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Seriation and Cladistics: The Difference between Anagenetic and Cladogenetic Evolution

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We have argued in numerous venues that a significant step in archaeological research involves the construction of evolutionary histories of cultural phenomena (Lyman and O'Brien 1998; O'Brien and Lyman 2000a, 2000b, 2002a, 2003a). These histories can concern artifacts of any scale, from design motifs on ceramic vessels, to projectile-point shapes, to architectural forms, to tool kits. A critical aspect of constructing these histories involves ascertaining the *mode* of evolution, by which we mean the form of the evolutionary history of a lineage. Did the members of the lineage change in a linear fashion (perhaps projectile points got consistently longer over time)? Did the members diversify over time (did the projectile points in one population get longer whereas those in another population got shorter)? Was there hybridization (did a population with long, narrow points exchange ideas with a population having short, wide points so as to produce a new kind of point)? Was there a combination of these modes of change?

The evolution of a lineage is historical in the particularistic sense of being contingency bound (Simpson 1963, 1970)—minimally, the gene pool has unique spatial and temporal coordinates (Cooper 2002; Gould 1986). This does not mean, however, that determining the evolutionary history of some set of phenomena is less of a scientific endeavor than, say, calculating the atomic weight of an element (Lyman and O'Brien 2004). Indeed, it is precisely the theoretically driven nature of research on particularistic evolutionary histories that makes those histories empirically testable. The use of a theory with empirical implications is arguably a necessary condition of any science (Moore 2002).

In part because of the linear cultural-evolutionary models they have adopted, archaeologists have long examined culture change as if it were a linear progression of (typically, artifact) forms within a lineage (Lyman and O'Brien 1997). Contributing to the general feeling that prehistoric cultural evolution was generally linear were some of the chronometric methods developed by archaeologists early in the history of the discipline (O'Brien and Lyman 1999). In particular, various techniques by which the seriation method is operationalized produce linear orderings of phenomena that have the appearance of a linear mode of evolution.

This is, in part, a result of how change is graphed and the scale of the graphed units, but it is also in part a function of how change is viewed on a graph displaying a seriated ordering of artifacts. In particular, it involves an implicit view of evolution as occurring at the scale of a "culture" or some unit more inclusive than the classes of artifacts graphed. Many such units have been called "traditions," each of which is defined as "a socially transmitted form unit (or a series of systematically related form units) which persists in time" (Thompson 1956: 38). A tradition is equivalent to a biological lineage, or line of heritable continuity, but note that the definition of tradition specifies no scale. Contributing to conceptual and analytical difficulty is the fact that although we often speak of the evolution of culture, the unit that we call "a culture" in fact has no good, generally agreed-on definition within anthropology.

We explore here what we take to be two critical issues in the study of cultural phylogenies. First, we briefly expand on the immediately preceding statements and argue that the scale at which evolution occurs is an important consideration—a point emphasized in several other chapters of this book (e.g., chapters 10 and 11). Second, we show that our perceptions of evolutionary mode depend on the analytical technique, particularly the graphing technique, used to monitor evolutionary change and the scale of the units used to track evolution (see chapter 6, this volume). We conclude that evolution occurs at many and varied scales within cultural phenomena and that archaeologists interested in writing the phylogenetic histories of artifacts must be aware that the scale of units chosen for analysis and the graphic technique used to plot change both influence our perceptions of evolutionary mode.

Evolutionary Modes and Biological Methods

Evolution in the organic world is viewed as typically having two modes, each of which creates a particular phylogenetic pattern. The mode can be either "anagenetic" or "cladogenetic." Prior to about 1970, the former was characterized as linear (phyletic) evolution, in which the parental taxon becomes (evolves into) a daughter taxon. An important characteristic of anagenetic evolution is that the parental taxon goes extinct when the daughter taxon appears. In modern biology, most biologists relegate anagenesis to the

production of intraspecific, small-scale changes that organisms go through as they pass from one generation to the next, though a few biologists believe that anagenesis can and does sometimes produce new species (e.g., Gingerich 1985; see Barnosky 1987).

Cladogenetic evolution is branching evolution; the Greek word *klados* means "branch." Cladogenesis occurs if the parental taxon goes extinct simultaneously with the appearance of two (or more) distinct daughter taxa. Importantly, cladogenesis can also occur when a parental taxon gives rise to a daughter taxon and then coexists with it. This is the mode of evolution that Niles Eldredge and Stephen Jay Gould (1972) had in mind when they coined the term *punctuated equilibrium*, a theory of both tempo (rate) *and* mode. Most biologists today believe that cladogenesis is (and was in the past) largely responsible for the creation of new species.

