitative Applications in the Social Sciences 95. Sage Publications, New York.
- Morse, D. F.
1973 *Nodena: An account of 75 years of archaeological investigation in southeast Mississippi County, Arkansas*. Arkansas Archeological Survey Research Series, 4, Pine Bluff, Arkansas.
1982 Regional overview of northeastern Arkansas. In *Arkansas archeology in review*, edited by N. L. Trobowitz and M. D. Jeter, pp. 20–36. vol. 15. Arkansas Archaeological Survey Research Series, Fayetteville, Arkansas.
1989 The Nodena phase. In *Nodena: An account of 90 years of archaeological investigation in southeast Mississippi County, Arkansas*, edited by D. F. Morse, pp. 97–113. vol. no. 30. Arkansas Archaeological Survey, Fayetteville, Arkansas.

- 1990 The Nodena phase. In *Towns and temples along the Mississippi*, edited by D. H. Dye and C. A. Cox, pp. 69–97, University of Alabama Press, Tuscaloosa.
- Morse, D. F., and P. A. Morse
 1983 *Archaeology of the Central Mississippi Valley*. Academic Press, New York.
- 1990 The Spanish Exploration of Arkansas. In *Columbian consequences*, edited by D. H. Thomas, ed. Pp. 197–210, Vol. 2. Smithsonian Institution Press, Washington.
- 1996 Northeast Arkansas. In *Prehistory of the Central Mississippi Valley*, edited by C. H. McNutt, pp. 119–135. The University of Alabama Press, Tuscaloosa.
- Morse, P. A.
 1981 *Parkin*. Arkansas Archeological Survey Research Series No. 13, Pine Bluff.
- 1990 The Parkin site and the Parkin phase. In *Towns and temples along the Mississippi*, edited by D. Dye and C. Cox, pp. 119–134. University of Alabama, Tuscaloosa.
- Neiman, F.
 1990 *An evolutionary approach to archaeological inference: Aspects of architectural variation in the 17th-century Chesapeake*. Ph.D. dissertation, Yale University.
- 1992 *Stylistic variation in evolutionary perspective: Implications for Middle Woodland Ceramic diversity*. Paper presented at the 57th Annual Meeting of the Society for American Archaeology, Pittsburgh, PA.
- 1995 Stylistic variation in evolutionary perspective: Inferences from decorative diversity and inter-assembly distance in Illinois Woodland Ceramic assemblages. *American Antiquity* 60(1):7–36.
- Newell, H. P., and A. Krieger
 1949 *The George C. Davis site, Cherokee County, Texas*. Society for American Archaeology and the University of Texas, Menasha, Wis.
- Noreen, E.
 1989 *Computer intensive methods for testing hypotheses*. Wiley, New York.
- O'Brien, M. J.
 1994 *Cat monsters and head pots: The archaeology of Missouri's Pemiscot Bayou*. University of Missouri Press, Columbia.
- O'Brien, M. J., and G. L. Fox
 1994 Assemblage similarities and dissimilarities. In *Cat monsters and head pots: The archaeology of Missouri's Pemiscot Bayou*, edited by M. J. O'Brien, pp. 61–93. University of Missouri Press, Columbia.
- Payne, R. B.
 1996 Song traditions in Indigo Buntings: Origin, improvisation, dispersal, and extinction in cultural evolution. In *Ecology and evolution of acoustic communication in birds*, edited by D. E. Kroodsma and E. H. Miller, pp. 198–220. Cornell University Press, Ithaca, New York.
- Peregrine, P.
 1991 Prehistoric chiefdoms of the midcontinent: A world-system based on prestige goods. In *Core/periphery relations in precapitalist worlds*, edited by C. Chase-Dunn and T. Hall, pp. 193–211. Westview Press, Boulder.
- 1992 *Mississippian evolution: A world-system perspective*. Monographs in World Prehistory 9. Prehistory Press, Madison, Wisconsin.
- 1995 Networks of power: The Mississippian world-system. In *Native American interactions: Multiscalar analysis and interpretations in the Eastern Woodlands*, edited by M. S. Nassaney and K. E. Sassaman, pp. 247–265. University of Tennessee Press, Knoxville.
- Phillips, P.
 1970 *Archaeological survey in the lower Yazoo Basin, Mississippi*. Peabody Museum, Cambridge, MA.
- Phillips, P., J. A. Ford, and J. B. Griffin
 1951 *Archaeological survey in the Lower Mississippi Alluvial Valley, 1940–1947*. Papers of the Peabody Museum of American Archaeology and Ethnology 25. Harvard University, Cambridge.
- Phillips, P., and G. R. Willey
 1953 Method and theory in American archaeology: An operational basis for culture-historical integration. *American Anthropologist* 55:615–33.
- Plog, F.
