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The Nature of Organization of Intrasite Archaeological Records and Spatial Analytic Approaches to Their Investigation

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INTRODUCTION

In the past 10 years, major advances have been made in the analysis and behavioral interpretation of spatial patterning within archaeological sites. Two areas of growth are apparent. First, a number of quantitative methods that allow the discovery of spatial patterning among entities have been introduced to archaeology, permitting more sophisticated analysis of the arrangement of artifacts within sites and more precise definition of tool kits and activity areas. These techniques, derived largely from the field of mathematical ecology (Greig-Smith 1964; Pielou 1969, 1977), include: the Poisson method of detecting spatial clustering of items (Kershaw 1964), dimensional analysis of variance and covariance used in conjunction with correlation analysis (Greig-Smith 1952b; Whallon 1973), several nearest neighbor approaches (Clark and Evans 1954; Morisita 1959; Whallon 1974), and segregation analysis (Pielou 1961; Peebles

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1971) used in conjunction with clustering algorithms. Additionally, correlation analysis followed by principal components analysis has been employed (Speth and Johnson 1976; Schiffer 1975c). Both Price (1975) and Brose and Scarry (1976) have summarized the methods, as well as some of the assumptions of some of these techniques within the context of examples. Price has illustrated how the techniques may be integrated into a multistep analytic design.

The second area of growth in intrasite spatial analysis consists of studies of archaeological formation processes, including behavioral and natural processes of formation and disturbance (Ascher 1968; Binford 1976; Gifford 1978, 1981; Gould 1971, 1978; O'Connell 1977, 1979; Schiffer 1972, 1973, 1975a, 1975c, 1976; Schiffer and Rathje 1973; Wood and Johnson 1978; Yellen 1974, 1977). Ethnoarchaeological, experimental, and formal-deductive approaches have been taken. These studies are useful because they document the kinds and distributions of archaeological remains that different activities and formation processes can generate under variable conditions, thereby helping the archaeologist to bridge the interpretive gap between the archaeological record and past behavior.

Up to now, these two approaches to describing and interpreting intrasite archaeological variability have proceeded relatively independently of each other. The precise impact of archaeological formation processes on the organization of artifacts within sites as they are mapped from the behavioral domain into the archaeological record has not generally been expressed with quantitative measures of spatial patterning. Inversely, mathematical techniques for analyzing intrasite artifact distributions have not commonly been evaluated for the appropriateness of their data requirements, given the structure of intrasite archaeological remains and the nature of the processes responsible for them. Exceptions include: (1) Speth and Johnson's (1974) delineation of several expected patterns of correlation between tool-type counts, given different depositional processes and spatial distributions of activity; (2) Schiffer's (1975c) study of the capability of correlation and factor analysis in identifying tool kits as the deposition of tools from distinct activity areas becomes more focal; and (3) Whallon's (1979, 1984) design of the new strategy, unconstrained clustering, to define activity areas.

It is clear, however, that a wedding of these two approaches to intrasite analysis is both desirable and necessary. For any quantitative analysis and interpretation of complex data to be accurate, the relationships of logical contingency existing between a predictive hypothesis (or law or model), its test implications, the technique chosen for analysis, and the data must be *logically consistent* ones. A test implication of an hypothesis must be expressed in mathematical terms reflecting the techniques to be used in analysis, to be fully operational and concordant with the hypothesis. Also, the techniques one chooses for analysis should make only those assumptions that are congruent with the expectable and empirical structure of one's data (Carr 1981, 1984b). For intrasite spatial analysis, these requirements translate as follows. (1) Given an hypothesis of the kinds of activities that occurred at a site, test implications stating the expectable spatial patterning of artifacts and derived with the aid of principles of formation of the archaeological record should be expressed in mathematical terms reflecting the analytical method to be used; Also, (2) the mathematical techniques one chooses to analyze the spatial arrangement of artifacts within a site should make only those assumptions that are logically concordant with the expectable structure of the data, as determined by the nature of the hypothesized activities and the formation processes that mapped them into spatial configurations of artifacts. To the extent that the empirical structure of remains is known, the technique also should be consistent, in its data requirements, with that structure. Only if these conditions of spatial analysis are met can one be confident of the logical consistency of one's analysis and the accuracy of one's quantitative results and conclusions.

This chapter is concerned with both aspects of a unified approach to intrasite spatial analysis. The nature of the organization of archaeological records within sites, as determined and impacted by human behavior, archaeological formation processes, and archaeological recovery techniques, is expressed as a partially mathematical model. Common techniques of spatial analysis are summarized and evaluated for the consistency of their assumptions with the proposed model. Alternative approaches to spatial analysis having designs more consistent with the proposed model—some new, others previously available but not applied in archaeology—then are described.

In evaluating analytical techniques against the model of intrasite archaeological records, the most conservative position possible has been taken. The model is generalized, encompassing the effects of a large number of behavioral processes and archaeological formation processes. It is assumed that (1) any or all of these effects may be present within a specific site of study, limiting which techniques are appropriate for analysis; (2) it may not be possible to determine which constraining effects are present within a site; and (3) consequently, spatial analytic techniques should be able to cope with all these constraining effects. Very robust, widely applicable techniques are considered preferable to more limited methods.

In practice, however, it is possible to determine to a certain degree what formation processes have occurred at a site (e.g., Schiffer 1973, 1975b). This is especially true where historic documentation is available but is becoming much more feasible for prehistoric sites, as well (Binford 1978; Schiffer 1982). Under these conditions, techniques that have certain limitations and that have been evaluated here as generally inappropriate may actually be useful. Also, it is possible to use multiple, restricted approaches to spatial analysis—different techniques in different known circumstances; one generalized technique need not always be preferable.

Whether or not the processes responsible for an archaeological record and its specific organization can be determined prior to spatial analysis, the discussions presented here on possible incongruencies between data and technique, their causes, and their effects on analysis should be helpful to archaeologists. First, they provide the archaeologist an awareness of those characteristics of intrasite data that *should* be investigated before a technique of analysis is chosen. It is the archaeologist's responsibility to try to determine what constraining effects of formation processes are and might be represented in the data, prior to analysis (Schiffer 1982), and to choose an appropriate technique in light of this knowledge. Second, when the nature of the data is clear, the discussions form a basis for choosing the one technique among the considered alternatives that *certainly* is most appropriate to the prevailing conditions. When the nature of the data remain impossible to specify, the discussions suggest which techniques are most robust and most *likely* to be appropriate.

THEORETICAL AND OPERATIONAL GOALS OF INTRASITE SPATIAL ANALYSIS

Goals

Intrasite spatial analysis has several goals, at both the *inferential* level, concerned with the reconstruction and explanation of past behaviors and activities (nonobservables), and the *operational* level, concerned with relationships between archaeological observables. At the inferential level, intrasite spatial analysis is undertaken for two reasons:

1. to define the spatial limits of *activity areas,* and
2. to define the organization of artifact types into *tool kits.*

(Appropriate use and definition of these terms are discussed later.) These two basic classes of information may be used to reconstruct the kinds, frequencies, and spatial organization of activities that occurred within a community, which in turn may be used to infer the seasons of occupation of the site, site function, community population, group composition, patterns of household interaction, community kinship and social organization, and many other behavioral and ecological phenomena.

At the operational level of analysis, intrasite spatial analysis seeks to answer four questions (after Whallon 1973):

1. Are the artifacts of each recognized functional type randomly scattered over space, aggregated into clusters, or systematically aligned?
2. If the artifacts of a given type cluster, what are the spatial limits of clusters of that type?

3. Whether or not the artifacts of given types are clustered, randomly scattered, or systematically aligned (see pages 107–108), do artifacts of different types tend to be similarly arranged such that, for example, their frequencies covary or their presence states associate over space?
4. If the artifacts of several types both cluster *and* are co-arranged, what are the spatial limits of multitype clusters?

The first, second, and fourth operational questions reflect concern at the inferential level in defining activity areas. The third question is posed in response to interest, at the inferential level, in defining tool kits.

The Appropriateness of Contingency Relations between Some of the Operational Goals of Spatial Analysis

In the past, the several operations of spatial analysis have been seen as *sequential* steps of analysis. When using grid-cell methods, it has been suggested (Whallon 1973:266) that analysis proceed from assessment of the form of arrangement of single types to assessment of the degree of co-arrangement of different types. When using nearest neighbor methods, the preferred sequence (Whallon 1974; Price 1975) has been to proceed from evaluation of the form of arrangement of single types to definition of clusters and finally to assessment of the degree of co-arrangement of artifact types. The manner of operation at later stages of analysis has been envisioned as contingent upon the results of earlier stages, either *algorithmically* or of *logical necessity*. For example, calculation of the degree of association between pairs of artifact types using Whallon's (1974) nearest neighbor approaches is *algorithmically* contingent upon (can only occur after) definition of the limits of single-type clusters. Definition of single-type clusters having statistical significance, using Whallon's nearest-neighbor approaches, is seen as *logically* contingent upon (should only occur after) determination of whether an artifact type significantly clusters, using the nearest neighbor statistic.

Not all the contingency relations implied by or stated as part of this "stepwise" approach to spatial analysis are necessary or desirable (Hietala and Stevens 1977:539). In particular, those operations concerned with the definition of tool kits are not logically contingent upon those concerned with the definition of activity areas, and vice versa. They probably should not be made algorithmically contingent upon each other, either.

As a case in point, consider the *logical* contingency expressed in the view that only those classes of artifacts showing significant trends toward clustering should be analyzed for their degree of co-arrangement (Whallon 1974). This perspective seems to have its basis in the following arguement: Only when artifacts are distributed among spatially nonoverlapping activity areas, apparent as artifact clusters, will types that belong to the same tool kit by detectable by patterns of covariation or association between them. This contingency need not be true (Hietala and Stevens 1977:539–540). Consider an activity that is not tied, operationally, to spatially permanent facilities and that generates several forms of debris, expediently. If the activity is performed numerous times, randomly over space, the several kinds of artifacts will each have random spatial arrangements, but the artifact types will covary in their frequencies over space. Flint knapping and whittling within hunter–gatherer camps can produce such artifact arrangements. Likewise, systematically aligned artifact types can covary or co-occur. Curated, domestic tools stored within the confines of houses having a regular arrangement over space would exemplify this pattern. Thus, investigation of patterns of co-arrangement of multiple artifact types should not be envisioned as logically contingent upon evaluation of the form of arrangement of individual artifact types. Nor should procedures of spatial analysis express this contingency as stepwise algorithmic dependency. (Currently used techniques do not.)

Similarly, the *algorithmic* contingency between definition of the limits of artifact clusters and assessment of the co-arrangement of artifact types, when using nearest neighbor methods (Whallon 1974), is undesirable. This stepwise procedure prohibits artifact types that do not cluster from being assessed for their degree of co-arrangement with each other and with those that do cluster. Methods of intrasite spatial analysis should not require this contingency.

Appropriateness of the Goal of Assessing the Form of Arrangement of Artifacts

Recently, the appropriateness of two of the four operational goals of intrasite spatial analysis just enumerated has been questioned. Whallon (1979, in press) has argued that assessment of the nature of the spatial distributions of artifact types (random, clustered, or aligned) is meaningless, given that results depend entirely on the size of the area chosen for analysis (when using the nearest neighbor statistic) or the size grid cells (when using the Poisson method). I disagree with his conclusion.

It is true that an assessment of the form of spatial arrangement of entities using the nearest neighbor statistic does depend on the size of the area chosen for analysis. Figure 3.1 illustrates this. Hsu and Tiedemann (1968; Pinder 1979: Figure 2) have demonstrated that if 10 regularly spaced points occupying a unit area are framed in increasingly larger areas, the nearest neighbor statistic will drop from values suggesting systematic alignment of points to values implying their random distribution, and finally to values implying their clustered distribution. It also is true that an assessment of the form of arrangement of items over space using grid-cell counts and the Poisson method depends on the scale of the grid laid over the distribution (Greig-Smith 1961). However, the existence of

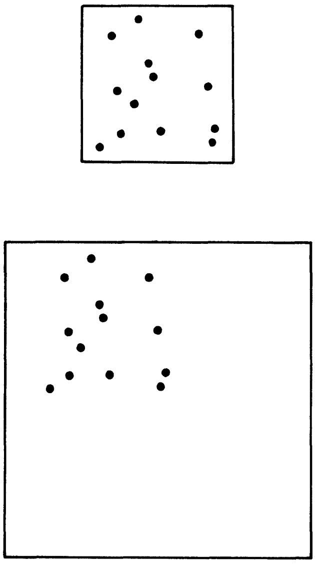


Figure 3.1. Whether a spatial arrangement of entities appears random or clustered to the human eye, and whether a nearest neighbor statistic indicating randomness or clustering is calculated, depends on the size of the area chosen for analysis.

such functional relationships between the size of frame units chosen for analysis and the estimate of arrangement obtained does *not* imply that assessment of the form of spatial arrangement of items with the nearest neighbor or Poisson methods is always a meaningless endeavor. Not all analyzable areas or grid-cell sizes are equally meaningful from a behavioral perspective, and not all possible results are important.

For an assessment of the spatial arrangement of artifacts to be meaningful using the nearest neighbor statistic, it is only necessary that the analyzed area be a ''natural'' unit having *meaning in terms of past behavior,* and have *clear boundaries* (Getis 1964:394–395). These conditions often can be met. For example, an archaeological site, as a whole, is a natural unit with behavioral significance. An estimate of the degree of clustering or random dispersion of artifacts within a whole site has behavioral meaning; it suggests the degree to which the site as *the* unit of analysis is internally differentiated into multiple use-areas. This condition of a site is important to know, for if it can be shown that artifacts within a site do cluster significantly, then further attempts to define the boundaries of clusters become justifiable. Sites, as wholes, also often meet the requirement of nearest neighbor analysis that the area to be examined have clear boundaries. The boundaries of sites often are delimited by a drop in the density of artifacts at a given high rate or to some minimal level of background noise.

Subareas of a site, which are delimited by some behaviorally significant archaeological criterion, also may be analyzed with the nearest neighbor statistic so as to produce meaningful results. An area of clustering of facilities or the interior of a house, for example, might be assessed for the form of arrangement of artifacts within it. In contrast, a block excavation within a site, having areal limits that are somewhat arbitrary and not meaningful in terms of past behavior, does not constitute a valid area of analysis using the nearest neighbor statistic. The interitem distances used to estimate the degree of clustering or dispersion of artifacts within a block are not assessed relative to the dimensions of a meaningful area.

Statements made by Clark and Evans (1954:450) in general terms, and reiterated by Pinder *et al.* (1979:433) for intrasite cases, imply that nearest-neighbor analysis of arbitrary units, such as block excavations within sites, is justifiable. These authors suggest that to avoid bias in the nearest neighbor statistic, the area of analysis should lie "*well within* the total area covered" by the distribution of items of interest (e.g., within a site). This strategy, however, clearly is inappropriate for artifact distributions. Artifact scatters often have multiple forms of arrangement, hierarchically organized. For example, within a random, low-density scatter of artifacts there may be high-density concentrations, themselves composed of artifacts that are randomly scattered. The form of arrangement of artifacts found within a block excavation will depend on its size and placement, and the particular level of the organizational hierarchy unveiled. Meaningful estimates of the form of arrangement of items within a block will be found only when its boundaries and areal extent correspond with the boundaries and extent of some natural, behaviorally meaningful, portion of the site.

Using the Poisson method, assessments of the form of arrangement of artifacts within a site are less clearly meaingful, and Whallon's skepticism of the method seems justifiable. The size of grid cells to be used for analysis *can* be chosen in reference to an expectable, meaningful scale of patterning, to reduce the arbitrariness of results. However, often factors that can lead to the arbitrariness of results, such as uncontrolled lack of correspondence between shape or orientation of grid cells and the shapes or orientations of artifact clusters, are less easily remedied (pages 143–144).

Appropriateness of the Goal of Searching for Site-Wide Patterns of Co-Arrangement of Artifact Types

Whallon (1979, in press) has implied, though never stated directly, that the search for site-wide organization of activities into depositional sets—including activity sets, storage sets, and discard sets—is meaningless. His technique of unconstrained clustering is designed explicitly (1979:4; in press) to avoid the assessment of site-wide relationships between artifact types, and focuses on patterns of internal association or covariation of artifacts within clusters.

The motive behind Whallon's efforts to avoid examination of site-wide relationships among artifact types is his observation that the same set of artifact types may show different patterns of covariation or association (positive, null, negative) in different portions of a site. From this fact he draws the conclusion that depositional sets as site-wide phenomena do not exist and need not be searched for. This conclusion, however, is not the only one that can be inferred and is not necessarily correct. Variable covariation and association of artifacts over a site also might indicate the incapability of correlation and simple association to accurately measure the strength of relationships between artifact types and to define site-wide depositional sets that really do exist (see pages 161–170, 172–175, and 191–199).

The view taken in this chapter is that site-wide depositional sets and activity sets often do exist but in forms that are *polythetic* rather than monothetic in organization, and *overlapping* rather than nonoverlapping in organization (terms defined on pages 113–121). Under these conditions, correlation and simple association are not accurate measures of the strength of the relationships between types. Thus, Whallon's empirical results can be explained by an incompatibility between the analytical techniques he used (correlation, simple association) and the structure of archaeological data.