There is a third mode of evolution that is sometimes identified, generally referred to as "reticulation." It involves hybridization—the interbreeding of two distinct taxa, usually species—and the subsequent interbreeding of the hybrid offspring with at least one parent such that a new descendant population representing a new taxon is eventually produced (Levin 2002). Thus, one of the parental taxa, or at least a population thereof, effectively goes extinct (Rhymer and Simberloff 1996). Keep in mind the scale at which hybridization is generally viewed—at the species or a higher, more-inclusive taxonomic level.

Methods for monitoring organic evolution among both living and fossil organisms include what are referred to as "evolutionary taxonomy" and "cladistics" (Mayr 1969; Mayr and Ashlock 1991). Application of these methods hinges on two key aspects of Darwin's (1859) "descent with modification." The first is the process of transmission, which produces descent and ensures heritable continuity between ancestor and descendant. In biological evolution, genes are transmitted; in cultural evolution, packages of information are transmitted (Lyman and O'Brien 2003a). The second aspect involves the modification of descendants relative to their ancestors. That is, replication need not be and typically is not, carried out with perfect fidelity. Descendants are different, if only slightly, from their parents, and they are successively more different from their ancestors as their remoteness from those ancestors increases. Importantly, evolution is not just descent, nor is it just modification; it is, in fact, descent *with* modification.

The important analytical operation to monitoring descent with modification involves classification of the evolving and evolved phenomena of interest, whether organisms or something else. Classification involves an analytical choice of characters and character states (or what an archaeologist might term attributes) of phenomena based on the analytical question being posed (Lyman and O'Brien 2002; O'Brien and Lyman 2002b). The character states chosen should reflect descent with modification; their underlying genes or packets of

information should have been transmitted (with greater or lesser fidelity) from parent to offspring, from ancestor to descendant (O'Brien et al. 2002). This means the chosen character states should be what are generally referred to as "homologues"—character states that are held in common by sister taxa precisely because the taxa are sisters. Evolutionary taxonomists and archaeologists have, to greater or lesser degrees, recognized this requirement for over a half century (Lyman 2001; Lyman and O'Brien 2003b), though archaeologists have struggled with determining which characters are homologues and which are not.

Evolutionary taxonomists consider all kinds of homologous characters in attempting to sort out phylogenetic history. They use what are called "shared ancestral characters," or those that are shared by a taxon and at least two generations of its descendants (figure 1.1). They also examine what are called "shared derived characters," which are shared only by a taxon and its immediate daughters (figure 1.1). Finally, they consider "unique characters" in order to determine the degree of morphological divergence among related and even unrelated taxa.

In contrast, cladists argue that only shared derived characters should be used when attempting to determine the phylogenetic relations of taxa. The reason to use only this particular subset of homologous characters (or character states) is that an ancestral trait is of no value in determining specific relationship. All animals with a backbone, for example, have the ancestral trait "vertebrae," but that homologue does not tell us whether Taxon A is more closely related to Taxon B or to Taxon C. Only shared derived character states allow us to make that determination. Cladistics is now the dominant method in biology for constructing phylogenetic hypotheses. We believe it can be equally usefully applied to cultural phenomena (e.g., Foley 1987; Foley and Lahr 1997; Gray and Atkinson 2003; Gray and Jordan 2000; Holden 2002; Holden and Mace 1997, 1999; Jordan and Shennan 2003; Mace and Pagel 1994; O'Brien and Lyman 2003a, 2003b; O'Brien et al. 2001, 2002; Rexová et al. 2003; Tehrani and Collard 2002).

Ontology of a Culture and the Scale of Evolution

Given the many discussions of what "culture" is that have appeared in the last fifty years (e.g., Keesing 1974; Kroeber and Kluckhohn 1952; Sahlins 1999; Shweder 2002), it is perhaps not too surprising that it is difficult to agree on what *a* culture is. In what we take to be an astute observation, George Murdock (1971: 19) noted that, to him, it was "distressingly obvious that culture, social system, and all comparable supra-individual concepts . . . are illusory conceptual abstractions inferred from observations of the very real phenomena of individuals interacting with one another." Such things as cultures and societies had, in Murdock's view, become "reified abstractions."