 1979 Prehistory: Western Anasazi. In *Handbook of North American Indians, Volume 9: Southwest*, edited by A. Ortiz, pp. 109–130. vol. 9. Smithsonian Institution, Washington, D.C.
- 1983 Political and economic alliances on the Colorado Plateaus, A.D. 400–1450. In *Advances in world archaeology*, edited by F. Wendorf and A. Close, pp. 289–330. vol. 2. Academic Press, New York.
- Renfrew, C.
 1977 Alternative models for exchange and spatial distribution. In *Exchange systems in prehistory*, edited by T. K. Earle and J. E. Ericson, pp. 71–90.
- Rindos, D.
 1980 Symbiosis, instability, and the origins and spread of agriculture: A new model. *Current Anthropology* 21:751–772.

- Rouse, I.
 1939 *Prehistory in Haiti*. Yale University Publications in Anthropology 21.
 1955 On the correlation of phases of culture. *American Anthropologist* 57:713–722.
 1965 The place of 'Peoples' in prehistoric research. *Journal of the Royal Anthropological Institute* 95(1–15).
- Scollar, I.
 1995 Bonn archaeological software package. 4.5 ed. Bonn Archaeological Software, Cologne.
- Simon, J. L.
 1990 *Resampling: Probability and statistics in a radically different way*. Unpublished manuscript available from Resampling Project, College of Business, University of Maryland, College Park, MD 20742.
- Simon, J. L., and P. Bruce
 1991 Resampling: A tool for everyday statistical work. *Chance* 4(1).
- Smith, G. P.
 1990 The Walls Phase and its neighbors. In *Towns and temples along the Mississippi*, edited by D. Dye and C. Cox, pp. 135–169. University of Alabama Press, Tuscaloosa.
- Sokal, R. R., and P. H. A. Sneath
 1963 *Principles of numerical taxonomy*. Freeman, San Francisco.
- Soltis, J., R. Boyd, and P. J. Richerson
 1995 Can group-functional behaviors evolve by cultural group selection? An empirical test. *Current Anthropology* 36(3):473–474.
- Teltser, P. A.
 1995 Culture history, evolutionary theory, and frequency seriation. In *Evolutionary archaeology: Methodological issues*, edited by P. A. Teltser, pp. 51–68. University of Arizona Press, Tucson.
- Trigger, B. G.
 1989 *A history of archaeological thought*. Cambridge University Press, Cambridge; New York.
- Upham, S.
 1982 *Politics and power: An economic and political history of the Western Pueblo*. Academic Press, New York.
 1983 Intensification and exchange: An evolutionary model of non-egalitarian socio-political organization for the prehistoric Plateau Southwest. In *Ecological models in economic prehistory*, edited by G. Bronitsky, pp. 219–245. vol. 29. Arizona State University Anthropological Research Papers, Tempe.
- Upham, S., K. G. Lightfoot, and G. M. Feinman
 1981 Explaining socially determined ceramic distribution in the Prehistoric Plateau Southwest. *American Antiquity* 46:822–833.
- Upham, S., and F. Plog
 1986 The interpretation of prehistoric political complexity in the Central and Northern Southwest: Toward a mending of the models. *Journal of Field Archaeology* 13:223–238.
- Weislo, W. T.
 1989 Behavioral environments and evolutionary change. *Annual Review of Ecology and Systematics* 20:137–169.
- Weinberg, S.
 1997 The first elementary particle. *Nature* 386(6632): 213–215.
- Willer, D., and M. Webster
 1970 Theoretical concepts and observables. *American Sociological Review* 35:748.
- Wiley, G. R., and P. Phillips
 1955 Method and theory in American archaeology. II: Historical developmental interpretation. *American Anthropologist* 57:723–819.
 1958 *Method and theory in American archaeology*. University of Chicago Press, Chicago.
- Williams, S.
 1954 *An archaeological study of the Mississippian culture in Southeast Missouri*. Unpublished Ph.D. dissertation, Department of Anthropology, Yale University.
 1980 The Armored Phase: A very Late Complex in the Lower Mississippi Valley. *Southeastern Archaeological Conference Bulletin* 22:105–110.
- Wright, S.
 1931 Evolution in Medelian populations. *Genetics* 16:97–159.
 1932 The role of mutation, inbreeding, crossbreeding and selection in evolution. *Proceedings of the Sixth International Congress of Genetics* 1:356–366.
 1940 The statistical consequences of Mendelian heredity in relation to speciation. In *The new systematics*, edited by J. S. Huxley, pp. 161–184. Oxford University Press, Oxford.
 1948 On the roles of directed and random changes in gene frequency in the genetics of populations. *Evolution* 2:279–294.
 1949 Population structure in evolution. *Proceedings of the American Philosophical Society* 93:471–478.
- Zeier, C. D.
 1980 The Willey and Phillips system revisited: A proposed expansion of the paradigm. *Plains Anthropologist* :29–36.