Ethnography, ethnoarchaeology, and experimental approaches to the study of tool manufacture and use suggest that certain kinds of tools do tend to be used together, repeatedly, constituting tool kits (see Table 3.1) (Cook 1976; Winters 1969). It is not necessary that archaeologists give up the search for such site-wide entities. Rather, it is only necessary that they realize that tool kits and depositional sets often are polythetic and overlapping in structure and that the mathe-

TABLE 3.1

Examples of Preservable Tool and Debris Types Often Used or Produced Together (Activity Sets) While Performing Some Specific Task

Artifact types used/produced together	Activity	Reference
Mauls, decortication debris	Quarrying and preforming chert	Crabtree (1940, 1967), Ellis (1940)
Decortication flakes, large hammerstones	Primary knapping	
Hard-hammer secondary flakes, hammerstones	Secondary knapping	
Pressure flakes, pressure flakers	Pressure flaking	
Edge-worn cobbles, prismatic cores, blades	Manufacturing blades	Crabtree and Swanson (1968)
Abraders, pressure flaker, pressure flakes	Roughening platforms while knapping	Crabtree (1972:7), Speth (1972)

(continued)

TABLE 3.1 *Continued*

Artifact types used–produced together	Activity	Reference
Abraders, drills, saws, notches, spurs, knives, scrapers	Working wood, bone	Cook (1973)
Saws, flake knives	Notching arrow shafts	Sollerberger (1969:238–239)
Gouges, chisels	Carving concavities such as wooden bowls	Waugh (1916:58)
Burned abraders, fire-cracked rock, hearth-liner	Straightening wooden shafts	Mason (1899)
Mauls, grooved axes	Felling or girdling trees; obtaining fire wood, slabs of wood, and bark	Waugh (1916)
Mauls, cobble anvils, knives	Pounding bark into cloth and cutting it	McCarthy (1967:51), Waugh (1916:61)
Spurs, antler debris	Working antler	Clark and Thompson (1954)
Spurs, pigment	Painting grooves in arrow shafts	Winters (1969:54)
Red ochre; mortar and pestle, or mano and metate	Grinding red pigment for paint	Battle (1922), Moorehead (1912)
Abraders, hide scrapers	Defleshing and thinning hides	Mason (1889:560, 572–573, 1899:78–79)
Hammerstones, hide scrapers	Dressing hides	Mason (1895:53)
Red ochre, hide scrapers	Coloring hides while dressing them	Mason (1889)
Denticulates, cobble anvil	Extracting plant fibers from stems and leaves to make cordage and textiles	Osborne (1965:47–48)
Spurs or drills, bone needles	Sewing	de Heinzelin (1962:29), Mason (1899), Nero (1957), Winters (1969)
Hammerstones, metates	Roughening and refurbishing grinding surface of metate	
Manos, metates	Grinding seeds; pounding large seeds, dried roots, bulbs, fruits, meat	Kraybill (1977), Riddell and Pritchard (1971), Driver (1961:93), Miles (1973:44), Wheat (1972:117)
Manos, nuttingstones	Cracking nuts	Battle (1922), Swanton (1946), Waugh (1916:123)
Hammerstones or mauls, unburnt bone, knives	Butchering	Wheat (1972)
Hammerstones or mauls, crushed bone	Extracting marrow, tallow	Mason (1895:28), Leechman (1951), Peale (1871), Wheat (1972:113)
Bone, pottery, fire-cracked rock, hearth liner	Boiling bone to soften it prior to working	Semenov (1964:159)
Pottery, fire-cracked rock, hearth liner	Boiling materials	Carr (1979:346)
Burned bone, fire-cracked rock, hearth liner, ash	Roasting meat over fire, feeding fire to cook	
Tempering material, water-smoothed pebble	Manufacturing pots	Swanton (1946:243, 529)

matical techniques used to search for depositional sets must be modified and made concordant with this structure. This conclusion was foreshadowed 15 years ago, when David Clarke (1968) introduced the concept of polythetic organization to the archaeological community (Thomas and Bettinger 1973).

A MODEL OF THE NATURE OF ORGANIZATION OF INTRASITE ARCHAEOLOGICAL RECORDS

The mathematical techniques that one chooses to search for spatial patterns among artifacts within a site in order to define depositional areas or depositional sets implies (or should imply, if one is interested in logical consistency during analysis) one's conception of the nature of organization of the archaeological record, the nature of the processes by which it was formed, and what one expects to find with the search technique. This section describes a model of the form of organization of intrasite archaeological records, in relation to which previously used techniques of spatial analysis can be assessed for their logical consistency, and new techniques can be proposed. The model was formulated in light of the new understanding of activity organization within sites and archaeological formation processes that has been reached over the course of the 1970s through ethnoarchaeological, experimental, and formal-deductive studies (see page 104). In as much as this research focuses largely on mobile to semisedentary populations, the model is biased toward processes pertinent to these groups.

The model has two primary components. One describes the organizational characteristics of archaeological "tool kits" in set-theoretic terms and enumerates some of the behavioral processes and archaeological formation processes by which the structural features of tool kits are generated. The second describes the characteristics of archaeological "activity areas" and some of the behaviors responsible for them. The first component is a product of my own efforts (Carr 1977, 1979, 1981), whereas the second was developed largely by Whallon (1979), with some additions by me (Carr 1979, 1981). The model pertains primarily to patterns of artifact deposition and distribution, but might be qualified to include patterns of facility manufacture and distribution.

Definitions: Activity Sets, Depositional Sets, Activity Areas, and Depositional Areas

Verbal models should use terms that are defined precisely. It is appropriate, then, to define the terms *activity set* and *activity area*—the entities an archaeologist hopes to reconstruct through spatial analysis.

In the archaeological literature, the term, activity set, is used to refer to two distinct phenomena: (1) those artifact types that repeatedly are used or produced together by the occupants of a site during the behavioral past; and (2) those artifact types that repeatedly aggregate in the archaeological record when it is excavated. Likewise, the term, activity area, has two referents: (1) the location at which an activity was performed in a site, during the behavioral past; and (2) the location where tools or debris indicating past activity aggregate within a site, at the time of excavation.

To avoid ambiguities, it is best if entities in the behavioral past are distinguished from entities in the archaeological present. The sets of tool types used repeatedly in the past to perform a particular task and the resulting debris may be called an *activity set*. The area in which the work occurred may be called an *activity area*. In contrast, the tool and debris types that repeatedly are found together in the archaeological record today may be termed, in the broadest sense (see page 115), *depositional sets*, and the areas in which they cluster, *depositional areas*. Activity sets and activity areas may be said to belong to a *behavioral domain*—the set of all phenomena that might possibly have occurred in the behavioral past. Depositional sets and depositional areas may be said to belong to an *archaeological domain*—the set of phenomena that might possibly occur in the archaeological record of the present. The terms *behavioral domain* and *archaeological domain* are equivalent to the terms *systemic context* and *archaeological context* defined by Schiffer (1972) and Reid (1973) but are introduced to bridge the former pair with mathematical set theory (see page 117).

This distinction of activity sets from depositional sets and activity areas from depositional areas is necessary because they—as all analogous phenomena in the behavioral and archaeological domains—may differ internally in their defining attributes and organization, externally in their relations with entities of like or different kind, and finally in their behavioral meanings.

Consider the differences between activity sets and depositional sets, activity areas and depositional areas, in their behavioral meaning. In the behavioral domain, tools and debris that associate are those actually produced and/or used together. In the archaeological domain, the tools and debris found together could represent a number of behavioral phenomena. They might represent all the tools and debris produced and used together in one kind of task by the previous occupants of the site and deposited in their locations of use. They also might include only a portion of the artifacts, if some were saved for use in other activities at a latter time. Such associations are called *primary refuse* (Schiffer 1972, 1975a). An association also could represent tools and debris that were thrown away together in a formalized dumping location. Associations of this kind have been called *secondary refuse* (Schiffer 1972, 1975a). Other possible kinds of artifact aggregations include: items stored together as a cache for later use—a special kind of primary refuse—or items used in a number of independent tasks that occurred at different times but happened to *overlap* spatially. An association of artifacts also might reflect a particular *social context* rather than some common task in which the artifacts were used (Yellen 1974:204, 207). For example, among the Alyawara Aborigines (O'Connell 1979), the Western Desert Aborigines (Gould 1971) and the !Kung Bushmen (Yellen 1974), a large group of activities occur within the context of the family around the hearth. The remains from such activities overlay each other and are mixed within a single area. Co-occurrences between different artifact types in this situation reflect the common social context in which they were used, rather than use in a common activity.

Adding further complexity, an aggregation of artifacts may not reflect past human behavioral processes at all, but rather, postdepositional processes of natural origin or contemporary human origin. Fluvial transport, solifluction, rodent activity, and contemporary farming are examples of such processes (Wood and Johnson 1978).

Similarly, an *area* in which several kinds of tools and debris cluster together on an archaeological site does not necessarily correspond to an "activity area" in the behavioral domain. Other possibilities include: a trash dump; a storage area; an area of social gathering where multiple activities were performed; or simply the common final resting place of the artifacts, each having been removed and transported from different primary depositional contexts by geological or other natural processes. An area of artifact aggregation also might represent any combination of these possibilities.

Thus, it is misleading to call all repeated associations of given artifact types in the archaeological record activity sets, and all locations of artifact aggregation in the archaeological record activity areas. The behavioral meanings of these terms, referring to phenomena in the behavioral domain, are too restrictive; they do not reflect the full range of archaeological phenomena that a depositional set or depositional area may represent. Similarly, it will be shown in the next section that activity sets and activity areas differ in their internal organizational and external relational properties from depositional sets and depositional areas. Consequently, depositional sets and depositional areas in the archaeological domain must be distinguished from activity sets and activity areas in the behavioral domain.

To refer in a precise way to the *multiple kinds* of depositional sets and depositional areas that may occur in the archaeological record, at the same time distinguishing them from activity sets and activity areas, a hierarchy of terms may be used (Figure 3.2). The terms within different levels of the hierarchy vary in their specificity as to the nature of the associations or aggregations. At the most general level, the terms *depositional set* and *depositional area* may be used to describe associations of artifact types and locations of artifact aggregation, without specifying the processes by which the associations and aggregations were generated. Behavioral, geological, biological, or agricultural processes might be responsible for them. If natural environmental or agricultural disturbances do not

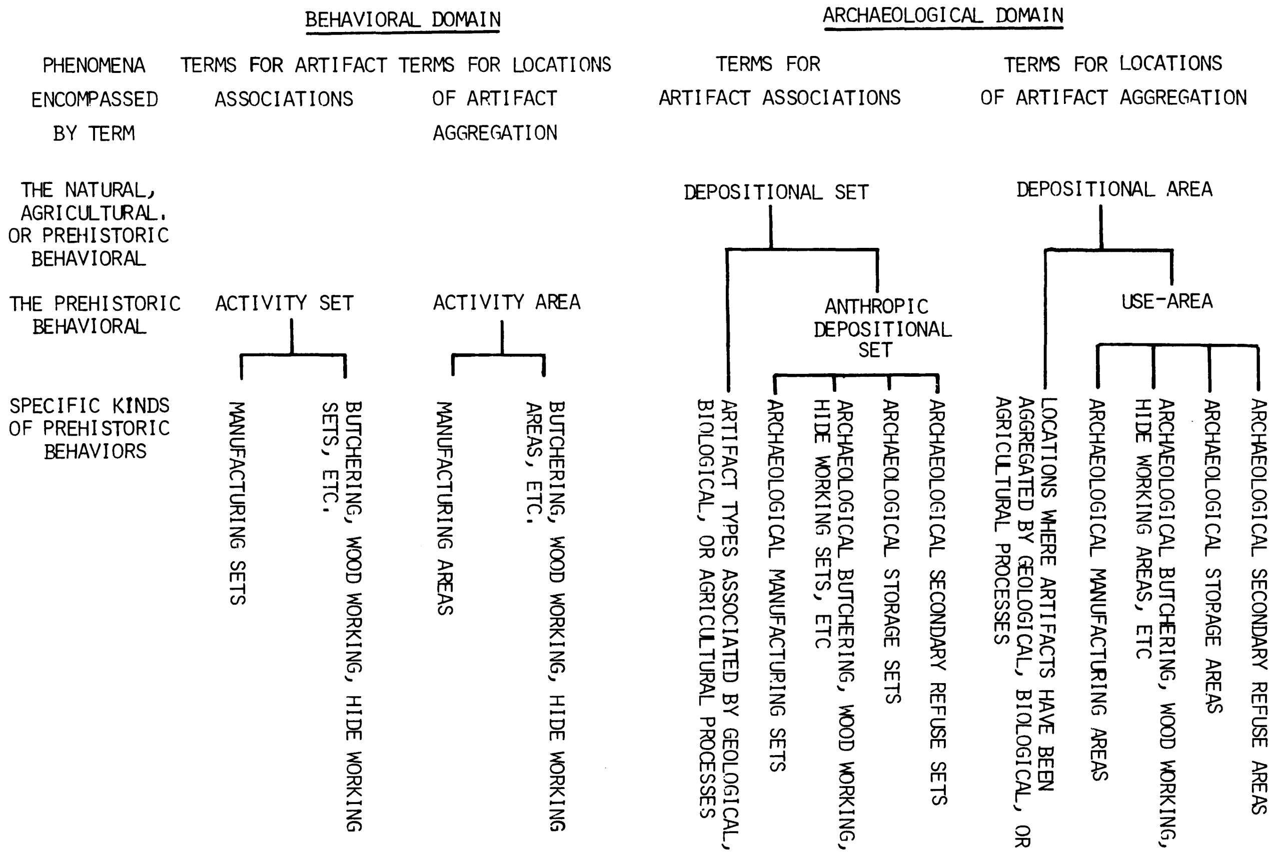


Figure 3.2. Terms for referring to artifact associations and locations of artifact aggregation in the behavioral and archaeological domains.

appear to have generated the associations and aggregations, and past behavioral processes appear responsible, more specific terms may be used. The term, *use-area,* may be applied to the locations, implying that they were used in the past for artifact manufacture, use, storage, or disposal, but not specifying which of these. The term, *anthropic depositional set,* can be used for the set of artifacts that repeatedly were manufactured, used, stored, or disposed of together. These midrange terms are of greatest importance to this chapter. Finally, at the most specific level of designation, associated artifact types might be termed *archaeological manufacturing sets, archaeological butchering sets, archaeological wood-working sets, archaeological storage sets, archaeological refuse sets,* etc. The corresponding locations of artifact aggregation would be *archaeological manufacturing areas, archaeological butchering areas,* etc.

The Polythetic, Overlapping Character of Activity Sets and Depositional Sets

Depositional sets and depositional areas of the archaeological present may be similar to or different from activity sets and activity areas in the behavioral past, not only in their meaning, but also in their organizational and relational properties. This section and the next two explore these similarities and differences.

Given the distinction between depositional sets and activity sets and between an archaeological domain and a behavioral domain, it is possible to view depositional sets as alterations of activity sets, with archaeological formation and disturbance processes linking the two. A depositional set may be thought of as a mathematical set, the organization of which is the end product of structural transformations (archaeological formation and disturbance processes) operating upon a previously structured set (activity sets organized by human behavior). In set theoretic terms, activity sets in a behavioral *domain* may be pictured as being *mapped* into depositional sets in an archaeological domain (or more precisely, *range*) through the operation of various *mapping relations* (Ammerman and Feldman 1974). Importantly, the organization of activity sets and depositional sets, and the nature of the change in organization as one is transformed into the other, also can be described in set theoretic terms.

In set theory, an organization of entities can be described using four basic concepts: (1) *sets*—groups of entities; (2) *members* or *elements of sets*—the entities that are grouped together; (3) *attributes*—the character states that the entities possess; and (4) the *list of attributes* that the entities in a set must share in part or completely to belong to the set. To apply these concepts to the behavioral and archaeological domains for the purpose of describing the organization of activity sets and depositional sets and the organizational transformations linking them, it is necessary to focus on sets of *events* and the sets of *deposits* generated by them, rather than on sets of artifact types (activity sets, depositional sets, tool kits). Suppose a group of past events at a site can be classified into several kinds, according to the functional types of artifacts they involved. The several events (entities) that are of one kind comprise a *set*; they always or often entailed certain common artifact types (attributes). The several artifact types that were used in common comprise a *list of attributes* defining the set, or what has been termed here an "activity set." Similarly, suppose that the archaeological deposits within a site can be classified into several kinds, according to the functional types of artifacts they contain. The several deposits (entities) of one kind comprise a set; they always or often contain certain artifact types (attributes). The several artifact types held in common or tending to be held in common by the deposits comprise a *list of attributes,* or what has been termed a "depositional set," here.

It is unfortunate that the term, activity set, occurs in the archaeological literature, for in set-theoretic terms, within the framework presented here, an activity set is a *list of attributes* required for membership in a set (of events) rather than a set, itself. Similarly, a depositional set is not a mathematical set, but rather is a list of attributes required for membership in a set (of deposits). Because the term, activity set, is cemented in the archaeological literature and depositional sets are analogous to them, I will continue to use these archaeological terms along with the mathematical ones.

Sets, and by extension, the list of attributes that characterize their members, may be described as *overlapping* or *nonoverlapping* in nature, and *monothetic* or *polythetic* in nature. Different sets are said to be overlapping when their members *share* some of the character states required of them (partially or completely) for admittance into their respective sets. Different sets are said to be nonoverlapping when the members do not have in common any of the character states required of them for admittance to their sets (Jardine and Sibson 1968; Sneath and Sokal 1973:207–208). In the behavioral domain, two different functional categories of events—different sets of events—which are defined by the artifact types used in them, would be considered overlapping sets if some of the defining artifact types were shared by the sets. The sets of events would be nonoverlapping if none of the artifact types defining them were shared by the sets. In the archaeological domain, two different functional classes of archaeological deposits—two different sets of deposits—would be considered overlapping if some of the artifact types defining the sets were the same. The different sets of deposits would be nonoverlapping if none of the artifact types defining them were the same (see Table 3.2).

Likewise, by extension, different lists of attributes required partially or completely of the members of different sets may be termed overlapping if some of the attributes in the lists are the same. They may be termed nonoverlapping if none of the attributes in the lists are the same. Two activity "sets" (two different lists of artifact types that always or often were entailed in the events falling in two

TABLE 3.2

Examples of Monothetic, Polythetic, Overlapping, and Non-overlapping Sets of Archaeological Deposits

A Monothetic Set of Archaeological Deposits

Set 1.	Member 1: deposit 1 with artifact types (attributes)	A, B, C, D
	Member 2: deposit 2 with artifact types (attributes)	A, B, C, D
	Member 3: deposit 3 with artifact types (attributes)	A, B, C, D
	Member 4: deposit 4 with artifact types (attributes)	A, B, C, D

Two Monothetic Sets of Archaeological Deposits That are Nonoverlapping

Set 1.	Member 1: deposit 1 with artifact types (attributes)	A, B, C, D
	Member 2: deposit 2 with artifact types (attributes)	A, B, C, D
	Member 3: deposit 3 with artifact types (attributes)	A, B, C, D
	Member 4: deposit 4 with artifact types (attributes)	A, B, C, D
Set 2.	Member 1: deposit 5 with artifact types (attributes)	E, F, G
	Member 2: deposit 6 with artifact types (attributes)	E, F, G
	Member 3: deposit 7 with artifact types (attributes)	E, F, G

No artifact type (attribute) is shared by the members of both Set 1 and Set 2, making them nonoverlapping in nature.