Twenty-five years later, Palmer et al. (1997: 296–297) reiterated Murdock's observation and added that whereas "conceptualizing and talking about people in terms of discrete categories referred to as 'cultures' or 'societies' is certainly a great convenience," the reification of these units is "scientifically unacceptable." They concluded that humans have a genetically programmed tendency that they termed "categorical perception," which causes us to unconsciously perceive individual phenomena and to group those individuals into categories. It is the unconscious nature of this grouping process that causes us to believe that we perceive discrete, well-bounded groups within a series of continuously varying phenomena. Human races are perhaps a prime example.

We believe the categorical-perception problem is well described by the differences between classes and groups as we and others have discussed them (Dunnell 1971; Lyman and O'Brien 2002; O'Brien and Lyman 2002b). Classes are ideational units with, ideally, explicit definitive criteria that have been chosen for their analytical and theoretical relevance. Because the criteria consist of character states, they are at a less-inclusive scale than the phenomena being classified. This is not trivial because it underscores the point that the phenomena being classified must all be of the same scale (e.g., set of artifacts, artifact, character, character state). Artifacts are classified based on their attributes; tool kits on the artifact types they include; site types on the architectural features they contain and the human behaviors that are inferred to have taken place; and so on. Groups are sets of empirical phenomena. The setness of each group rests on the criteria used to specify membership; the discreteness of each group rests on the distinctive and unique criteria of each group.

In our view, a culture is a particular kind of ideational unit that, unfortunately, at best has fuzzy definitive criteria, and thus its empirical members to greater or lesser extents are fluid and permeable. Each culture is not always equally distinct from every other culture because each has flexible boundaries (Palmer et al. 1997; Sahlins 1999). One might protest that a culture is manifest in a set of people who share a particular set of information that they acquired via enculturation (to put a modern spin on E. B. Tylor's [1871] seminal definition), but this leaves unspecified the definitive set of information making up the culture as well as the proportion of that information that must be shared by the society's members in order to be included within the bounds of one culture and excluded from a similar culture (Shweder 2002). Interestingly, most anthropologists during the first half of the twentieth century viewed cultures as having fuzzy, fluid boundaries precisely because of the interaction between them (Sahlins 1999).

It is difficult to identify a culture as a discrete unit with clear boundaries in an ethnographic setting. As with the spatial boundaries of culture areas, the definitive criteria and thus the boundaries of a culture must be specified by the anthropologist. Therefore, it is fallacious to argue that one cannot study the evolutionary history of a culture because cultural evolution is reticulate. Such

an argument presumes that there is a clear boundary around each culture, just as the biological-species concept of a reproductively isolated population specifies boundary lines across which gene flow either does not occur or is extremely limited.

There were those during the first half of the twentieth century who contrasted a culture with a biological species in order to emphasize that species had impermeable (to gene flow) boundaries whereas individual cultures did not have impermeable (to information flow) boundaries (e.g., Boas 1904; Gladwin 1936; Kroeber 1931; Steward 1944). We agree with this early assessment of fuzzily defined and bounded cultures, but we also know that the boundaries of biological species are not nearly as impermeable to gene flow as once thought (Arnold 1997). Biologists have, nevertheless, not stopped attempting to unravel phylogenetic history.

We think it is realistic to conceptualize cultural evolution as occurring at a less-inclusive scale than a culture. As archaeologists, we study the evolution of particular artifacts and thus of technologies—stone tools, ceramic vessels, and the like. There are different mechanical requirements and constraints for subtractive technologies such as stone working than there are for additive technologies such as building composite tools and for technologies that modify the chemical and/or molecular structure of raw material, such as pot making. As a result, we find it quite likely that each technology evolves largely, if not completely, independently of other technologies (Hunt et al. 2001). This shifts the scale of analysis from the evolution of a culture to the evolution of a technological lineage. This scale shift does not preclude the hybridization mode, but it does negate the argument that "cultural evolution" is reticulate and reduces it to the less-pernicious "cultures interact in various ways." This means that phylogenetic signals may be muted, but it is improbable that they will always be imperceptible (O'Brien and Lyman 2003a).

But why should hybridization be such a bogeyman? Reticulate evolution, when detected using particular methods (e.g., Skála and Zrzaýy 1994), may become a critically important part of writing an evolutionary history of a technological lineage (O'Brien and Lyman 2003a). Archaeologists have long struggled with the topic of cultural contact and have regularly attempted to develop methods for tracking the history of such contacts (e.g., Lathrap 1956; Thompson 1958). One early effort along these lines was James Ford's (1952) work. The basis for his effort was percentage stratigraphy and frequency seriation (Lyman et al. 1998; O'Brien and Lyman 1998), and his interpretations of the mode of cultural evolution rested in part on how he graphed change. Ford used what we call a centered-bar graph, which shows changes in the relative (proportional) frequency of each of several classes of artifacts over time. This brings us, finally, to the central issue of our discussion—the influence of scale and graphing method on our perceptions of evolutionary mode among artifacts.

Archaeology and Seriation

Seriation has a long history of use in archaeology. At least since John Evans (1850) ordered ancient British coins in the mid-nineteenth century, antiquarians and archaeologists have used character states to sort artifacts into what were believed to be chronologically ordered series. Augustus Pitt Rivers ordered an impressive array of archaeological and ethnographic artifacts, including throwing sticks, boomerangs, and spears from Melanesia (Pitt Rivers 1874a, 1875). Similarly, Sir William Flinders Petrie (1899, 1901) ordered a variety of ancient Egyptian artifacts that came from tombs along the Nile. We have referred collectively to such orderings as "phyletic seriations" (Lyman et al. 1997; O'Brien and Lyman 1999) to keep them distinct from the technique of "frequency seriation," invented by A. L. Kroeber (1916b), and from the distinctive "occurrence seriation," first described in the 1950s and early 1960s (Dempsey and Baumhoff 1963; Rowe 1959). Americanist archaeologists such as A. V. Kidder (1917) ordered artifacts using phyletic seriation before Kroeber's seminal frequency seriation, and some, such as E. B. Sayles (1937), continued to use the older technique well after Kroeber's work (figure 1.4).

As archaeological chronometers, all three seriation techniques (phyletic, frequency, and occurrence) rest on an assumption of historical continuity. That is, they assume that the degree of formal similarity between two phenomena is related directly to the degree of their temporal propinquity. The assumption of historical continuity in turn rests on an assumption of heritable continuity. In other words, the formal similarity of two phenomena is assumed to be a direct result of a genetic-like connection between them effected by cultural transmission. When the seriated phenomena are artifacts, the units of cultural transmission and heritability are packages of information—cultural replicators analogous to biological replicators (Dawkins 1976; Hull 1988).

Terms such as "replicator" and "meme" (Dawkins 1976) commonly occur in modern discussions of cultural evolution, but they were not coined until the last quarter of the twentieth century. Thus, Pitt Rivers, Petrie, and Kidder never used them when discussing their phyletic orderings of artifacts, though Pitt Rivers (1875) was explicit about "ideas in the mind" underlying artifact forms (a fair if general gloss of the meme concept) and that transmission of those ideas results in historical and heritable continuity and thus cultural traditions. It is clear that Pitt Rivers (1891: 116) had Darwin's (1859) descent with modification in mind when he pointed out that "knowledge of the facts of evolution, and of the processes of gradual development, is the one great knowledge that we have to inculcate, whether in natural history or in the arts and institutions of mankind."

Pitt Rivers was influenced by Tylor's (1871) unilinear cultural evolution, but he attempted to go beyond a simple rephrasing of Tylor's tenets and to link them to those of Darwin: "Human ideas as represented by the various products of

human industry, are capable of classification into genera, species and varieties in the same manner as the products of the vegetable and animal kingdoms.... If, therefore, we can obtain a sufficient number of objects to represent the succession of ideas, it will be found that they are capable of being arranged in museums upon a similar plan" (Pitt Rivers 1874b:xi–xii; see also Pitt Rivers 1875).

Phyletic seriation is an important method of ordering phenomena, and from an evolutionary standpoint it can be used to illustrate all three modes of evolution (cladogenesis, anagenesis, and reticulation), as we show below. We use the terms for evolutionary modes to refer to the same sorts of patterns and processes in cultural change, noting that in the latter, as in biology, the distinction between cladogenesis and anagenesis often reduces to a matter of the scale of the units being used to measure change and of the graphic method of building phylogenetic hypotheses. In the following we focus first on phyletic seriation and then on frequency seriation. We illustrate how these two forms of seriation differ in terms of the scale of the units typically used in each, and how graphs displaying each influence whether one sees cladogenetic, anagenetic, or reticulate evolutionary modes.