Two Monothetic Sets of Archaeological Deposits That are Overlapping

Set 1.	Member 1: deposit 1 with artifact types (attributes)	A, B, C, D
	Member 2: deposit 2 with artifact types (attributes)	A, B, C, D
	Member 3: deposit 3 with artifact types (attributes)	A, B, C, D
	Member 4: deposit 4 with artifact types (attributes)	A, B, C, D
Set 2.	Member 1: deposit 5 with artifact types (attributes)	D, E, F
	Member 2: deposit 6 with artifact types (attributes)	D, E, F
	Member 3: deposit 7 with artifact types (attributes)	D, E, F

Artifact type D is shared as an attribute of the members of both Set 1 and Set 2, making them overlapping in nature.

A Polythetic Set of Archaeological Deposits

Set 1.	Member 1: deposit 1 with artifact types (attributes)	A, B, C, D
	Member 2: deposit 2 with artifact types (attributes)	A, B, C
	Member 3: deposit 3 with artifact types (attributes)	B, C, D
	Member 4: deposit 4 with artifact type (attribute)	A
	Member 5: deposit 5 with artifact types (attributes)	A, C, D

Two Polythetic Sets of Archaeological Deposits That Are Overlapping

Set 1.	Member 1: deposit 1 with artifact types (attributes)	A, B, C, D
	Member 2: deposit 2 with artifact types (attributes)	A, B, C
	Member 3: deposit 3 with artifact types (attributes)	B, C, D
	Member 4: deposit 4 with artifact types (attributes)	A
	Member 5: deposit 5 with artifact types (attributes)	A, C, D
Set 2.	Member 1: deposit 6 with artifact types (attributes)	D, E, F
	Member 2: deposit 7 with artifact types (attributes)	E, F
	Member 3: deposit 8 with artifact types (attributes)	D, E
	Member 4: deposit 9 with artifact types (attributes)	D, F

different sets) would be considered overlapping if some of the artifact types comprising each activity set were the same. Two depositional "sets" (two different lists of artifact types that always or often are found among members of two different sets of deposits) would be considered overlapping if some of the artifact types comprising each depositional set were the same. The depositional sets would be considered nonoverlapping if none of the artifact types comprising each depositional set were the same (Table 3.2).

Set theoreticians use the adjectives, overlapping, nonoverlapping, monothetic, and polythetic, to describe only sets, not attribute lists. In this chapter, the use of these adjectives is extended to attribute lists, such as activity "sets" and depositional "sets," in accordance with the different use of the term, set, in the archaeological literature.

The distinction between overlapping and nonoverlapping sets and attribute lists refers to the *external* organization of sets. The distinction between monothetic and polythetic sets, and between monothetic and polythetic attribute lists, refers to the *internal* organization of sets. In a monothetic set, the elements of the set all share the same character states; all character states are essential to group membership. In a polythetic set, the elements share a large number of character states, but no single state is essential to group membership (Sneath and Sokal 1973:21; Clarke 1968:37). In the behavioral domain, a functional set of events defined by the artifact types used in them would be monothetic if all the events used the same artifact types. The set of events would be polythetic if the events used a similar but not identical array of artifact types, and no one artifact type was essential to the occurrence of the events. In the archaeological domain, a set of functionally similar deposits would be monothetic if each deposit encompassed the same artifact types. The set of deposits would be polythetic if they shared many artifact types in common, but no single artifact type were essential to the deposits' character.

By extension, if *all* the attributes possessed by the members of a set as a whole are also possessed by each member, the list of attributes may be said to be *monothetic,* or more precisely, *monothetically distributed* among members of the set. If *most* of the attributes possessed by the members of a set are shared in common by them, but no one attribute is required for membership in the set, then the list of attributes may be said to be *polythetic,* or *polythetically distributed* among members of the set. An activity "set" (the list of artifact types characterizing a set of events) would be monothetically distributed among the events if all the artifact types in the activity "set" were used in each of the events. An activity "set" would be polythetically distributed among the events if the events involved in common most of the artifact types in the activity "set," but no one artifact type were used in all the events. A depositional "set" (the list of artifact types characterizing a set of deposits) would be monothetically distributed among the set of deposits if all the artifact types in the depositional "set" were contained in each of the deposits. A depositional "set" would be polythetically distributed among a set of deposits if the deposits held in common most of the artifact types in the depositional "set," but no one artifact type were required of a deposit to be a member of the set of deposits (Table 3.2).

Polythetic sets can vary in the degree to which their members share attributes; one set may be *more polythetic* than another. By "more polythetic," I mean that the percentage of attributes shared by a given percentage of the members of a set is less, or that the percentage of members sharing a given percentage of the attributes is less. A polythetic set of archaeological deposits would be more polythetic than the set of events that generated them if a given percentage of the deposits shared a lower percentage of the artifact types characterizing them as a set compared to those shared by the same given percentage of events. Likewise, the set of archaeological deposits would be more polythetic if the percentage of its members sharing a given percentage of artifact types were less than the percentage of events sharing the same given percentage of artifact types.

Processes Responsible for the Polythetic, Overlapping Organization of Activity Sets and Depositional Sets

Activity sets and depositional sets may be either monothetic or polythetic, nonoverlapping or overlapping, in organization. It is suggested, however, that in most circumstances, at least some of the activity sets used on a site and some of the depositional sets formed at a site are polythetic and overlapping. It also is suggested that, in many cases, depositional sets tend to be more polythetic than the activity sets from which they are derived. These generalizations are supported in this section.

The overlapping organization of some activity sets in the behavioral domain results from at least two factors. First, single-type tools (tools having one kind of functional edge) may have multiple purposes and may be used in combination with several different sets of tools. Prismatic blades, for example, may be used to whittle wood, butcher animals, or shave the scalp (Crabtree 1968). Table 7.1 clearly shows the extensive degree to which tools may have multiple purposes, and thus, may participate in different activities and activity sets. This fact has previously been emphasized by Cook (1976). Second, a single item may have multiple functional edges used in different activities, all the functional edges of which spatially coincide when the item is used in any one of the activities. For example, a Swiss army knife has knife blades, a can opener, a cork screw, a fingernail file, and other functional edges. As a result of the compound nature of the item, by physical constraint but not functional requirement, all the activity sets in which any one of the functional edges participates must share the Swiss army knife as a whole item and all the functional edges (individual tools) comprising it.

The polythetic organization of some activity sets results from the fact that several alternative tool types may be used to accomplish the same ends. For example, the Nunamiut Eskimo use both saws and knives to cut meat (Binford 1976). In any particular butchering event, one or the other of these tools might be used, but not necessarily both. A set of Nunamiut butchering events would be defined by all the tool types (attribute list) usually used to butcher animals, but only some of the events would involve saws and only some would involve knives.

The polythetic, overlapping organization of depositional sets results in part from their derivation from activity sets having a polythetic, overlapping structure. The *more* polythetic nature of depositional sets than activity sets derives from a number of additional factors involving behavioral processes, processes of formation and disturbance of the archaeological record, and processes of recovery and analysis (Binford 1976; Schiffer 1972, 1973a,b, 1975a,c, 1976, 1977, 1982).

Factor 1: Time of deposition of artifacts within their life-histories. The artifact types comprising an activity set in the behavioral domain may enter the archaeological domain as subsets, separated in different locations of their manufacture, use, storage, or discard.

Factor 2: Size-sorting of artifact classes. Artifact types of different size classes, belonging to the same activity set, may be discarded in different locations upon fulfillment of their use. Large items will tend to be discarded in convenient, out-of-the-way, secondary trash deposits, whereas smaller items may be discarded or lost anywhere (McKellar 1973).

Factor 3: Curation and differential wear and breakage rates of artifact classes. If the artifact types within an activity set are *curated*—that is, removed from one use-area for reuse at another later in time (Binford 1976)—and if the activity is not performed repeatedly in the same use-areas, differential wear rates and breakage rates may lead to different subsets of the activity set being deposited in the different locales. The degree to which the artifact types within an activity set are curated and not always deposited with each other depends on the labor invested in manufacturing them, their cultural importance, the ease with which they can be moved, the distance to the next site to be occupied in the annual round of the community, the availability of the types (or the raw materials from which they can be made) at the next site, whether abandonment of the current site is planned, and the degree of mobility of the community (Schiffer 1972:160, Lange and Rydberg 1972:430; Joslin–Jeske 1981). The number of classes of tools curated by a social group tends to increase with the residential stability of that social group (Binford 1976:42).

The great impact that curation can have on the organization of the archaeological record is illustrated by Binford's (1976) work among the Nunamiut Eskimo.

Binford recorded the number and kinds of items that were taken by the Nunamiut on 47 logistics trips away from their base camps. Of the 647 trip-items carried, 99 were totally consumed in the course of their use, most of these being food items. The remaining

> five hundred and forty-eight (548) of the trip-items carried were visible in that there were tangible by-products from their use or no destruction occurred during their use. Of these items, fifty-three, or only 9.67 percent of the total visible items were not returned to the village. . . . Of these fifty-three (53) trip-items, thirty-six (36) are items which are disposable byproducts in the context of their use, including the peanut butter jar, sardine can. . . . Of the remaining eighteen (18) items not returned to the village, fourteen (14) or 26.3% of the total were cached in the field for future use. Of the remaining four items, three were unintentionally lost on the trail and *only one was discarded, broken at the location where it was used.* This is not, however, the only item broken during the course of the forty-seven trips. Twelve additional items were broken, but returned to the village for repair [1976: 334–335].

Factor 4: The multipurpose nature of tool types. The multipurpose nature of some tool types, which in the behavioral and archaeological domains is responsible for the overlapping organization of activity sets and depositional sets, also is responsible for the polythetic organization of depositional sets. A multipurpose tool can be deposited with the members of only one of the activity sets in which it participates.

Factor 5: The compound nature of tool types. In a similar manner, a compound tool having several different functional edges and used in several different activities, such as a Swiss army knife, not only will make the activity sets and depositional sets to which it belongs overlapping, but also will make the depositional sets polythetic. A multifunctional compound tool can be deposited with the members of only one of the activity sets in which it participates.

Factor 6: Recycling of artifacts. The polythetic organization of depositional sets may be caused by the reworking of an artifact of one type, that has been used or produced in one activity and that belongs to one activity set, into a different type used in another activity (''recycling'' in Schiffer's terminology). The reworked artifact will be deposited with the members of only the last activity set in which it participated.

Factor 7: Mining of artifacts. When a site is abandoned over an extended period of time, useful or valuable material items in the abandoned area may be ''mined'' (another form of recycling) by the residual occupants and reused for the same or different purposes in other areas of the site. This behavior creates deposits in the abandoned area that form polythetic sets. Similarly, but on a smaller scale, Reid (1973) has noted that as households expand and contract in size over time and new rooms or huts are built and abandoned, the abandoned ones may be mined for materials by the members of the household. Also, as a site shifts gradually in location without loss of membership to the social group, previously occupied areas may be mined of tools and debris for use in the newly occupied part of the site (Ascher 1968). The artifacts mined are not always tools; debris items and junk also may be picked up. Some debris items are recycled immediately, but some are cached as raw material to be used at a later time and might never be reused (James O'Connell, personal communication 1977).

A site also may be mined of materials after its total abandonment by either prehistoric individuals or contemporary artifact collectors (Schiffer 1977:26). This behavior may cause items to be missing from deposits where they normally would occur, some artifact types being picked up more heavily than others.

The methods of data collection and analysis used by the archaeologist may artifically cause recovered depositional sets to appear polythetic in organization. Factors 8 through 11, below, are of this artificial nature.

Factor 8: Incomplete recovery of artifacts. When recovery of artifacts is not complete, as is the case with surface survey data or when screening is not used during excavation, depositional sets will be polythetic (Collins 1975; Schiffer 1977:26).

Factor 9: Classification of artifacts using other than functional attributes. When tool and debris classifications are based on stylistic rather than functional attributes, functionally equivalent items belonging to the same activity set may be classified into separate types, causing depositional sets to appear more polythetic. This is the case when classic lithic tool typologies are used, in which attention is given to flake shape and size and to retouch patterns (e.g., Balout 1967; Bordes 1961, 1968; de Heinzelin 1962; Tixier 1963) rather than to more functional attributes, such as the angle, shape, and wear of the working edge of the tool (e.g., Ahler 1971; Keeley 1977; Odell 1977; Odell and Odell–Vereecken 1980; Wilmsen 1970).

Factor 10: Overly divisive artifact classification. An overly divisive typology also will yield polythetic depositional sets. Care must be taken not to overclassify artifacts, particularly with the assemblages of mobile populations who apparently are more opportunistic about the tools they use to accomplish tasks. As Gould *et al.* have pointed out:

> [It would be] a mistake to overclassify the ethnographic adzes (i.e., scrapers) of the Western Desert Aborigines. Ethnographic observations over an extended period of time and in a variety of situations lead, instead, to an appreciation of the casualness and opportunism of present day Aborigine stone chipping. To these people, the primary aim is to perform a task involving either cutting (of sinew, flesh, vegetable fibers, etc.) or scraping (of wood) with little interest in the shape of the tool except for the angle of the working edge relative to the particular task involved [1971:154].

James O'Connell (personal communication, 1977) estimates that there are only about 10 functional types of artifacts in Alyawara assemblages—a quite small number compared to the elaborateness of some supposedly functional typologies of tools of mobile groups that archaeologists have designed. Binford and Binford's (1966:251) list of 40 tool types used in examining the Mousterian of Levallois facies would be an example of an overly divisive tool typology.

Factor 11: Misclassification of artifacts. Finally, misclassification of artifacts will cause certain classes of artifacts to appear missing from the deposits where they are expected to occur, producing depositional sets with a greater degree of polythetic organization than would otherwise be the case.

In summary, a consideration of human behavior, the organization of artifacts in the behavioral domain, the processes by which that organization is transformed when mapped into the archaeological record, and archaeological recovery and typological techniques suggest that some artifact types are likely to be distributed polythetically among activity sets and depositional sets, and that some activity sets and depositional sets are overlapping in nature. Additionally, depositional sets tend to be more polythetic than the activity sets from which they were derived. These facts must be taken into consideration when designing spatial analytic techniques that search for depositional sets and use-areas and when interpreting the results of applying those techniques.

Characteristics of Activity Areas and Use-Areas

In this section, I will not try to specify the nature of *all* depositional areas. In particular, I will not discuss the nature of areas of artifact occurrence resulting solely from natural or agricultural transport processes (e.g., fluvial transport, landscaping). This would require a treatment of geomorphological, sedimentological, and agricultural taphonomic processes that would be too broad in scope for this chapter (e.g., Behrensmeyer 1975; Gifford 1978; Hill 1975; Saunders 1977; Shipman 1981; Voorhies 1969a,b). Instead, I will discuss the nature of only use-areas—those areas of artifact occurrence that result from primary or secondary refuse deposition by *past human agents,* with *incomplete* postdepositional disturbance. Areas of artifact manufacture, use (e.g., butchering and cooking areas), storage, and disposal are of concern.

The characteristics of use-areas, like those of anthropic depositional sets, may be seen as the end product of structural transformations (archaeological formation and disturbance processes) operating on previous structure in the behavioral domain. To define the nature of use-areas, therefore, it is necessary to specify first the characteristics of the entities from which they are derived—activity areas.

Characteristics of Activity Areas

Whallon (1979) has specified four characteristics of activity areas that one must take into account when designing spatial analytic techniques that search for use-areas. Activity areas vary greatly in their size, shape, artifact densities, and artifact compositions. To these characteristics may be added the following. Activity areas are not necessarily high-density clusters of artifacts in a background of lower densities of artifacts; they may be areas of low-artifact density surrounded by zones of higher artifact density. Activity areas may vary in the degree to which they are internally homogeneous in their artifact densities. They may differ in the degree to which they are internally homogeneous in their artifact composition. The borders of activity areas may vary in their crispness. Finally, activities and activity areas within a site may be hierarchically organized, with more localized areas of activity (general or special purpose) aggregating and forming broader zones of activity.

A large number of behavioral processes are responsible for these characteristics of activity areas. Some may be enumerated, in the order of the characteristics they determine.

Factors Affecting the Size, Shape, and Artifact Density of Activity Areas.

Factor 1. Different kinds of activities may produce different amounts of debris, creating different densities of artifacts within the areas where these activities are performed. For example, secondary butchering (requiring only a few flake knives), hide dressing (requiring only a few scrapers, knives, and organic materials), and weaving all produce very little preservable refuse compared to activities such as primary butchering, shelling mollusks, flint knapping, or pottery manufacture.

Factor 2. Different kinds of activities may require different amounts and shapes of space, producing activity areas of different sizes and shapes. Hide dressing, for example, requires more room than whittling wood or knapping flint. In Alyawara Aborigine base camps hides are worked away from the huts, where space is more abundant and they can be laid out without interferring with the space requirements of other activities (O'Connell 1979, personal communication 1977). At the Crane site, a Middle Woodland base camp in Illinois, tools used to work hides were found to have larger nearest neighbor distances than did artifacts used for or produced by butchering meat, boiling meat, hulling nuts, grinding seeds, and sewing/basket-making (Carr 1977). The different space requirements of different kinds of activities also have been noted on a grander scale by Binford (1972). Binford suggests that the functions of sites and the activities performed at them may change directionally over time in response to directional changes in the amount of space available at the site for use. For example, the functions of a cave site may change as it becomes filled with debris and provides less utilizable space.

*Factor 3. The degree to which an activity (*a*) requires much space and time, (*b*) produces much debris, and (*c*) creates obnoxious byproducts, such as smoke or animal residues that attract vermin or carnivores, may determine where it is performed within a community. The placement of an activity, in turn, may* *constrain the size, shape, and artifact density of the area in which it is performed.* Activities that require large amounts of space or that are obnoxious often are performed away from residential locations or at the periphery of the base camps or mobile to semimobile peoples. There, space is not so limited and valuable as in the central portion of camp, and the activities may be performed without interfering with other events; they also are of less annoyance at a distance. In the periphery where more work space is available, debris from the activities may tend to be spread more widely and randomly. Also, activity areas may be shifted laterally to avoid debris buildup within them, rather than cleaned. The result is work areas that are larger, are more amorphous in shape, and contain a lower density of debris than might be expected from the rate of refuse production of the activities. In contrast, centrally located activities (e.g., knapping, sewing, food preparation) may occupy smaller areas in which debris tends to concentrate. More commonly, all the central activities may be performed in one large, multipurpose activity area that is within easy access of residences and is cleaned periodically and between activities of different kinds. The action of cleaning the area will cause it to have a low density of items of all sizes, except those that are very small. Centrally located activity areas will tend to be well defined in shape, as a result of their location where space is limited and allocated with care.