Phyletic Seriation—The Scale of Character State of a Discrete Object

An example of a phyletic seriation is Kidder's (1917) ordering of decorative motifs on southwestern pottery shown in figure 5.1. Stratigraphic information told him which end of the sequence was older and which was younger. The character used to produce the ordering is found in the upper left portion of the motif. This character shifts in state from what might be described as a rectangle nearly filled with adjoining black rectangles in number 1, to about a third filled with two sets of adjoining black rectangles in number 2, to an empty rectangle in number 3, to more open space in number 4, to, finally, a nearly empty triangle in number 5. These descriptions are cumbersome at best, and we would need considerably more care in writing the character-state definitions were these to be reliable. If we were to transfer these data to a phylogenetic tree, the only possible result is what is shown in figure 5.2.

Another example of phyletic seriation is Pitt Rivers's evolutionary history of paddles from New Ireland, part of the Bismarck Archipelago. His depiction was anagenetic. We have modified it in figure 5.3 by adding arrows to show his proposed developmental sequence. If we were to transfer these data to a phylogenetic tree, the only possible result is shown in figure 5.4. But suppose we have additional phylogenetic information that allows us to create a cladogenetic ordering like that shown in figure 5.5. Notice that the sequence in figure 5.5 is the same as in figure 5.4, where the paddles are arranged anagenetically, but in figure 5.5 we are illustrating cladogenesis—the *mode* of evolution rather than the sequence. The differences between figures 5.4 and 5.5 tell us that analytically the cladogenetic evolution of taxa and the temporal sequence





Figure 5.2 A Phylogenetic Tree of A. V. Kidder's Ceramic Design Motifs in Figure 5.1



Note that the sequence of branching can be read as the same temporal sequence shown in figure 5.1.

Figure 5.3 A. H. Pitt Rivers's Evolutionary History of Paddles from New Ireland, Bismarck Archipelago (modified from Pitt Rivers 1875)



of the appearance of taxa are two different things. Thus, we cannot determine from figure 5.5 alone whether paddle form 3 or 5 appeared first.

Pitt Rivers did not suggest a cladogenetic arrangement of paddles—we made one up strictly as an example—but other prehistorians *did* propose that the cladogenetic mode occurred during the evolution of artifacts in phyletic seriations. An example is Petrie's arrangement of ceramic vessels from Egypt, part of which is shown in figure 5.6. Interestingly, Petrie (1899) referred to portions of his temporal sequence as "genealogies." The "genealogy" shown



Note that the sequence of branching can be read as the same temporal sequence shown in figure 5.3.

Note that the sequence of branching cannot be read as a temporal sequence like that in figure 5.3.

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in figure 5.6 contains instances of both anagenesis and cladogenesis as modes of evolution. In terms of the latter, the jar form in period 38 gives rise to two forms—those in periods 48 and 49. Similarly, the form in time period 48 gives rise to two forms, as does the jar in period 70. In most other cases, the evolutionary mode is anagenetic, but in two places the mode of evolution is reticulate. The jar in period 38 is a hybrid of jars in periods 34 and 36, and the form in period 70 is a hybrid of two forms in period 60.

Petrie offered no clue as to how or why he distinguished instances of cladogenesis, anagenesis, or reticulation. We suspect that his basic method involved two steps. First, he ordered classes of vessels in what he believed was a temporal sequence according to an assumption of historical and heritable continuity. His temporal ordering was on a relative scale, and in some cases more than one form of vessels occurred during one time period. During the second step, we suspect Petrie judged whether a class of vessel displayed character states of one or two temporally contiguous earlier classes; if the former, anagenesis was

Figure 5.6 W. M. Flinders Petrie's Genealogy of Ceramic-Vessel Forms Recovered from Egyptian Burials (after Petrie 1899)

Numbers refer to temporal periods. Note that all three modes of evolution-anagenetic, cladogenetic, and reticulate-are indicated.

suggested, and if the latter, hybridization was suggested. A similar judgment accompanied inspection of classes that occurred later in the sequence.

Temporal propinquity and the ratio of shared to unique character states probably implicitly guided whether Petrie saw anagenesis, cladogenesis, or hybridization. We have modeled how Petrie's thinking might have looked in figure 5.7. Each capital letter denotes a particular character state, and the position of the letter in a list of states denotes a particular character. For example, assume that the last letter in a list represents the character "rim form:" F means an inverted-rim character state, H a vertical rim, and Z a lipped rim (compare figures 5.6 and 5.7). The scale of the evolutionary mode here concerns how the characters of vessels, not vessels themselves, change states over time. The form of recombination (note the word choice) of sets of particular character states on a discrete vessel suggests the evolutionary mode. It is important to emphasize that Petrie did not make explicit the definitions of his vessel classes, and thus it is unclear which character states he considered. We suspect that he used character states that represented both shared derived and shared ancestral character states, meaning that what he did was more akin to modern evolutionary taxonomy than to modern cladistics.