Activity areas in the base camps of !Kung Bushmen (Yellen 1974) and Alyawara Aborigine (O'Connell 1977, 1979; personal communication, 1977) follow the pattern of location, size, shape, and artifact density just described. For example, stretching hides (a long-term activity that requires much space) and repairing cars (a messy activity) occur at the periphery of Alyawara camps. In Bushman camps, stretching hides and roasting meat (messy activities) occur peripherally. In Ainu base camps, skinning, skin decomposition, drying fresh meats, and fish processing are done away from the house (Watanabe 1972:Figure 4). Archaeologically, at the Boston Ledges Rock Shelter (Brose and Scarry 1976), tools for scraping hides and butchering animals occurred peripheral to hearth-oriented activities. At the Hatchery West site (Binford et al. 1970), shallow earth ovens that were used in preparing animal products and that would have produced obnoxious odors were placed away from the houses. At the Crane site (Carr 1977), hide dressing, pottery manufacture, rough working of wood, butchering, and possibly drying of meat occurred with greater frequency away from the central, residential portion of the site, whereas chert knapping, nut processing, seed grinding, and sewing/basket-making occurred in the central, residential portions of the site in a multipurpose work area. The centrally located activities were performed in a constrained area, whereas the peripheral activities were widely scattered.

Factor 4. Different kinds of activity areas may be used repeatedly for different lengths of time. In addition to causing differences in the amount of refuse generated by the activities per episode of use, this behavior will cause the density of artifacts within the areas, and perhaps their size, to vary from area to area. The period of time over which an activity area is used in turn can depend upon a number of factors. (*a*) If an activity produces obnoxious organic refuse, it probably will be relocated periodically to avoid distasteful and unhealthy conditions in the area of work. (*b*) If an activity requires the use of a permanent facility as well as work space, and if the facility represents an investment of labor and time, the activity area probably will be cleaned rather than relocated to avoid the interference of refuse, and will be used for a long time. (*c*) Activities that can occur under cover or indoors during rainy or cold seasons will tend to be repeated in the same protected location for a length of time dependent upon the length of the harsh season and the use-life of the protecting structure. (*d*) As before, the length of time over which an activity occurs in the same area can depend on whether it is located peripherally in a site, where space is less constrained and periodic relocation of the activity is possible, or more centrally in the site, where space is at a premium and relocation is less feasible. (*e*) Dumping stations may be used for variable lengths of time, depending on: whether they remain close to work areas that shift in space over time; the amount of space allocated for growth of the dump before it interferes spatially with neighboring activity areas; or the time at which the refuse begins to produce a stench.

Factors Affecting the Artifact Composition of Activity Areas. The composition of activity areas of the same function can vary as a result of at least three factors.

Factor 1. The factors that cause an activity set to be polythetic may cause different locations of the same activity to encompass different subsets of the activity set used. In some locations of an activity, some combinations of tool and debris types may be used or produced, whereas in other locations of the same activity, other combinations of tool and debris types may be used or produced, all of which comprise one activity set.

Factor 2. The composition of activity areas of the same function may vary according to their durations of use. This relationship, between composition and duration of use, can arise from either of two circumstances: one pertaining to the different *combinations* of artifact types (subsets of an activity set) that are *used or produced* in an activity area at different times, and the other pertaining to the different *probabilities of discard* of the artifact types in an activity set. (1) Given an activity with a polythetic activity set, as the number of times the activity is performed at an area increases, the variety of *combinations* of artifact types used or produced in the area and the variety of artifact types deposited there will increase. Eventually, most or all of the artifact types within the activity set will be deposited at the location, provided it is not cleaned regularly. Thus, different activity areas of the same kind may encompass different numbers of artifact types that more or less represent the complete activity set of which they are a part, as a function of the life spans of the areas and the *number of different subsets* of the activity set used or produced at each of them. (2) Not all of the artifacts and artifact types used in or produced by any single occurrence of an activity are necessarily deposited expediently at the location of activity. The probability of deposition of each artifact class involved in one activity occurrence depends on its rate of breakage and the suite of factors governing its rate of curation (see pages 122–123). An activity area used only a few times may bear only a few of the artifact types used or produced at it—those with high rates of breakage or wear and low curation rates. The deposited artifacts will be a subset of those used at the location (which in turn may be a subset of the activity set to which they belong, as in Circumstance 1). As the length of time over which the location is used increases, the probability that artifact types with longer life spans and greater curation rates will be deposited at it will increase, provided the area is not cleaned regularly. Thus, different activity areas of the same kind may encompass different numbers of artifact types that more or less represent the complete activity set to which they belong, as a function of the life span of the areas and the relative probabilities of discard of the artifact types. Longer-used activity areas of the same function will tend to be more similar in their artifact compositions.

These circumstances pertain equally to activity areas used for work and those used for refuse deposition. Storage areas, however, do not show the time-dependent alternations in artifact composition just discussed.

Factors Affecting the Artifact Density of Activity Areas Compared to Their Surroundings. Activity areas may be zones of low artifact density within a background of higher artifact density, as well as high density clusters of artifacts. This pattern relates to the fact that activity areas may be cleaned and swept. The swept refuse may be deposited around the activity area, emphasizing the locally low relative artifact density in the area of work, or it may not.

Several factors determine whether an activity area is cleaned. First is the degree to which space in the vicinity of the area is limited. If space is limited and the activity area cannot be moved, upon becoming cluttered, to a new, clean area, it will be cleaned for reuse. This logic is exemplified in Alyawara and Bushman camps; activity areas next to residences, where space is at a premium, are cleaned, whereas work areas around the periphery of the camps are moved laterally. Space can be limited because the site population is high or because the ground available for habitation is constrained (as in a rock shelter or house). A second determinant of whether an activity area is cleaned is the degree to which the area, itself, is valued. An area may be the prefered location of an activity because it includes a permanent facility that is not easily rebuilt elsewhere, or because of intrinsic reasons (it has a pleasant view; it is shaded or protected from the wind; etc.). Finally, the degree to which the refuse generated in the activity area is messy or unhealthy determines whether an activity area is cleaned.

Factors Affecting Internal Variation in the Artifact Densities and Compositions of Activity Areas. The degree of homogeneity of an activity area in its artifact densities and compositions depends on several factors. For primary refuse deposits, these factors include: whether use-space is limited, whether the activity area of concern is swept for reuse, and whether the activity is tied to a permanent facility. When an activity occurs in a portion of a site where space is abundant, debris can be scattered widely, producing a large, amorphous activity area with internally variable artifact density and artifact composition. Under conditions of space restriction and some other circumstances (above), on the other hand, an activity area may be swept for reuse, leaving within it a scatter of artifacts that is uniformly low in density and relatively homogenized in artifact type composition by the sweeping action. Also, an activity that requires, in part, the use of a permanent facility may produce a scatter of artifacts that has higher densities of artifacts, or more artifacts of specific kinds, in the immediate vicinity of the facility.

For secondary refuse deposits, internal density and composition depend on how the area of primary deposition (source of refuse) was cleaned, how refuse was transported to the dumping location, and the transportability of the refuse (dependent on the sizes, weights, and shapes of the refuse items). For example, if a refuse dump is generated from the sweepings of an adjacent work area, and if all items of refuse of different kinds are similarly transportable, the dump may be fairly homogeneous in artifact composition as a result of the randomizing action of the broom. Homogeneity in composition will decrease as variability in the transportability of artifacts by class becomes more pronounced and sorting of artifacts by type occurs. Similarly, the dump's internal pattern of artifact density will depend on the degree of variation in the transportability of refuse items. If the work area is cleaned by collecting refuse in containers that are filled and dumped many times, rather than by sweeping, the dump may exhibit a more heterogeneous artifact density and composition.

A Factor Affecting the Crispness of the Borders of Activity Areas. This attribute of an activity area depends particularly on how constrained space is. Where space is abundant, work areas and refuse areas can be expected to have "fuzzy" borders characterized by a slow gradient of change in artifact density. This results from the broadcasting of refuse from the core of the work space outward, and a lack of concern for where the refuse is deposited. Artifact scatters from space-consuming, time-consuming, or messy activities performed at the peripheries of sites, as those in Bushman and Alyawara camps, can be expected to show this pattern. Where space is limited, activity areas—whether work, storage, or refuse areas—can be expected to have better monitored, imposed borders.

Factors Affecting the Hierarchical Clustering of Activity Areas. Activity areas within a site, and the artifacts composing them, often are arranged in a hierarchically clustered form, rather than a random one (Figure 3.4). For example, a community might be arranged into two groups of residences, each with multiple households that, in turn, have multiple activity areas around them. Artifact distributions would parallel this structure, ignoring the effects of secondary depositional processes. Within the wide, low-density scatter of artifacts defining the site (community) would occur two broad zones of moderate, average artifact density (residential groups), themselves composed of multiple zones of high artifact density (residences) that could be subdivided into areas of varying artifact density (activity areas of different kinds). The hierarchical arrangement of activities and activity areas within a site may derive from the social segementation and organization of the occupants, the different degrees to which different kinds of activities are contingent upon each other, and site topography, among other things.

Characteristics of Use-Areas

Use-areas, as transformations of activity areas, may have all the variable characteristics of activity areas as just described, plus an additional one. Use-areas of similar or different function may *overlap spatially*. The overlapping nature of use-areas may result from either *accidental* or *planned* overlapping of activity areas within a site over time. Accidental overlapping of activity areas may occur, for example, when a base camp is annually reoccupied by the same local group but the camp is set up in a slightly different arrangement each year. The ''homogeneous'' middens of many Late Archaic sites in the Eastern United States exemplify the results of this process. Planned spatial overlap of activity areas may occur when work space within a community is limited. For example, valued work space around the hearths and huts of Bushman and Alyawara camps is used for multiple purposes, with different kinds of activities scheduled at different times (Yellen 1974; O'Connell 1977, 1979).

Use-areas may vary more than activity areas in the characteristics they share as a result of the broader range of factors affecting use-areas.

Factor 1. Variation in the degree of spatial overlap of use-areas within a site may increase the range of variation in their other characteristics. A greater degree of overlap among use-areas may cause them to have higher artifact densities, more internal variation in artifact density, less distinct borders, and a more diversified artifact composition than they would have otherwise.

Factor 2. When an activity occurs in a portion of a site where space is unconstrained, its location may shift gradually over time, from its original position where primary refuse has built up, to adjacent, cleaner zones. This process will create a composite use-area that is larger, more amorphous, and less distinct in its boundaries than the numerous activity areas that generated it.

Factor 3. Numerous postdepositional processes of disturbance in the archaeological domain (Schiffer 1976; Wood and Johnson 1978) may alter the characteristics of activity areas, producing use-areas of modified size, shape, average artifact density, overall artifact composition, degree of internal variation of artifact density and composition, and border definition. The operation of these factors differentially over space may cause variability among and within use-areas in these attributes to be greater than that of the activity areas from which they are derived.

Most postdepositional processes have the effect of disordering artifact patterning in the archaeological record—increasing the entropy of the archaeological record (Ascher 1968). They make use-areas larger, more amorphous, lower in artifact density, more homogeneous in their internal artifact density, less distinct in their boundaries, and more similar (or at least skewed) in artifact composition. Examples of such processes include: (1) trampling of abandoned use-areas by residents of the site or contemporary artifact collectors (Ascher 1968; Gifford 1978); (2) systematic mining of abandoned use-areas by residents of a site or contemporary artifact collectors (Ascher 1968); (3) plowing and other farming operations (Roper 1976; Trubowitz 1981; Lewarch and O'Brien 1981); and (4) a variety of natural pedoturbations of biological and geological cause, such as the burrowing actions of mammals, insects, and earthworms (Stein 1983); tree falls; soil creep; solifluction; cryoturbations and aquaturbations (Wood and Johnson 1978). Some postdepositional disturbance processes, however, may increase the degree of patterning of artifact disturbances, but toward natural arrangements. Examples include the burrowing actions of earthworms, which can produce novel arrangements of surficial debris (Ascher 1968); freeze–thaw cycles, which produce ''patterned ground'' (surface stone aggregations in the shapes of rings, polygons, or stripes) or stone pavements; expansion–contraction cycles in vertisols, which form ''linear gilgai''; precipitation of salt crystals in the soil, followed by cracking the soil, producing patterned ground; and soil creep, which may result in the accumulation of heavier or denser objects downslope (Wood and Johnson 1978). Finally, some postdepositional processes may simply truncate use-areas, altering only their size and shape. Examples include the scooping up of archaeological deposits by site occupants to build earthworks and mounds (Schiffer 1977:25), modern landscaping, and intensive localized fluvial disturbance.

In summary, activity areas, as the products of many different behavioral processes, may be highly variable in their size, shape, and many other basic characteristics. Use-areas, being derived from activity areas and operated on by additional archaeological formation and disturbance processes, may be even more variable. Mathematical techniques used to search for use-areas within archaeological data consequently must not assume that they are similar in nature, if the methods are to be concordant with the structure of the archaeological record.

A REVIEW OF PREVIOUSLY USED SPATIAL ANALYTIC TECHNIQUES AND EVALUATION OF THEIR APPROPRIATENESS FOR INTRASITE ANALYSIS

Introduction

Despite the advances made in recent years in techniques for quantitatively analyzing spatial arrangements of artifacts within archaeological sites, satisfaction with these techniques and their results has been limited (Whallon 1979). In general, the results of such analyses have told archaeologists less about the arrangement of artifacts within sites than have their own perceptions of the data and their own mental capabilities to discover and understand patterns within the data. As a consequence, quantitative spatial analysis of intrasite patterning has not become the standard approach in archaeology that once seemed probable.

There is good reason for this state of affairs. The techniques of spatial analysis currently available to the archaeologist do not have assumptions that are logically consistent with: (1) the organization of archaeological remains, and (2) the patterns of human behavior and the archaeological formation processes responsible for that organization, as modeled here.

This section briefly describes the mathematical techniques that currently are available to archaeologists for intrasite spatial analysis, cites more detailed explanations and examples of use of the techniques, and evaluates the methods for their logical consistency with the structure of intrasite archaeological records, as modeled. The techniques to be discussed are shown in Table 3.3, along with their manner of concatenation into several alternative approaches for meeting the several operational goals of intrasite spatial analysis. Table 3.4 summarizes, for quick reference, the unwarranted assumptions that the techniques make about the spatial structure of artifacts within archaeological sites, and by implication, the nature of human behavior, archaeological formation processes, and archaeological recovery techniques.

Methods for Assessing Whether Artifacts Cluster in Space

Definitions and Qualifications

A study area with scattered artifacts minimally has two global attributes that are important to the archaeologist: (1) the average *density* of artifacts within it, and (2) the *form of arrangement* of artifacts within it—clustered, random, or

TABLE 3.3

Alternative Routes of Spatial Analysis Using Different Sets of Techniques

	Previously used approaches[a]			New, more appropriate approaches[a]		
Question	Approach 1 (grid-cell counts)	Approach 2 (grid-cell counts)	Approach 3 (point locations of items)	Approach 4 (point locations of items or grid-cell counts)	Approach 5 (point locations of items preferable)	Approach 6 (grid-cell counts)
Artifacts randomly scattered?	Poisson method of assessing if random scatter	Dimensional analysis of variance or Morisita's Index	First-order nearest neighbor statistics	Bypass, "not considered relevant" by Whallon (1979)	*N*th-order nearest neighbor statistics or point-to-item distance statistics	Luton and Braun's contiguity method
Spatial limits of clusters, defining "activity areas"?	No attempt to define	No attempt to define	Whallon's "radius approach"	Whallon's "unconstrained clustering"	Carr's modifications, 1 or 2, of Whallon's "radius approach"	Contiguity– anomaly method
Artifact types covary/co-occur, defining "tool kits"?	Correlation of artifact type counts within excavation/survey grid units, *over whole site,* followed by factor analysis, cluster analysis, matrix ordering, or *MDSCAL*	Correlation of blocked data, *over whole site,* followed by factor analysis, cluster analysis, matrix ordering, or *MDSCAL*	Pielou's segregation analysis, *over whole site,* or Whallon's "radius approach" over *whole site*	Correlation or association of artifact type counts *within clusters* after they are defined. Avoidance of defining site-wide "tool kits"	Carr's "polythetic association" *over whole site*	Appropriate index of co-arrangement yet to be designed

[a] The form of data required is given in parentheses under each approach.

systematically spaced—independent of density (Pielou 1977:124). For clustered arrangements of artifacts, the degree of clustering (form) is a function of both the *intensity* and *grain* of patterning of artifacts (Pielou 1977:155) and whether clusters themselves cluster hierarchically in a *nested* or *unnested* fashion. The intensity of a clustered pattern is the extent to which clusters and sparse areas differ in their density. An intense pattern is characterized by very high density clusters and very low density interstitial spaces. The grain of a clustered arrangement refers to the size of clusters and sparse areas. A coarse-grained arrangement has very large clusters widely spaced, whereas a fine-grained arrangement has small, closely spaced clusters. All clustered arrangements are hierarchical (compared to arrangements that are uniformly random or aligned throughout) in that they exhibit minimally two levels or organization: arrangement of items within clusters, and the spacing of clusters with respect to each other (Figure 3.3). Additional hierarchical levels may take the form of nested or unnested clusters of clusters (Figure 3.4).

A large number of techniques are available in the ecological literature for assessing the form of arrangement of items over space, most of which are summarized and evaluated by Greig-Smith (1964:54–111) and Pielou (1969:124–165). The various techniques allow assessment of arrangement in either or both of two ways. (1) They may provide an *index* of the degree of aggregation or dispersion of items over space (e.g., the variance:mean ratio) that may be compared between areal units (statistically or not), giving a *relative* assessment of arrangement. (2) They may provide a statistical test measuring the significance of the deviation of an observed index value for a scatter of items from that expected for a random arrangement of items of the same number and density, giving an *absolute* assessment of form of arrangement. Applied archae-

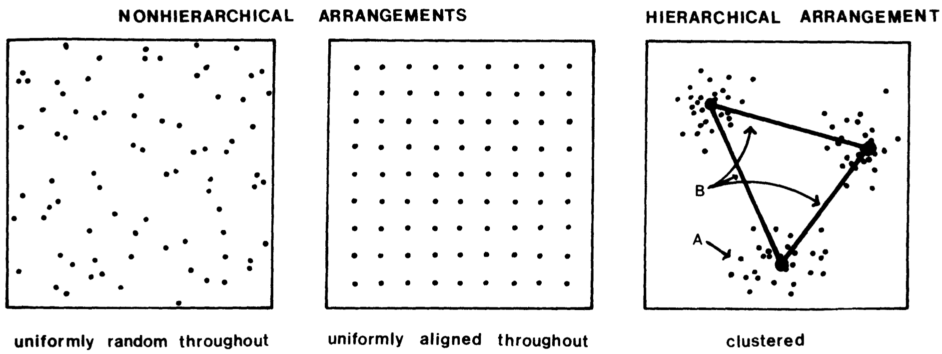


Figure 3.3. Clustered arrangements are hierarchical compared to arrangements that are uniformly random or aligned throughout. Clustered arrangements exhibit two levels of arrangement: (A) arrangements of items within clusters and (B) the spacing of clusters with respect to each other.

TABLE 3.4

Unwarranted Assumptions Made by Spatial Analytic Techniques Currently Used by Archaeologists Regarding the Nature of Formation/Organization of the Archaeological Record

	Technique					
Unwarranted assumptions	Poisson method	Dimensional analysis of variance	Morisita's Index	First-order nearest neighbor statistics	Correlation analysis	Association analysis
Assessment of co-arrangement is contingent upon delimiting clusters.						
Activity sets are always monothetic.					X	X
Members of activity sets are deposited expediently in their locations of use.					X	X
Artifact types in the same activity set are deposited in pairs in all locations of their deposition.						
Artifact types in the same activity set are deposited in similar proportions in all locations of their deposition.					X	
Artifact types in the same activity set are deposited together in unspecified numbers in all locations of their deposition.						X
Artifacts are not disturbed by polythetic-causing, postdepositional processes.					X	X
Artifact types are completely recovered and correctly classified to function.					X	X
Activity areas were used an extended, approximately equal period of time.					X	X
Activity sets are always nonoverlapping.					X	X
Use-areas are of similar size.	X	X	X		X	X
Use-areas are of similar shape.	X	X	X		X	X
Use-areas, if oblong, have the same orientation.	X	X	X		X	X
Use-areas are spaced systematically.	X	X	X		X	X
Use-areas are of similar density.						
Use-areas have the same number of artifacts.						
Use-areas are internally homogeneous in artifact density.						
Use-areas are internally homogeneous in artifact composition.						
Use-areas have crisp borders.						
Use-areas do not overlap spatially.						
Use-areas are always high-density clusters of artifacts in a background of lower artifact densities.						
Use-areas are never hierarchically arranged.	X			X		
Sites are of square or rectangular shape.		X	X			

	Technique										
	Segregation analysis	Whallon's overlapping clustering approach	Whallon's radius approach	*N*th-Order nearest neighbor statistics	Pielou's point-to-item distance statistics	Luton and Braun's contiguity method	Polythetic association	Modified radius approach I	Modified radius approach II	Contiguity–anomaly method	Unconstrained clustering
	X	X									X
	X	X									X
	X	X									
											X
	X	X									X
	X	X									X
		X									X
	X	X									
						X					
						X					
						X					
			X								
				X							
		X	X								
		X						X			X
										X	
											X
		X	X				X	X	X		

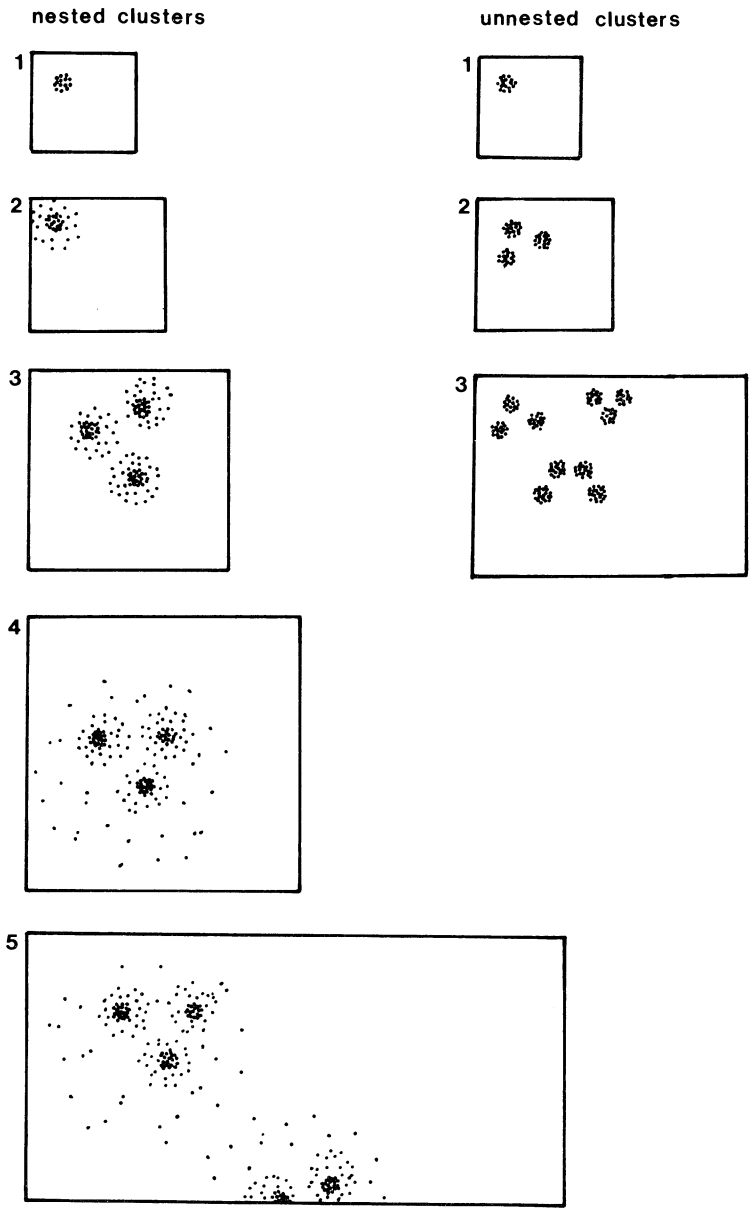


Figure 3.4. Clusters, themselves, may cluster in either nested or unnested patterns.

ologically, the former approach allows comparison of the arrangement of items within different use-areas or sites directly to each other, whereas the latter allows an absolute evaluation of arrangement within single study units.

Archaeologists most frequently have used four methods to assess the form of arrangement of artifact scatters. These are listed in Table 3.5, along with: their sensitivity to the various aspects of arrangement form just described, whether they provide relative or absolute measures of arrangement, and the kind of data they require (grid-cell counts or point locations of items).

The usefulness of these or any of the available techniques for assessing the form of arrangement of artifacts within a study area depends on the nature of the data and the information sought. When average artifact densities within a study area are high, in many circumstances the pattern of arrangement may be clear on visual inspection, and no rigorous testing may be necessary. At lower average densities, however, the same arrangement may become more difficult to evaluate for its form, as a result of the loss of potential contrast between high-density and low-density areas (Kershaw 1964:106). Quantitative assistance then is required for evaluation. Also, visual inspection may not allow one to determine the scale(s) of patterning within an artifact scatter and the form of patterning at different scales, whereas quantitative approaches can provide such information.

Finally, it must be stressed that for all the available techniques evaluating form of arrangement, meaningful results can be obtained only if the study area approximates a behaviorally significant unit, such as a site at large or an activity area (see pages 109–110). In all cases, form of arrangement is evaluated *relative* to the size and shape of the analytical frame; widely differing assessments may be obtained for the same scatter of items framed differently.

TABLE 3.5

Characteristics of Archaeologically Used Techniques for Evaluating the Form of Arrangement of Items

Technique	Aspect of form of arrangement to which sensitive	Relative or absolute measures of arrangement provided	Form of data required
Poisson methods	Intensity	Relative, absolute	Grid counts
Dimensional analysis of variance	Intensity, grain, hierarchy	Absolute	Grid counts
Morisita's method	Intensity, grain, hierarchy	Relative, absolute	Grid counts
First-order nearest neighbor analysis	Intensity	Relative, absolute	Point location of items

The Poisson Method

The oldest quantitative method for detecting nonrandomness in the arrangement of items within a study area is the Poisson method. It was first used by the plant geographer, Svedberg (1922), and since has been evaluated by several plant ecologists (Greig-Smith 1964:57–63; Pielou 1977:124–126, 144). Archaeologically, the approach has been suggested for use by Whallon (1973) and has been applied in several contexts (Dacey 1973; Brose and Scarry 1976; Hodder and Orton 1976:35).

Good descriptions of the method with example calculations are provided by Kershaw (1964) and Greig-Smith (1964:61–62), so only a minimal presentation is required here. The approach is based on the fact that when a random arrangement of items is overlaid with a grid of quadrats of sufficiently small size such that the chance of occurrence of an item in a quadrat is very small (Greig–Smith 1964:57–58; see below), the frequency distribution of number of cells with n items will approximate a Poisson distribution,

$$P_n = \frac{\bar{X}^n \exp(-\bar{x})}{n!} \tag{3.1}$$

where $\bar{X}$ is the average number of items per cell and P_n is the probability of finding n items in a cell. The expected number of cells, E, having n items, can be found by multiplying P_n by the total number of cells, N, in the study area.

Given this fact, it is possible to use the variance:mean ratio of the frequency distribution of number of cells with n items, for a scatter, as an index of its form of arrangement (Pielou 1977:125). A Poisson distribution has a variance equal to its mean, and a variance:mean ratio equal to 1. A random arrangement of items, therefore, will produce a variance:mean ratio similar to 1. A clustered arrangement will define a larger variance:mean ratio, whereas a more aligned arrangement will be characterized by a lower value.

The degree to which two study areas differ relative to each other in the form of arrangement of items within them may be tested statistically by a procedure described by David and Moore (1954; Pielou 1977:125–126; Greig–Smith 1964:65–66). If two study areas have the same number of items n, variances $s_1{}^2$ and $s_2{}^2$, and means $\bar{X}_1$ and $\bar{X}_2$, the statistic

$$w = -\frac{1}{2}\ln\left(\frac{s_1{}^2/\bar{X}_1}{s_2{}^2/\bar{X}_2}\right) \tag{3.2}$$

will lie outside the range of $\pm 2.5/\sqrt{n-1}$ if the variance:mean ratios of the two populations differ significantly at the 5% level. This test has seldom, if ever, been used in an archaeological context.

Evaluation of a study area on an absolute scale for the degree to which items within it depart from a random arrangement can be tested by two methods. First, a Student's *t*-test may be calculated under the null hypothesis that the observed histogram of number of cells with *n* items has a Poisson distribution and a variance:mean ratio of 1 (VMR test). The statistic

$$t = \frac{(\text{observed } S_x^2/\bar{X}) - 1}{\sqrt{2/(N - 1)}} \qquad (3.3)$$

may be compared to *t* tables using a one-sided test with a significance level of α and degrees of freedom equal to $N - 1$, where N is the number of quadrats. The observed *t* statistic will be greater than $t_{(1-\alpha)}$ (df) if the arrangement is significantly aggregated and less than $-t_{(1-\alpha)}$ (df) if the arrangement is significantly dispersed.

The second method of absolute evaluation is a χ^2 test of the goodness of fit of the observed histogram of number of cells with *n* items to a Poisson distribution with the same mean number of items per cell. The expected number of cells, *E*, with *n* items is determined with Equation 3.1 and compared to the observed, *O*, so as to allow the calculation of a χ^2 statistic

$$\chi^2 - \text{stat} = \sum_{i=1}^{c} \frac{(O - E)^2}{E} \qquad (3.4)$$

where *c* is the number of histogram classes compared. It is appropriate to compare only those histogram classes for which five or more cells with *n* counts are expected. For classes with lower expectations (usually in only the right tail of the distribution), the pooling of expected counts and the pooling of observed counts is required (Greig-Smith 1964:69). The χ^2-stat then may be compared to values in a χ^2 table ($\chi^2_{(1-\alpha)}$(df)) for a given significance level, α, and with $c - 2$ degrees of freedom. Values larger than those found in the table will indicate significant departure of the observed arrangement from the expected random one, but without specifying whether it tends to be clustered or aligned.

The Poisson approach to evaluating item arrangement has a number of technical problems and problems of concordance with the archaeological record. Let us begin with the technical problems.

Problem 1. The χ^2 test may vary in its accuracy, depending on the mean number of items per quadrat. When this figure is low, the expected number of quadrats having certain large numbers of items per grid cell may be less than 5, and the counts of quadrats (expected and observed) for these classes may have to be lumped to perform the χ^2 test. Lumping reduces the accuracy of the χ^2 test because it reduces the effect of the individual classes of quadrats with *high* numbers of items on the χ^2 statistic; it is these classes with many items per cell (as well as those with few items per cell) that are most likely to express deviations between expected and observed frequencies when an arrangement of items is nonrandom (Greig-Smith 1964:68). As a result, a clearly nonrandom arrangement of items may be found not to differ significantly from a random one. Greig-Smith (1964:68–69) gives an example of this.

Problem 2. The VMR test may not give accurate results, depending on the shape of the observed distribution of number of cells with n items. Many distributions that are shaped differently from the Poisson and suggest departure from random arrangement can have variances equal to their means and produce test results suggesting randomness. Evans (1952) provides one possible example.

Problem 3. The VMR test may behave inaccurately when the average density of items per cell is very low, ''presumably because the distribution of deviations of the variance of a Poisson distribution from its mean is too strongly skewed'' (Jones 1955, 1956).

As a result of these three technical problems, the χ^2 test and VMR test may produce contradictory results. Either one may detect nonrandomness when the other fails (Greig-Smith 1952a,b). When the average density of items per cell is great and the χ^2 test is accurate, however, the χ^2 test is to be preferred over the VMR test, because it *directly* assesses distribution shape.

Problem 4. The Poisson approach, in general, involves a loss of information that may lead to inaccurate results. It assesses the *frequency* distribution of cells having given numbers of items, rather than the *spatial arrangement* of cells having given numbers of items. A set of grid-cell counts having a Poisson distribution may be arranged in space such that high count cells and low count cells mingle randomly, or segregate so as to form a clustered distribution (Pielou 1977:135, 144; see Hietala and Stevens 1977 for an illustrated example). Consequently, although it is true that all random arrangements of items, when overlaid with a grid of sufficiently small cells, will yield a Poisson distribution of number of cells with *n* items, it is not true that such a Poisson distribution always indicates a random arrangement of items among grid cells. Thus, the results of a Poisson test suggesting random arrangement must be verified visually, with consequent loss of rigor.

The Poisson approach requires a number of assumptions about the nature of the archaeological record that need not be true (Table 3.4).

Problem 5. The Poisson approach assumes that the chance of occurrence of an item within a quadrat is very small, and that the density of items within a quadrat is much lower than the maximum possible density (Greig-Smith 1964:57). If the average density of items per quadrat approaches the maximum possible, then the expected frequency distribution of number of cells with *n* items, for a random arrangement of items, will approximate a binomial distribution rather than a Poisson, and the Poisson method cannot be used. The Poisson approach, therefore, can be applied to investigate the form of arrangement of only those artifact classes having low volumetric densities compared to their maximum possible volumetric densities. For example, the approach could not be used to assess the form of arrangement of pottery sherd counts among grid cells within a secondary pottery refuse dump, where pottery comprised a moderate to high percentage of the dump's volume.

A number of constraining assumptions about the archaeological record are made by the Poisson method, resulting from its operation on grid count data. These constraints it shares with many techniques that attempt to assess form of arrangement with grid count data.

Problem 6. It is assumed that if a scatter of items is arranged in a nonrandom way, the mesh of the grid corresponds to the dominant, behaviorally meaningful scale of variability in item density. For a clustered arrangement, it is assumed that the size of grid cells approximates the size of clusters. For an aligned arrangement, the cells should be larger (preferably several times larger) than the approximately equidistant interval between items. If this condition is not met, the Poisson approach may assess the form of arrangement of items different from that of its dominant, behaviorally significant arrangement.

For any one arrangement of items, the Poisson method produces different results with grids of different mesh (Greig-Smith 1952b, 1964:56–57). When applied to a clustered arrangement, the Poisson approach will suggest first a random arrangement, then a contagious one, and finally a uniform arrangement, as the grid mesh is increased from very small (compared to the size of clusters and density of items), through the size of clusters, to a mesh much larger than clusters (Kershaw 1964:104). When grid cells approximate the size of clusters and clusters center within them, grid cell counts will be either very high or very low, resulting in a distribution of "number of cells having *n* items" with a large variance compared to its mean (Figure 3.5a). Reducing the mesh of the grid reduces the counts of cells in the high density areas disproportionally compared to those in the low (reduces the contrast between high-density and low-density areas) so as to produce a frequency distribution with fewer outliers, more cells having moderate to low counts, and a more Poisson-like shape (Figure 3.5b). Increasing the mesh of the grid greater than the maximum scale of clustering, such that each cell includes a number of clusters, equalizes the number of items found among cells such that their frequency distribution again deviates from a Poisson shape, but in the direction of alignment (Figure 3.5c). In a similar manner, for an arrangement of items tending to be aligned, detection of nonrandomness becomes easier as the mesh of the grid is increased and local stochastic variation is averaged out geographically (Greig-Smith 1964:57).