Numbers refer to temporal periods. Each capital letter represents a unique character state; the position of a letter in each class definition (list of letters) represents a particular character. Note that the class in period 38 is a hybrid of the classes in periods 36 and 34.

Frequency Seriation—Evolution at the Scale of Classes of Discrete Objects

As an archaeological chronometer, frequency seriation typically concerns discrete objects, though it could be used with any scale of item. In the discussion that follows, we consider classes of discrete objects in order to make our point that the scale of the units used to track evolution and how evolutionary change is graphed influence our interpretations of evolutionary mode. Frequency seriation assumes that each historical class occurs during only one span of time and that it has a frequency distribution that is unimodal relative to the frequencies of other classes. Thus, a dozen collections of artifacts, say, each with various classes of artifacts and sharing some classes, can be ordered such that each class displays a single continuous occurrence through the ordering and a unimodal frequency distribution. That the ordering reflects the passage of time is an inference and must be tested with independent chronological data. In the following, we presume for sake of discussion that the fictional frequency seriation in fact does reflect the passage of time.

An example of thirteen seriated collections with four classes is shown in figure 5.8. Notice that not only does each of the four classes occur during only one span of time and each displays a unimodal frequency distribution, but classes overlap in the sense that they occur in multiple assemblages that are adjacent to one another in the ordering. Simply put, overlapping is the basis for the underpinning assumption of historical continuity between assemblages affected by heritable continuity (O'Brien and Lyman 1999). Assume that each of the classes in figure 5.8 is defined by three characters, each having two possible states, A and B, and that the position in the list of character states defining a class specifies the character (first position is first character, second position is second character, and so on). Eight classes are possible (AAA, AAB, ABB, BBB, BBA, BAA, ABA, BAB). In the following discussion, we presume that the four classes represented in the collections in figure 5.8 are the first four listed.

Virtually all published frequency seriations made up of centered-bar graphs like that in figure 5.8 lack the definitions of the classes as part of the graph. If we were to inspect figure 5.8 without the class definitions clearly indicated, the evolutionary mode(s) represented by the graph would be obscure. On the one hand, that graph might be considered to show a cladogenetic mode, given that the oldest class could be interpreted as having diverged into the second class to appear in the sequence. The class definitions suggest such a cladogenetic event is likely because the two classes differ in terms of only one character (BBB versus ABB). We could show this with diagonal lines running from an early type to a later type; we might call such lines "phylogenetic-divergence" lines.

On the other hand, we might step back (lower the magnification power) and argue that the change from type BBB to AAA represents an anagenetic mode. Basically the same temporal information as is found in figure 5.8 is available

in the ordering Class 1 (BBB), Class 2 (ABB), Class 3 (AAB), Class 4 (AAA). This listing, if graphed as in figure 5.7, would make the evolutionary mode appear anagenetic when in fact all we have done is alter the means of graphic representation and shifted the scale from frequencies of classes (in figure 5.8) to class definitions (lists of character states in figure 5.7).

Notice that in altering the scale of the evolutionary unit to frequencies of specimens within classes of discrete objects we have, in effect, masked the changes in character states displayed by those discrete objects (figure 5.7). Nothing about the mode of artifact evolution actually changed; only the scale of the classificatory unit and the means of graphing were changed, which is our main point. Thus one might find it rather perplexing that James Ford, who popularized centered-bar graphs like that in figure 5.8 (Lyman et al. 1998; O'Brien and Lyman 1998), would publish the model of change in artifacts shown in figure 5.9. The latter figure is in fact how Ford thought of change in artifact lineages-anagenetically-whereas graphs like that in figure 5.8 allowed him to monitor change over time.