Problems 7–9. It is assumed that if a scatter of items has a clustered arrangement, clusters are the *shape* of the grid cells, are *centered* within grid cells, and if oblong, are *oriented* in the direction of the grid; that is, the clustered arrangement must conform to the shape, placement, and orientation of the grid. If any one of these conditions is not true, even though grid mesh is chosen carefully to correspond to the size (area) of clusters, the items in a cluster will be subdivided

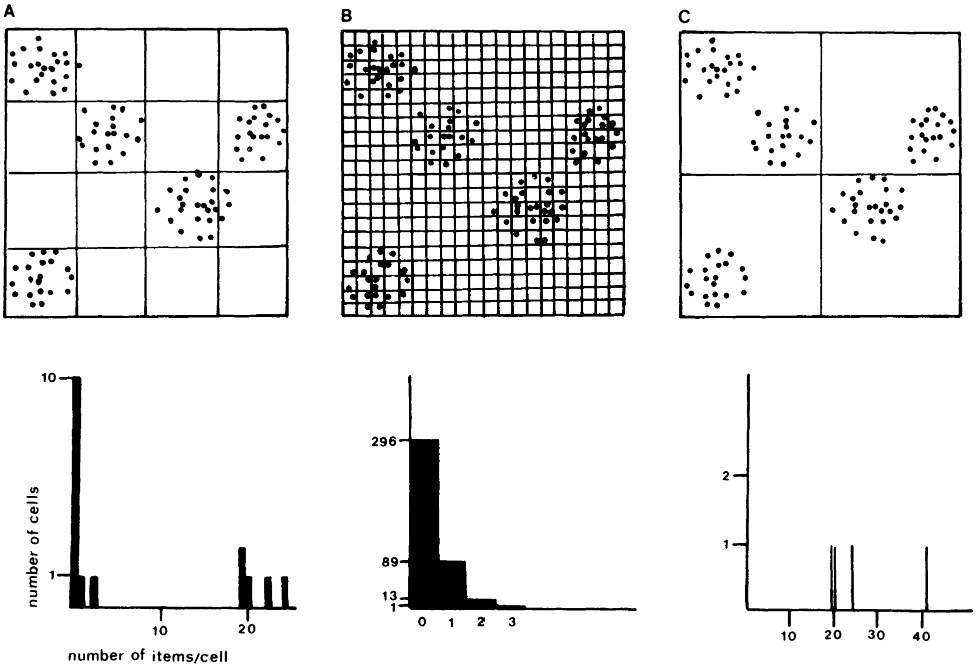


Figure 3.5. Changing the mesh of a grid over a clustered arrangement of items can produce frequency distributions of "number of cells with N items," suggesting the items' (A) clustered arrangement, (B) random arrangement, or (C) alignment. The frequency distribution for the fine mesh grid is equivalent to a Poisson distribution with an average density of .3 items/cell, $N = 104$.

among several grid cells and the cluster will not stand out as readily as an outlier in the histogram of number of cells with n items (Figure 3.6).

Problems 10–13. By logical extension of the constraints that clusters of items in a scatter must have the same size, shape, placement, and orientation as grid cells, they must be similar to *each other* in these regards.

Problem 14. Finally, the Poisson approach allows evaluation of the form of arrangement of items at only one scale: that of the grid. It ignores the possibility that artifact scatters may have multiple levels of organization at different spatial scales, with different forms of arrangement at each scale.

Dimensional Analysis of Variance

Dimensional analysis of variance (DAV) was designed by plant ecologists to eliminate some of the problems and ambiguity involved in the Poisson method. The founding concept and rationale for the approach are attributable to Greig-Smith (1952b), with extensions by Kershaw (1957, 1964), and particularly, Thompson, (1958) who provides tests of significance. Excellent descriptions of

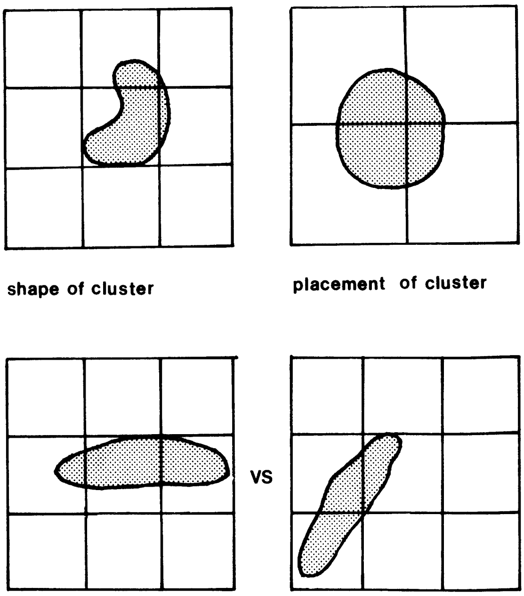


Figure 3.6. When clusters are the size (area) of grid cells yet do not correspond to cells in their shape, placement, or orientation, their items become subdivided among multiple cells, and they do not stand out as readily as an outlier in a histogram of number of cells with *N* items.

the technique are given by Greig-Smith (1961, 1964), Kershaw (1964), Pielou 1977:140–144), and Whallon (1973).

The method was introduced to archaeology by Whallon (1973). It has been applied in this field in only a few instances (Whallon 1973; Paynter *et al.* 1974; Price 1975; Brose and Scarry 1976; Wandsnider and Binford 1982), largely for the purpose of assessing the technique, rather than in the course of normal research.

From an archaeological perspective, the goal of DAV is to assess the form of arrangement of artifacts within a study area using multiple grid systems with cells of differing sizes, shapes, and orientations, in order to find that grid system for which clustering of artifacts is most significant. This grid system is taken to represent an organization of the data that concords most with the organization of depositional areas within space: counts of artifacts within its grid cells are taken to approximate counts of artifacts within *behaviorally significant clusters,* rather than within arbitrarily sized grid units. Only when gridded data are organized in this manner does correlation analysis between artifact types produce meaningful results (see pages 166–170).

Dimensional analysis of variance aims at assessing the form of arrangement of items within a study area on an absolute scale, rather than relative to the arrangement of items in other areas. This is achieved in the following manner. Counts within the cells of some original grid system are summed into counts within square or rectangular blocks of 2, 4, 8, . . . , 2^j, . . . , T adjacent cells, where T is the total number of cells in the study area. The total variance in counts of items among the original grid cells then is partitioned (Greig-Smith 1961:696), using the usual analysis of variance procedure, into variances derived from the differences in counts between original cells with blocks of size 2, differences in counts between blocks of size 2 within blocks of size 4, etc. If N_i is the number of items found in block i, then the sums of squares pertinent to variation at the scale of blocks with 2^j cells, that is, to the differences in counts between blocks of scale 2^j cells within blocks of scale 2^{j+1} cells, is

$$S_j = \frac{1}{2^j} \sum_{i=1}^{T/2^j} N_i^2 - \frac{1}{2^{j+1}} \sum_{i=1}^{T/2^{j+1}} N_i^2 \qquad (3.5)$$

Dividing this quantity by its degrees of freedom, $T/2^j$, yields the sought difference of variances (Kershaw 1964:107), and dividing again by the mean number of items per original grid cell defines a variance:mean ratio (Greig-Smith 1964:86; Mead 1974:297). (Whallon [(1974:272)] makes the latter division by the mean number of items per block of size 2^j cells, which is inappropriate [Greig-Smith, personal communication, 1983].) The notation used here parallels that provided by Pielou (1977:140–141) but applies the symbols of Whallon (1973:271). Differences in the equations presented here from those of Whallon stem from this change and from his ambiguous use of the letter j for two parameters.

To determine the scale(s) at which potentially significant clustering of artifacts occurs, a plot is made of the observed variance:mean ratios against block size. If artifacts are perfectly randomly arranged within the study area, the variance:mean ratios will equal 1 at all block sizes, as in the Poisson approach (Greig-Smith 1964:86). A negative deviation from this value indicates a tendency toward uniform alignment at the block size of the deviation, whereas a positive one indicates a tendency toward clustering at the corresponding block size.

For a clustered arrangement, the height of a peak in the graph indicates the *intensity* of clusters having a scale corresponding to the block size of the peak, comparable to that of other peaks in the graph (Greig-Smith 1961:698). The measure can not, however, be used to compare the intensity of clustering within different study areas overlain with grids of the same mesh yet having different mean numbers of items per original grid cell. For this purpose, a measure proposed by Hill (1973:227) may be used:

$$I_{jk} = (V_{jk} - m_k)/m_k^2 \qquad (3.6)$$

where I_{jk} is the intensity of the clustered pattern in study area k using blocks of size 2^j cells, V_{jk} is the variance in number of items among the blocks in area k, as calculated above, and m_k is the mean number of items per original grid cell in area k.

Additional information in a plot of variance:mean ratios against block size pertains to the spread of a peak over a number of block sizes. This indicates the *range* of *sizes* of clusters (Greig-Smith 1961:698–699) of one hierarchical level or multiple levels. If a trend in artifact density occurs over the site, within which there is clustering, the graph of variance:mean ratio against block size will exhibit a steady rise at larger block sizes that may mask patterning at some scales. To avoid this circumstance, it is necessary to make the spatial arrangement stationary in mean density (Greig-Smith 1961:700), using any of a number of methods (e.g., trend surface analysis, spatial filtering).

To test statistically whether a spatial arrangement, as a whole, departs from random expectation, considering all scales of arrangement, confidence intervals for the variance:mean ratios at various block sizes can be constructed and overlain on the graph of ratios vs. block sizes. Deviation of one or more peaks beyond the intervals indicates nonrandom tendancies. Confidence intervals of 95% are provided in tables by Greig-Smith (1961, 1964). Intervals having other significance levels can be constructed using the method of Thompson (1958). It is based on the fact that for a random arrangement, having a Poisson distribution with unit variance, the sums of squares calculated in equation 3.5 have an approximately χ^2 distribution with 2^j degrees of freedom, and the sought variances a $\chi^2/2^j$ distribution.

The confidence interval approach of Greig-Smith and Thompson has the disadvantage that it does not allow the testing of individual peaks in the graph for nonrandomness at scales of several block sizes. Only the distribution as a whole can be assessed (Mead 1974:298), a point that Whallon (1973:275) mistakens. To test for nonrandomness at each block size, Mead (1974:298–302) provides three alternative approaches, all based on whether the counts of items in blocks partition or combine randomly within the nested hierarchy of blocks.

The above analysis is performed on each artifact type separately to determine how its form of arrangement varies with scale and to assess the scale of clusters, if they occur. To define depositional sets, correlation analysis between artifact types can be performed, with grid-cell counts grouped at that block size exhibiting significant clustering for the greatest number of artifacts (Whallon 1973).

Use of the grouped cell counts to calculate correlation coefficients among artifact types, though common practice in archaeological applications, is not the most preferable approach to defining correlations among types. The resulting coefficients will necessarily reflect the covariation of types not only at the scale of blocking, but also at all larger scales. To obtain measures of correlation among types pertaining to only the scale of interest, dimensional analysis of covariance procedures (Kershaw 1960, 1961) may be used. The procedures require the determination of the dimensional partitioned variances of counts of each type $(S_j/\ (T/2^j)$ among cells and blocks of various sizes, as in DAV, plus the partitioned variances of the *combined* counts of each pair of types. The correlation between any two types, A and B, at each scale of blocking and attributable to covariation at that scale, alone, then can be determined as

$$r_j = \frac{V_{AJ+BJ} - V_{AJ} - V_{BJ}}{2/V_{AJ}V_{BJ}} \tag{3.7}$$

where r_j is the sought correlation at the scale of blocks with 2^j cells, V_{AJ} and V_{BJ} are the partitioned variances of counts of types A and B at that scale, and V_{AJ+BJ} is the partitioned variance of the combined counts of types A and B at that scale.

The mathematical procedures of dimensional analysis of variance and covariance can be applied to transect as well as two-dimensional grid data, to find the simple average linear dimensions of clusters in some one direction (Kershaw 1957; Greig-Smith 1961:696, 1964:87). Quadrats along the transect are expanded into blocks in the same way as the two dimensional situation, but with the potential for blocks to be any multiple of the original quadrats in size rather than simply multiples of two (Hill 1973:228). Multiple, parallel transects, dispersed or contiguous, may be used. In the latter case, two dimensional gridded data are envisioned as a series of transects, with grid expansion restricted to one dimension. The procedure may be repeated, expanding in the second dimension of the grid.

Dimensional analysis of variance circumvents only some of the problems mentioned previously as being inherent to the variance:mean ratio approach to evaluating form of arrangement, for it is similar to a series of concatentated VMR tests. Most of the technical problems encumbered by the VMR test, including dependence of the accuracy of results on the shape of the observed distribution, inaccuracy at very low item densities, and assessment of the frequency distribution rather than spatial arrangement of items among grid cells (Problems 2–4, above), also plague DAV to the same degree. DAV is limited equally by the archaeological requirement that artifact classes have low volumetric densities (Problem 5, above).

The method offers some improvements over the VMR test in its requirements of several aspects of the organization of the archaeological record, but these are only partial (see Table 3.4).

Problems 6 and 10, above. The method only partially circumvents the erroneous assumption that all clusters are of one specified scale, equivalent to the mesh of the grid. (1) It is constraining in requiring the size of clusters, if they exist, to be some multiple of two times the original grid mesh if two dimensional grid methods are used, or any multiple if transect methods are used (Hill 1973:228). If the sizes of clusters fall in between the required multiples of the original grid, the block sizes at which significant clustering is found will be larger than the actual scales of clustering (Figure 3.7). (2) It also is preferable if the sizes of clusters are distributed modally over the block sizes investigated, rather than continuously, so that one or a few scales of significant clustering can be found. This is not strictly a *requirement* of the technique, however; if clusters range continuously in size, the graph of variance:mean ratios against block sizes will indicate this circumstance accurately.

Problems 7 and 11, above. To a minimum extent, limitation on the shape of clusters by the VMR test is lifted in DAV. Clusters need not approximate squares. However, it still is assumed, if two dimensional grid methods are used, that clusters tend to be rectangular with lengths equal to or twice their width and that all clusters of one type are the same shape. Similar restrictions hold if transect methods are used, only the length of the clusters may be any multiple of their width. To the extent that these restrictions are not true, significant clustering will be found at block sizes larger than the areas of clusters (Figure 3.7).

Problems 8 and 12, above. When clusters are not centered in grid cells and their counts are partitioned among multiple cells, DAV will correctly detect clustering whereas the VMR test may not. The scale at which clustering is

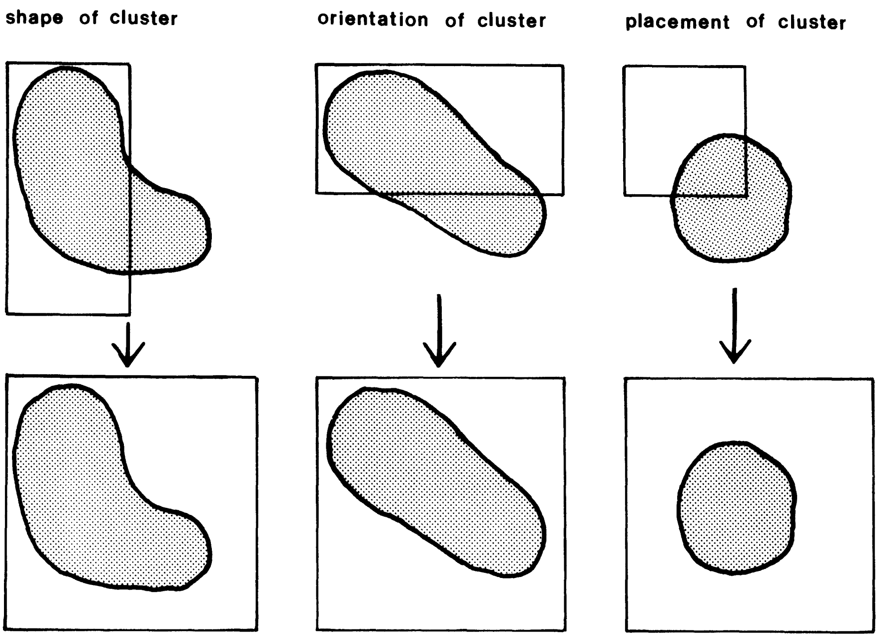


Figure 3.7. Discordance between a grid system and the shape, orientation, or placement of artifacts will cause clustering to be found at erroneously large block sizes when dimensional analysis of variance is applied.

indicated, however, will be erroneously large by *at least* 2–4 times that which would be found if the clusters were centered within cells using two-dimensional grid methods. Using transect methods, the determined scale of clustering will be 2 times the true scale.

Problems 9 and 13, above. A minimal allowance is made in DAV for differences in the orientation of clusters compared to that of the grid. When grid cells are grouped into blocks, some of which are rectangular (blocks of 2, 8, and 32 cells), rectangles may be oriented horizontally or vertically. Two analyses can be done per artifact type, one lumping cells horizontally, the other vertically. Those analyses providing graphs of variance: mean ratio against block size with the clearest peaks then are used to determine the scale(s) of clustering of artifacts. Although this procedure allows some flexibility in the orientation of clusters, it is still quite constraining: orientation can be in only two directions, determined a priori by and corresponding with the alignment of the grid, and all clusters must have a similar orientation. If this is not true, significant clustering will be found at scales one to several block sizes larger than the size of clusters (Figure 3.7). A similar problem holds when transect methods are applied to two dimensional gridded data, only clustering may be found at scales intermediate between the length and width of clusters.

Problem 14, above. The primary improvement of DAV over the VMR test is that it allows multiple scales to be investigated for the form of arrangement of items, thereby acknowledging that clusters may be organized into multilevel hierarchies. Again, however, the scales that can be investigated are limited.

Dimensional analysis of variance involves a number of *additional* problems that do not encumber the VMR test, most of which are technical in nature.

Additional Problem 1. The mesh of the original grid has a strong effect on the scale at which patterning is detected. This is so for two reasons. (1) The minimum size of cluster that can be detected effectively by the technique is twice the size of the original grid (Kershaw 1957). (2) As block sizes increase geometrically, so do *differences* in the mesh of grids derived from different original grid systems.

Additional Problem 2. The degree of precision with which the scale of clustering can be specified decreases geometrically as the size of clusters increases. This results from the doubling of block sizes at each step of the analysis. Thus, for example, a peak in the graph of variance:mean ratio versus block size at block size 2 would indicate clusters of 1–4 units in size, whereas a peak at block size 16 would indicate a much wider potential range of cluster sizes, 8–32 units.

Additional Problem 3. Accuracy of analysis—specifically, the estimates of variance—decreases as block size increases. This results from halving the degrees of freedom (numbers of blocks) with each step (Pielou 1977:142). Consequently, at larger block sizes, confidence intervals must be much wider, and peaks indicative of clustering may be assessed insignificant.

Additional Problem 4. The graph of variance:mean ratios against block size often has a sawtoothed shape, making assessment of the significance of peaks unreliable. This noise results from alternating between blocks having square and those having rectangular shapes. Oblong blocks consistently give lower mean squares than do square blocks (Pielou 1977:142). All of these problems, save 1a, are less encumbering or do not occur when using transect methods of analysis. In this case, blocks can be any multiple of the original grid mesh and the grid is expanded in only one direction.

Additional Problem 5. Dimensional analysis of variance also is discordant with the organization of the archaeological record in one way that the VMR test is not. DAV requires a square or rectangular study area. Most behaviorally significant archaeological units (e.g., sites, portions of sites used for broad classes of activities) are not of this shape. Technically, it is possible to achieve analysis by ''filling out'' a natural area with extra grid cells of zero counts until the required shape is obtained. This, however, may cause patterning to appear at erroneous block sizes (Price 1975:211).

Morisita's Method

Dimensional analysis of variance represents the first attempt made by plant ecologists (Greig-Smith 1952b) to cope with the problems of the VMR and χ^2 tests in assessing the form of arrangement of items over space. Excluding Mead's test of significance, however, DAV is still a Poisson-based approach, having many of the difficulties of that approach. More recent advances not utilizing the Poisson distribution but following the dimensional strategy of DAV include Morisita's method (Morisita 1959, 1962; Stiteler and Patil 1971) and Goodall's method (Goodall 1974; Pielou 1977:142). Of these, only the former has been applied archaeologically (Price 1975; Brose and Scarry 1976).

Archaeological literature does not explain the mathematical basis of Morisita's method. This is done here so that the potential of the method for archaeological applications then may be evaluated. Following Pielou's (1977:139) discussion, Morisita's method is based on Simpson's (1949) measure of diversity. If each cell of a grid is imagined to be of a different nature, having items of different kinds, then the probability of choosing at random (without replacement) two items of the same kind (from the same cell) is

$$\delta_0 = \frac{\sum_{i=1}^{q} x_i(x_i - 1)}{N(N - 1)} \tag{3.8}$$

where x_i is the number of items in cell i, there being q cells and N items in total. If items are aggregated in only a few cells, and the diversity of kinds of items is low, the probability, δ_0, of obtaining two items of the same kind will be high. If items are dispersed uniformly among cells and there is great diversity in the kinds of items, δ_0 will be low.

To obtain an index relating the observed δ_0 to its expected value given a random level of diversity (random arrangement of items among grid cells), it is noted that for such an arrangement, the probability of selecting one individual from a given quadrat is 1/q and two individuals from the same quadrat is $1/q^2$. The expected value for the probability δ, then, summing over all q cells, is $\delta_e = q(1/q^2) = 1/q$. Morisita's Index, relating the degree of observed aggregation or dispersion to that expected for a random distribution is defined as

$$I_{\delta_q} = \frac{\delta_O}{\delta_e} \tag{3.9}$$

$$= \frac{\sum_{i=1}^{q} x_i(x_i - 1)}{N(N - 1)} \Big/ (1/q) \tag{3.10}$$

$$= q \left[\frac{\sum_{i=1}^{q} x_i(x_i - 1)}{N(N - 1)} \right] \tag{3.11}$$

This index constitutes a relative measure for comparing arrangement between study units having the same area and examined with the same mesh grid. It takes the value 1 for a random arrangement of items. It ranges from greater than 1 to q (the number of cells/study area) for more aggregated arrangements, and from 1 to 0 for more dispersed arrangements.

Using the strategy of dimensional analysis of variance, Morisita's Index may be calculated for blocks of 2, 4, 8, . . . 2^j . . T adjacent grid cells. A graph of I_{δ_q} against block size will have a shape characteristic of the form of arrangement of items (Figure 3.8). If the plot indicates clustering of items, it is possible to determine the scale of clusters and whether multiple levels of clustering occur by plotting a graph of $I_{\delta(2^j)}/I_{\delta(2^{j+1})}$ against block size 2^{j+1} (Morisita 1959:230), or preferably 2^j (Price 1975:210). The ratio of $I_{\delta(2^j)}/I_{\delta(2^{j+1})}$ will indicate changes in the slope of the graph of I_{δ_q} against block size, some of which pinpoint the scale of clusters. Using a plot of the ratio rather than I_{δ_q} is preferable for two reasons. First, it emphasizes more clearly the block size at which clustering occurs. Second, $I_{\delta(2^j)}$ varies as a function of the number of blocks considered as well as form of arrangement; the effect of the former can be approximately factored out

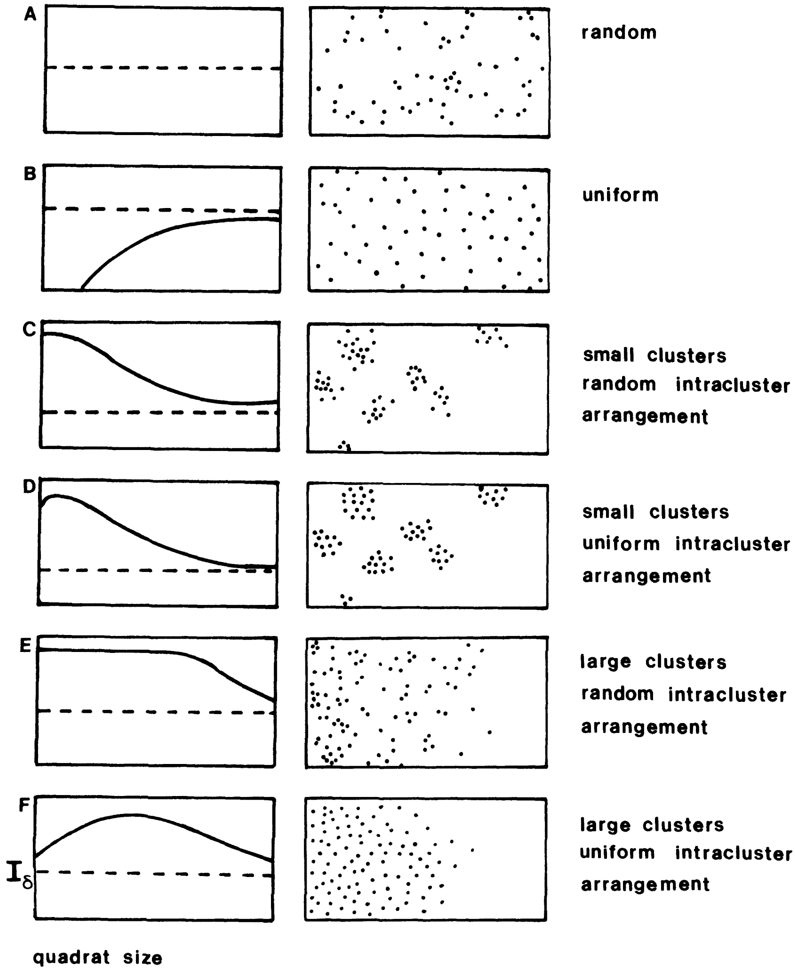


Figure 3.8. Variation in Morisita's Index with quadrat size for item-scatters of several arrangements.

by dividing $I_{\delta(2^j)}$ by $I_{\delta(2^{j+1})}$. A plot of this form can be interpreted like one made with DAV, with peaks identifying potential scales of clustering.

An absolute assessment of the degree of deviation of an arrangement of items at a given block size from a random arrangement may be made using an F test. The statistic

$$F - \text{stat} = \frac{I_{\delta(2^j)}\,(N - 1) + 2^j - N}{2^j - 1} \tag{3.12}$$

will have an $F\ (q - 1, \infty)$ distribution if items are arranged randomly (Morisita 1959:221). For a chosen level of significance, α, a value of F − stat greater than $F_{(1-\alpha)}\ (q - 1, \infty)$ will indicate significant aggregation, and a value less than $F_{(\alpha)}$ $(q - 1, \infty)$ will indicate significant alignment. This F test of Morisita's Index is equivalent to the χ^2/df test used by Brose and Scarry (1976:189).

Morista's method offers some, but hardly a complete improvement over DAV. The measure of relative assessment of arrangement, because it is not founded on the Poisson distribution, is not hampered with most of the technical problems of DAV and the VMR test associated with the Poisson strategy (Problems 2 and 3, page 142). One exception is that it assesses the distribution of counts (variability in counts) among grid cells rather than the spatial arrangement of counts. As a consequence, some clustered arrangements can erroneously be identified as random. Morisita's absolute test of the arrangement of items, on the other hand, is not as free of technical constraints as is his relative method. The test is simply a restatement of the VMR test in terms of Morisita's Index (Stiteler and Patil 1971:446). It is encumbered with all of the technical problems of that test (problems 2–4, page 142). Additionally, all the technical problems and erroneous assumptions about the nature of the archaeological record specific to DAV, related to expanding the mesh of a two dimensional grid, encumber Morisita's approach (see Table 3.4 and pages 148–151).

Empirically, the results of Morisita's method have been compared to those of DAV for at least two archaeological data sets (Price 1975; Brose and Scarry 1976). In both instances, the methods produced comparable results. Price (1975:211), however, notes that in plots of the two measures of aggregation against block size, when multiple scales of clustering are apparent, Morisita's measure emphasizes the significance of clustering at the lower scales, whereas DAV exaggerates the significance of clustering at the larger scales.

First-Order Nearest Neighbor Statistics

When the point locations of artifacts within a site are known, rather than simply their counts in grid cells, it is possible to assess their form of arrangement using nearest neighbor statistics. The nearest neighbor statistics were developed by plant geographers to assess community patterning (Clark and Evans 1954; Thompson 1956; Pielou 1959, 1960) and more recently have been applied by geographers to problems of locational analysis (e.g., Getis 1964; Haggett 1965; Pinder 1971). In archaeology, they have been used primarily for the analysis of regional site distributions (Adams and Nissen 1972; Earle 1976; Hodder 1972; Hodder and Hassal 1971; Hodder and Orton 1976; Plog 1974; Washburn 1974; Zubrow 1971). They have been applied less frequently to artifact distributions within sites (Brose and Scarry 1976; Graybill 1976; Price 1975; Trubowitz 1978; Whallon 1974).

Nearest neighbor analysis begins with a *finite* plane of unrestricted area A, unrestricted shape, and scattered with N items to be assessed for the form of their arrangement *relative to the size of their framing area.* The scatter of items is characterized by its density, d, within the framing area,

$$d = N/A, \tag{3.12}$$

and by the average distance $\bar{r}_0$, between nearest neighbor items within the plane,

$$\bar{r}_0 = \frac{\sum_{i=1}^{N} r_i}{N}, \tag{3.13}$$

where r_i is the distance from each item to its nearest neighbor.

The form of arrangement of items over the plane is assessed by comparing the *empirical* average nearest neighbor distance between items to the average distance between nearest neighbor items expectable if an *infinite* number of items were scattered at the same density in a random pattern over an *infinite* plane. The expected average nearest neighbor distance, $\bar{r}_e$, between items is calculated by

$$\bar{r}_e = 1/(2\sqrt{d}) \tag{3.14}$$

The comparison between the observed and expected average nearest neighbor distances is given by the *nearest neighbor statistic, R,* where

$$R = \frac{\bar{r}_0}{\bar{r}_e}. \tag{3.15}$$

R will be approximately equal to 1 if items are scattered randomly across the whole framing area. If they tend to cluster within the frame, the nearest neighbor statistic will tend toward its minimum possible value, 0, for a perfectly clustered arrangement. As items become more evenly spaced (systematically aligned), R will tend toward its maximum value 2.149, for a perfectly aligned arrangement.

The statistical significance of deviations of the arrangement of a scatter of items from a random scatter may be determined by calculating the following test statistic,

$$C - \text{stat} = \frac{\bar{r}_0 - \bar{r}_e}{\sigma_{\bar{r}_e}} \tag{3.16}$$

where

$$\sigma_{\bar{r}_e} = .26136/\sqrt{Nd} \tag{3.17}$$

A value of C $-$ stat less than $-z_{(1-\alpha)}$ will indicate significant clustering at the α level of significance, whereas a value greater than $z_{(1-\alpha)}$ will indicate significant alignment. The tests of significance should be one-sided, as given, if the direction of departure from randomness is of concern (most instances). If not, then a two-sided test should be used.

This test for deviations from randomness requires the assumption that nearest neighbor distances are distributed normally when items are scattered randomly. This is true only for large N, greater than 100. For random scatters with fewer items, nearest neighbor distances are positively skewed, resembling a Pearson's type III distribution. Thus, when N is less than 100 items, test statistic values should be compared to Pearson's III distribution rather than to normal tables (Clark and Evans 1954:448) (The opposite condition is mistakenly stated by Whallon 1974:19).

A preferred alternative for measuring the significance of departure of an arrangement of items from a random pattern is the χ^2 test (Dacey 1963; Whallon 1974). For the test statistic

$$\chi^2 - \text{stat} = 2\pi d \sum_{i=1}^{N} r_i^2 \qquad (3.18)$$

a value less than $\chi^2_{(\alpha)}(\text{df})$ indicates significant clustering at the α level of significance, whereas a value greater than $\chi^2_{(1-\alpha)}(\text{df})$ indicates significant alignment. The appropriate degrees of freedom are $2N$. If the number of items within the scatter is greater than 15, the χ^2 statistic can be converted to a standard normal variate

$$S - \text{stat} = \sqrt{2\,\chi^2 - \text{stat}} - \sqrt{2(2N) - 1} \qquad (3.19)$$

and the new statistic can be compared to normal tables. A value of S − stat less than $-z_{(1-\alpha)}$ indicates significant clustering at the α level of significance, whereas a value greater than $z_{(1-\alpha)}$ indicates significant alignment. Whallon (1974) found the χ^2 test of significance more conservative in assessing spatial distributions as clustered than the Clark and Evans statistics for one archaeological application.

When applied to scatters of items of a finite number, including artifact distributions, the nearest neighbor statistics just outlined provide biased assessments of item arrangement. The bias can result from two problems: a *framing problem,* which can be circumvented by appropriate application of the technique, and a *boundary problem* inherent in the statistics.

The framing problem refers to the fact that the value of the nearest neighbor statistic determined for a scatter of items varies greatly with the size of the area within which it is framed. If a scatter of items is systematically arranged, R can range from values suggesting clustering (when a frame much larger than the scatter is used), through values indicating randomness (when a somewhat oversized frame is used), to values indicating systematic alignment (when the frame is the size of the scatter or smaller) (Hsu and Tiedemann 1968). If the scatter of items exhibits a random arrangement, R can range from values suggesting clustering (for an oversized frame) through values indicating randomness (for a frame coincident with or smaller than the cluster).

Previously, several authors (Clark and Evans 1954:450; Pinder *et al.* 1979: 435) have suggested that the framing problem can be circumvented by placing the analytical frame "well within" the scatter of items to be evaluated. Additionally, the frame would have to be large enough to encompass several clusters, should the distribution be a clustered one, or a number of items (as many as possible), should the distribution be random or aligned, to ensure an adequate sample of the arrangement. Clearly, however, this approach is appropriate only when the scatter of items is *uniformly* clustered, random, or aligned throughout, as opposed to *hierarchically* arranged, with different or similar forms of arrangement at different geographic scales (see Figure 3.3). Only if the scatter is similarly arranged throughout will any *one* frame of one large size, placed anywhere within the scatter and sampling only a portion of its arrangement, always accurately assess the nature of the scatter.

In many archaeological circumstances, this is not the case, and the solution to the framing problem offered by Clark and Evans and Pinder *et al.* is not appropriate. Activity areas and artifact scatters may be hierarchically arranged, with different forms of arrangement at different hierarchical levels (see pages 130–131; Figure 3.4). Under these conditions, the results of a nearest neighbor analysis will vary with the size and placement of the frame.

The only universally applicable solution to the framing problem is to ensure that the area of interest is behaviorally meaningful and that the boundary of the analytical frame coincides with the boundary of that area. Only under this condition will the form of arrangement of items be assessed relative to an area of meaningful scale and will all local arrangements within the scatter contribute to the estimate of its overall arrangement.

The boundary problem results from a discordance between assumptions and operations used in deriving the nearest neighbor statistics, regardless of how the scatter to be analyzed is framed. The expected average nearest neighbor distance, $\bar{r}_e$, is calculated for an *infinite* number of items postulated to occur over a plane of *infinite* expanse, including the study area, at a density equal to item density inside the study area. The postulated items inside the study area have extant counterparts. Those outside the study area and near its border may or may not have extant counterparts, depending, respectively, on whether the analytical frame lies within the scatter of items being investigated, or whether it coincides with or is larger than the scatter. In contrast, the observed average nearest neighbor distance, $\bar{r}_0$, is calculated for a finite number of extant items within the *finite* area of the study unit, alone, irrespective of postulated items outside the study area. Thus, in calculating $\bar{r}_0$, the boundary of the study area severs some theoretical connections between real items just inside the area and their postulated nearest neighbors outside the area (with or without real counterparts). The theoretical, severed connections may or may not have extant counterparts, depending on the size of the frame relative to that of the scatter of items. As a result of such severed connections, for those items inside the area having nearest neighbors (extant or theoretical) outside it, the distance (r_i) found to their nearest neighbors within the area will be greater than the distance to their true nearest neighbors outside the area. The average observed nearest neighbor distance for items within the area will be inflated, as will the nearest neighbor statistic, R. This will bias against the detection of clustered arrangements.

This boundary effect will increase with: (1) a decrease in the number of items within the area of analysis (particularly as N drops below 100 for square or circular areas), or (2) an increase in the circumference of the boundary of the analytical frame compared to the area enclosed (as in the case of rectangles or amorphous frames compared to square or circular ones). With either condition, the proportion of interitem connections that are severed between nearest neighbors by the boundary will increase.

Pinder *et al.* (1979) and McNutt (1981) explain the boundary problem in terms that assume the area of analysis occurs within the scatter of interest and that all severed connections are existing ones. The problem, however, also occurs when the area of analysis includes the scatter of interest completely, and the severed connections are theoretically postulated ones. The problem results from the discrepancy between the theoretically infinite scatter of items assumed to calculate $\bar{r}_e$ and the finite scatter of items used to calculate r_0, rather than whether extant connections, per se, are severed.

Several solutions have been offered to the boundary problem since the time of its original definition by Clark and Evans (1954). Each diminishes the problem, regardless of whether the study area lies within or surrounds the scatter of interest and whether the severed connections have real counterparts or not. Dacey (1963:505) suggests using in analysis only those items within the study area that are located more than a specified distance from its boundary and that could not possibly have severed connections with nearest neighbors. This approach overcorrects for the boundary effect, producing a deflated R. Hodder and Orton (1976:41) approximately offset the effect of severed connections by surrounding the study area with randomly placed points at the same density as items within it and allowing the points to serve as nearest neighbors to items within the study area. The analysis must be repeated a number of times, with different random placements of points, to obtain an estimate of the expected value and range of potentially accurate results.

The approach of Pinder *et al.* (1979) allows a much closer estimation of the nearest neighbor statistic and the significance of its departure from values indicating randomness than the two solutions just cited. These authors have derived empirical constants for modifying the values of $\bar{r}_e$, R, and $\sigma_{\bar{r}_e}$ to compensate for the boundary effect. The approach is highly constrained, however, in requiring that the frame of analysis be square. The framing errors introduced by this requirement, when the natural area of interest is of some other shape, may offset in magnitude the accuracy gained in circumventing the boundary problem.