Importantly, Ford had a particular analytical goal in mind when he used centered-bar graphs. He typically was concerned with what change within artifact lineages indicated about the passage of time and less often with evolutionary mode, at least in the sense that we have defined it here. In what we consider one of only two studies in which he specifically sought to detect evolutionary mode, Ford (1952) used centered-bar graphs to assist with chronological ordering of archaeological manifestations, but he also superimposed

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Note that within each lineage change is anagenetic. Compare with figure 5.6.

the vessel classes on those graphs. This resulted in a hybrid graph that combined features from figures 5.8 and 5.9, but it was the vessel classes, not the relative frequencies of those classes, that allowed him to infer evolutionary mode. Perhaps without knowing it, he was mimicking Petrie's procedure as we have modeled it in figure 5.7. The fact that different columns of centered bars contained from one to several classes of vessel and represented different geographic areas allowed Ford to track both the diffusion and the evolutionary mode of vessel forms across space and time. Ford's (1969) final monographlength study of pottery evolution omitted the centered-bar-graph portion of the illustrations and focused only on simple phyletic seriations, arranged so as to imply diffusion and divergence (cladogenesis) across space and time.

Phyletic Seriation—Scale and Mode

In the two studies just mentioned, Ford (1952, 1969) clearly had questions of evolutionary mode in mind, though he did not phrase them in explicit evolutionary terms. The fact that he used a form of phyletic seriation to study artifact phylogeny and evolutionary mode is, we think, significant. It harks back more than fifty years to earlier phyletic seriations such as that by Petrie (figure 5.6). This seems to be the basic method many individuals used to track phylogenetic histories of artifacts. For example, numerous examples of artifact phylogeny are found in the work of Bashford Dean, curator of fishes at the American Museum of Natural History and honorary curator of arms and armor at New York's Metropolitan Museum of Art. In 1915 Dean published figure 5.10 in an article geared to changing how museums labeled exhibits. Dean's complaint was that museums for the most part did a terrible job of educating their visitors. Museums tended to fall into one of two camps: those that let objects speak for themselves and those that drowned the visitor in verbiage. Dean believed that visitors were confused by disassociated objects and that what was needed was a "plan" to bring together in the visitor's mind what he or she saw in the display cases. In Dean's view, one way to pull this off was to choose a category of items familiar to the visitor and to arrange the items so as "to show the changes which have taken place during the centuries," with "the first form begat[ting] the second, perhaps in a vaguely evolutional way" (Dean 1915: 173).

There was nothing "vaguely evolutional" about what Dean proposed (Coen 2002). His scheme was anchored in a diagram—shown in the lower left of figure 5.10—that illustrated the "characteristic parts" of a class of object. Those nine "characteristic parts" of helmets are the characters we believe Dean used to help construct his phylogeny. The larger diagram illustrates how and when those parts came into being and how once they came into being they changed states. Note, for example, that the earliest helmets do not have visors. Those come in later, at different times and in different branches. The same pattern exists with respect to crests. Once those characters come in, they change states rapidly. Dean followed the lead of paleontological practice and marked off temporal horizons for his helmets. The result, in Dean's words, was an illustration of, in this case, helmets "evolving." Significantly, Dean (1915: 174) noted that the graph displayed a chronological order of helmet parts—our characters and character states.

Dean's diagram not only epitomizes how important classification is to phylogenetic research but also highlights differences in the kinds of trees that can be used to illustrate phylogenetic relations. Notice that Dean labeled most of the branches on his phylogenetic tree. The labels refer to general kinds of helmets, with individual "taxa" represented by the small drawings. Dean's diagram shows both anagenesis and cladogenesis. This is a very different kind

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Figure 5.10 Bashford Dean's Model of Phylogenetic Evolution in Helmets

Note the designation of critical characters in the lower left and that both anagenetic and cladogenetic modes are shown (after Dean 1915).

of arrangement than would be shown in a cladistically derived phylogenetic tree built using only shared derived characters and character states. We show one in figure 5.11 strictly as an example. Note that all taxa are shown at the branch tips. Some taxa might be directly ancestral to other taxa, but it is unlikely that we will ever be able to verify such a relationship using strict cladistic methods. Thus, our tree shows all taxa as "terminal taxa."

Although Dean published only one drawing of an artifact phylogeny, he drew numerous other phylogenetic orderings of various kinds of artifacts. For example, he modeled an overall phylogeny of swords and the evolution of various sword subgroups, but the individual phylogenies were presented only in general form in one of Dean's figures, here reproduced as figure 5.12. Dean also took some of the individual subgroups-cinquedeas (figure 5.13) and rapiers and court swords (figure 5.14)-and traced their phylogenies at a detailed scale. In biological terms, the subgroups are individual "clades"-all descendant taxa of one ancestral taxon plus that common ancestor-in the overall "sword" phylogenetic tree. Importantly, the ordering is based on phyletic seriation, not on cladistics, just as was Petrie's ordering of Egyptian pottery in figure 5.6. We suspect that were we to build classes similar to Dean's and to build a phylogenetic tree cladistically, the sequence of taxa and the order of branching would pretty much mirror Dean's arrangement. This is because he had good chronological control of the artifacts he was concerned with, and he noticed which characters changed states over time.

Dean's graphs are phylogenetic trees, but not necessarily ones with single roots. Dean's trees show real ancestors, which cladistically derived trees cannot, and many of Dean's taxa are not terminal taxa, such as are produced by a

Note that the sequence of branching cannot be read as a temporal sequence such as can be done in figure 5.10.

Figure 5.12 Bashford Dean's General Model of Phylogenetic Evolution in Swords

Note the designation of critical characters in the lower right and that both anagenetic and cladogenetic modes are shown. (Not previously published.)

cladistic analysis. The important thing to realize in the context of our discussion here is that figures 5.10 and 5.12–5.14 show both anagenetic and cladogenetic evolutionary modes. None of Dean's sixteen drawings of artifact phylogenies that we have inspected includes instances of reticulate evolution. We suspect this is because when he was constructing the graphs, during the second decade of the twentieth century, many biological evolutionists

Figure 5.13 Bashford Dean's Detailed Model of Phylogenetic Evolution in Cinquedeas

Compare with the "cinquedeas" branch in figure 5.12. Note the designation of critical characters in the lower left and that both anagenetic and cladogenetic modes are shown. (Not previously published.)

considered hybridization improbable. Given that Dean was curator of fishes at the American Museum and presumably knew evolutionary theory as it was at the time, he likely did not even consider hybridization of artifacts. Virtually

Compare with the "rapiers" and "court swords" branches in figure 5.12. Note the designation of critical characters in the lower right and that both anagenetic and cladogenetic modes are shown. (Not previously published.)

all phylogenetic trees drawn by biologists (e.g., Matthew 1926, 1930) were similar to those Dean constructed for weapons. This again underscores our take-home message: how we graph evolutionary history and the units we use to construct the graph will influence our interpretations of evolutionary mode among empirical phenomena. The next chapter in this volume builds on this recognition to provide a method for constructing graphs in a way that resembles Dean's.

Conclusion

The application of cladistics to artifacts is not without controversy, but the fact that seriation ultimately rests on the assumption of heritable continuity, just as cladistics does, in our view serves as a sufficient warrant for applying cladistics to artifacts (O'Brien and Lyman 2003a; O'Brien et al. 2001, 2002). One critical difference between seriation and cladistics is that the latter assumes that the evolutionary mode is always cladogenetic. Another difference is that in cladistics the temporal sequence of various taxa in different clades may be obscured. This is not a damning observation; cladistics is designed to demonstrate patterns of branching, whereas seriation is meant strictly to order phenomena lineally.

Phyletic seriation focuses on changes in character states that make up the definitions of artifact classes. As practiced by Petrie over a century ago and by Ford over a half-century ago, phyletic seriation can be used to graph any and all of the three modes of evolution. Frequency seriation, as typically implemented in a centered-bar graph, obscures evolutionary mode in favor of sequence. To make the mode clear, one must consider the definitions of the graphed classes rather than their frequencies of representation over time. We suggest that cladistics adds an important dimension to efforts to monitor phylogenetic history because of its analytical rigor and the fact that it requires explicit definitions of characters and character states. Further, it highlights the fact that the evolution of artifact lineages may well be cladogenetic.

The past decade or so has seen increasing efforts on the part of anthropologists and archaeologists to study the evolutionary history of various cultural lineages. We have shown here that both the scale of unit used to monitor phylogenetic evolution as well as the means used to graph it influence our inferences regarding evolutionary mode. This must be kept in mind when using any of the various methods and techniques discussed here. So should two other seemingly obvious points. First, although we focus on material items when we perform a seriation or cladistic analysis, it is not the materials per se that evolved but the ways people made them. Second, phylogenetic methods are only the first of a long series of steps that need to be taken in an evolutionary study. Enrico Coen (2002: 50) summed up both points beautifully in his discussion of Bashford Dean's diagram of helmet evolution: "[the diagram] tells a story about changes in how people fashion helmets in re-

sponse to changing circumstances, materials, and traditions." It is in figuring out those circumstances, materials, and traditions where evolutionary studies become exciting.

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