The most preferable solution to the boundary problem—being most precise, least constrained by assumptions, and based on mathematical theory—is that formulated by McNutt (1981). McNutt has deduced, from geometric considerations, equations specifying the number of items within a study area that can be expected to have severed connections. This figure may be used to determine *finite-corrected* values for d and $\bar{r}_e$, which may then, therefore, be compared to $\bar{r}_0$ (a finite-based statistic) with logical consistency in calculating R.

For rectangular study areas, the expected number of items, N_0, having severed connections with nearest neighbors is

$$N_0 = \frac{(s_x + s_y)\sqrt{N - 1}}{3\sqrt{A}} - \frac{1}{12}. \tag{3.20}$$

where s_x and s_y are the lengths of the sides of the study area, N is the number of items within it, and A is its area. Analogous formulae are given for equilateral triangles, other triangles, and circular study areas. A finite corrected density then can be calculated using the formula

$$d = \frac{N - 1 - N_0}{A}. \tag{3.21}$$

This value may be used with Equations 3.14 and 3.15 to determine an unbiased nearest neighbor statistic.

The formulae given by McNutt for determining N_0 for study areas of given shapes are not nearly as important as the equations provided by him for determining N_0 for *components* of such shapes: linear borders (equation 7), 90° corners (equation 13), 60° corners (equation 32), and circular arcs of a specified sweep (equation 40 multiplied by the proportional sweep of the arc compared to that of a full circle). These may be used in combination to approximate N_0 and finite corrected values for d and $\bar{r}_e$, for polygons of many complex shapes.

The array of analyzable, geometric study areas could be increased significantly, and particularly to the archaeologist's advantage, if an equation determining N_0 for 270° corners were available (the obtuse angle *inside* the study area). This, with the equations for linear borders and 90° corners, would allow the definition of accurate nearest neighbor statistics for complexly shaped areas approximately represented by an aggregate of squares. An important archaeological application would be to a behaviorally meaningful area approximately represented by a group of excavated units.

McNutt does not say whether his approach to correcting the nearest neighbor statistic can also be used to correct the values of $\sigma_{\bar{r}_e}$, which is underestimated by Equation 3.17 (Ebdon 1976; Pinder *et al.* 1979). Presumably, d in this equation can be calculated with Equation 3.21 and N can be reduced by 1 and N_0 to yield an accurate estimate of $\sigma_{\bar{r}_e}$. This possiblity needs to be researched.

Nearest neighbor analysis is a highly unconstrained approach to assessing the form of arrangement of artifacts within a study area (Table 3.4). As such, it has several distinct advantages over dimensional analysis of variance and Morisita's method. The nearest neighbor statistics make no assumptions about the size, shape, relative placement, or orientation of clusters of artifacts that might occur within the area of analysis. Clusters of artifacts can vary freely in these attributes without inhibiting their detection. Also, the statistics do not limit analysis, as do dimensional analytic techniques, to square or rectangular areas. An area of any shape can be analyzed, *so long as the area coincides with the boundaries of a behaviorally meaningful unit and includes all artifacts of potential meaning for that area.*

In other ways, nearest neighbor analysis is less informative or logically less consistent with the organization of intrasite archaeological records than is DAV or Morisita's method. First, nearest neighbor analysis allows evaluation of only the intensity (significance, relative density) of clustering of artifacts within a study area, not the grain (size and spacing) of artifact clusters. Dimensional analysis of variance and Morisita's method allow assessment of both. This limitation may be corrected by extending nearest neighbor procedures to include the assessment of *n*th-order nearest neighbor distances (see pages 183–188).

Second, artifact distributions within sites sometimes may exhibit multiple scales of clustering hierarchically organized (see pages 130–131 and Figure 3.4). Dimensional analytic methods assume that such hierarchical organization is possible and allow the significance of clustering of artifacts at multiple scales of potential clustering to be evaluated. Nearest neighbor analysis, on the other hand, assumes that the form of arrangement of items is nonhierarchically random or aligned, or if clustered, seeks evaluation of form of arrangement at only one scale—the smallest scale of potential clustering. It focuses on distances between nearest neighbor items (within clusters), and ignores distances between the centroids of aggregates of items (Figure 3.3).

This bias of first-order nearest neighbor analysis may cause misleading as well as incomplete results to be obtained. For example, suppose artifacts are distributed across a site in reflexive pairs (pairs of items both closer to each other than to other items) or in clusters of several items, as a result of artifact breakage, but the pairs or clusters themselves are distributed randomly (a hierarchical arrangement). From an interpretive standpoint concerned with the spatial organization of past activities or refuse deposits, the random arrangement of the pairs/clusters of artifacts is more important than the clustering of the individual subportions of broken items. A first-order nearest neighbor analysis of such a distribution, however, would focus on interitem patterning, finding significant clustering of the artifacts and leaving undetected the higher-level pattern of arrangement of clusters. This situation was found to be a problem by Brose and Scarry (1976) in their spatial analysis of one site. To circumvent this problem, either *n*th-order nearest neighbor statistics (Thompson 1956) or point-to-items statistics (Pielou 1959) may be used (see pages 183–190).

Methods for Assessing Whether Artifact Types are Co-Arranged

General Approach of the Methods

Most analytic approaches that attempt to define site-wide depositional sets involve two steps. First, the degree of co-arrangement of *pairs* of artifact types is expressed with any of a number of statistics, such as a correlation coefficient or an average nearest neighbor distance. Then, a matrix of the coefficients for all possible pairs of artifact types is subjected to a higher level pattern-searching algorithm to reveal groups of one to multiple artifact types that are more similar to each other in their spatial arrangement than they are to artifact types in other groups. The many varieties of factor analysis (Christensen and Read 1977; Davis 1973; Rummel 1970), cluster analysis (Anderberg 1973; Hartigan 1975; Sneath and Sokal 1973), multidimensional scaling (Kimbell *et al.* 1972; Kruskal and Wish 1978), and matrix ordering (Cowgill 1972; Craytor and Johnson 1968; Hole and Shaw 1967; Marquardt 1978) can be used for this purpose. In this section, the appropriateness of only the pairwise coefficients of co-arrangement to intrasite spatial analysis will be discussed.

Correlation Analysis of Grid-Cell and Block Counts

The degree of co-arrangement of artifact types within a site can be expressed with several coefficients—on nominal, ordinal, or ratio scales of measurement—when artifact locations are recorded as counts per grid cell. These coefficients include Pearson's correlation coefficient, Kendall's and Spearman's rho (rank correlation coefficients; Kendall 1948), and a variety of similarity coefficients, such as the simple matching, Jaccard, and indices of Dice and Bray (Cole 1949; Sneath and Sokal 1973). There also is choice in the frequencies of artifacts to be manipulated—those found within the original grid cells used to record the data or those within larger blocks of grid cells derived from dimensional analytic techniques.

Plant ecologists have discussed at length the relative appropriateness of the different coefficients, of working at different scales of measurement, and of using blocked or unblocked data of different spatial scales (Cole 1949; Greig-

Smith 1961, 1964; Kershaw 1964; Pielou 1969). Archaeologists have shown concern for the effect of grid cell and block size on the pattern of co-arrangement found in analysis (Hodder and Orton 1976; Whallon 1973), but generally have not appreciated the relative merits of using the different coefficients and scales of measurement in spatial analysis. Most intrasite spatial analyses using cell count data have proceeded directly on raw ratio-scale counts using the most common measure of relationship, Pearson's *r,* without considering if evaluation on that scale, using that coefficient, is justifiable in light of the characteristics of depositional sets and use-areas.

One important exception is Hietala and Stevens's (1977:540–543) discrimination of three degrees of strength in spatial relationships that may occur between artifact types (uniform, strong, weak), which correspond to ratio, ordinal, and nominal scale relationships. The significance of the different kinds of relationships in terms of behavior or archaeological formation processes, however, is not discussed. A second exception is Speth and Johnson's (1976) postulations of the impact of various kinds of depositional patterns on correlations among artifact types.

The following two sections, on correlation and association, question the validity of using these common measures of relationship in searching for depositional sets. They lay the foundation for the introduction of an alternative method (see pages 191–199).

The correlation coefficient has been used with original grid-cell counts to define depositional sets in many intrasite studies. Examples include: Brown and Freeman's (1964) pioneering application of the technique to differentiate the functions of Pueblo rooms, and works by Anderson and Shutler (1977), Freeman and Butzer (1966), Goodyear (1974), Hill (1970), Kay (1980), and Schiffer (1976). Correlation of blocked cell frequencies of artifacts has been used less commonly (e.g., Brose and Scarry 1976; Price 1975; Whallon 1973).

Pearson's correlation coefficient applied to grid-cell or block counts of artifact types, or any measure of covariation so applied, are poor indicators of the degree of co-arrangement of artifact types in most archaeological circumstances (Table 3.4). For these measures to accurately reflect co-arrangement, several characteristics of activity sets, depositional sets, and use-areas, which are inconsistent with their nature, must be true.

Condition 1. Most problematic, the activity sets sought must have been *monothetic*. At every location where a task was performed, the same artifact types must have been used. More restrictive, the artifact types used together must always have been used in similar proportions (such that their frequencies covary).

Condition 2. The artifacts must have been deposited *expediently* at their locations of use.

Condition 3. The deposited artifacts must have *remained* in their approximate locations of deposition until the time of excavation, without the polythetic-causing effects of postdepositional disturbance processes.

Condition 4. The artifact types must have been recovered completely and classified as to their function correctly.

Only if these four conditions are true will *depositional* sets by monothetic, will like use-areas have the same sets of artifact types present in them, and will the proportions of artifact types within like use-areas be similar, regardless of the duration of use of use-areas, such that measures of covariation accurately define the depositional sets.

The inverse of these conditions, more typical of the archaeological record and its formation and disturbance, will cause depositional sets to be polythetic. The proportions of artifacts of different types belonging to the same depositional set and found within use-areas of similar kind will vary among them. Covariation and correlations between the types over the several use-areas, consequently, will be weakened, inadequately measuring their co-arrangement and membership in one depositional set. For example, if an activity set were polythetic in organization, different subsets of it will have been used during different occurrences of the activity at different locations, producing like use-areas differing in the kinds and combinations of artifact types they encompass and thus, the proportions of artifact types within them. If artifacts were not deposited expediently at the locations of their use, but rather, in accord with when they *happened* to break at the locations and *happened* to be no longer repairable with efficiency, then again, different kinds of artifact types will have been deposited in different areas of use, and proportions of artifact types among like areas will vary greatly. If postdepositional disturbance processes were operative, if artifact recovery was incomplete, or if artifact classification was inaccurate, causing depositional sets to be more polythetic or appear to be more polythetic than they would be otherwise, like use-areas will have become more variable in the kinds of artifact types present in them and the proportions of artifact types within them.

Condition 5. When measures of covariation are used to define co-arrangements, the requirement that artifacts were deposited expediently may be relaxed, if another requirement is made in its place: that all activity areas were used an *extended, approximately equal period of time*. If an activity was performed numerous times at a location, if the activity set used was monothetic, and if no archaeological formation processes that cause depositional sets to be polythetic other than differential artifact breakage and curation rates operated, then the relative frequencies of artifact types deposited in that location will have stabilized over time to constant values approaching the ratios of the discard rates of those types. For a number of locations of this kind, correlation will be an appropriate measure of the strength of the relationship between the various artifact types. However, conditions 1, 3, and 4, above, would still have to be true. For example, if the number or intensity of polythetic-causing processes involved in the formation and disturbance of the deposits were increased and randomness in the net accumulation of the artifact types at different locations were introduced, the tendency of the locations to have the types in the same relative frequencies approaching the ratios of their discard rates over time would decrease. This would weaken correlations between artifact types in the same depositional sets. The appropriateness of correlation as a measure of the strength of relationship between artifact types would decrease.

The inadequacy of covariation as a measure of co-arrangement of artifact types, with respect to its requirements that activity sets and depositional sets be monothetic, can be illustrated in the following way. Suppose two artifact types exhibit perfect positive covariation in their grid-cell frequencies within a site, defining a monothetic depositional set. If the counts of one of the artifact types in some cells are reduced to zero (Table 3.6), grossly simulating the effect of polythetic-causing processes of formation of the archaeological record, the strength of correlation found between the two artifact types will be attenuated. The rate of attenuation will tend to be a linear function of the percentage of grid cells having frequencies reduced to zero for the one artifact type (a function of the degree of polytheticness introduced into the depositional set), if frequencies are reduced to zero at random. For a 10% increase in the number of cells with a

TABLE 3.6

Simulating Monothetic and Polythetic Depositional Set Organization[a]

Grid-cell observation number	Frequency of artifact type *A*	Frequency of artifact type *B*	Modified frequency of artifact type *B*
1	1	1	1
2	2	2	0
3	3	3	3
4	4	4	4
5	5	5	0
.	.	.	.
.	.	.	.
.	.	.	.
95	95	95	95
96	96	96	96
97	97	97	97
98	98	98	0
99	99	99	0
100	100	100	100

[a] In Columns 2 and 3, two artifact types, *A* and *B*, show perfect correlation in their grid-cell frequencies within a site, defining a monothetic set, *AB*. In Column 4, the frequencies of artifact type *B* in some grid cells have been modified to grossly simulate the polythetic organization of depositional set *AB*. The two artifact types show less than perfect correlation in their grid-cell frequencies within the site, as a result of this modification.

zero count, the correlation coefficient will decrease approximately .1 units (Whallon, personal communication, 1976).

In real archaeological data, the effect of polythetic organization of depositional sets on cell counts is not as clear as that simulated. Artifact type counts are not necessarily reduced to *zero* in affected cells, but rather, are reduced by a *percentage* of the number of items expected to occur in them under the assumption of monothetic organization of depositional sets. The percentage varies from cell to cell, as the number and intensity of polythetic-causing factors that produced the effect varied spatially. As a consequence of the nonsystematic nature of the disturbing variation, screening methods bringing concordance between data structure and technique, including identification of the affected cells and removal of them from analysis or correcting their counts, become difficult to operationalize.

Condition 6. Measures of covariation will accurately assess the degree of co-arrangement of artifact types belonging to multiple depositional sets only when the depositional sets and activity sets from which they are derived are non-overlapping. Suppose an activity set is monothetic and expediently deposited, producing a monothetic depositional set. If none of the artifact types within the activity set are shared with other activity sets, each artifact type will be used and deposited at each location of activity in the same proportions. The correlations between the artifact types within the set will equal +1. If one of the artifact types within the set is shared with a second set used in different locations from the first, the shared artifact type will be deposited more widely than the other members of either the first or second set (Figure 3.9). At the various locations at which the shared type is deposited, the artifact types with which it co-occurs, and their proportions, will vary. Consequently, the correlation of the shared type and the other members of either of the activity sets to which it belongs will be less than 1. For example, in Figure 3.9, artifact type X is shared by two activity sets (XO, XAB). The ratio of artifact type counts X:O would be 1:1 in all locations, and the correlation between types X and O would be 1, if type X were not a member of activity set XAB. Because it is, however, the ratio of artifact type counts X:O varies between 1:0 (where X occurs with members of activity set XAB) and 1:1 (where X occurs with members of activity set XO). The correlation between types X and O, consequently, is less than 1. This effect of overlap among activity sets and depositional sets has been noted previously by Speth and Johnson (1976).

Condition 7. Spatial overlap of activity areas and use-areas does not affect the accuracy of correlation and other measures of covariation as measures of co-arrangement of artifact types. As the debris generated from multiple kinds of activities overlap more and more, the identity of the separate activity sets becomes less pronounced in the matrix of correlation coefficients, which becomes dominated by strong positives between members of different activity sets as well

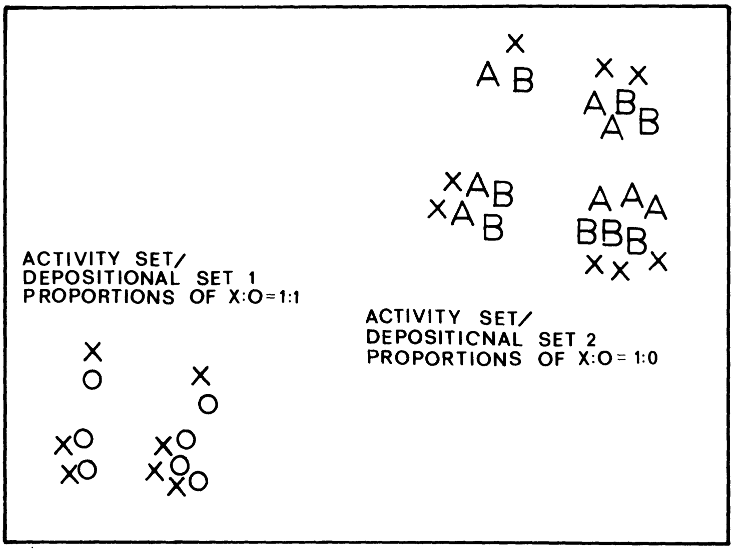


Figure 3.9. When an artifact type is shared by two activity sets, the kinds of artifacts and their proportions, deposited where the shared type was used, will vary.

as members of the same activity sets. This is as would be expected (assuming activity sets are monothetic and nonoverlapping).

The response of the correlation coefficient to spatial intermingling of artifact types from separate activity sets obviously does not facilitate the detection of depositional sets that reflect activity sets. This, however, is not to be expected of the technique. No analytic method can find sets of artifacts that initially were manufactured, used, or stored separately *after* they have become spatially intermixed to a large extent (Schiffer 1975c).

The inability of Pearson's r and other measures of covariation to accurately describe the degree of co-arrangement of artifact types and their organization into polythetic, overlapping depositional sets, as a result of the inadequacies of the measure mentioned previously, is suggested by recent findings by Whallon (1979, in press). Whallon found that across the occupation floor of a hunter–gatherer camp, from locale to locale, patterns of correlation among artifact types varied. This is precisely what would be expected if the degree of polytheticness and degree of overlapping of activity sets and depositional sets varied over space, and if different use-areas were used for different lengths of time.

Additional problems in using correlation analysis to define the degree of co-arrangement of artifact types stem from the use of grid-cell counts (or block counts when concatenated with DAV or Morisita's method.

Condition 8. The use of grid cells of one size requires that all artifact clusters, the same or different in kind, be the same size—that of the cells—if correlation analysis is to be accurate. When grid cells or blocks are larger than clusters and may encompass clusters of different kinds, the correlations between artifact types belonging to *different* depositional sets (and clusters) may become *greater* than the correlations would be if cells of the size of the clusters were used (Figure 3.10). There will be no effect upon correlations between artifact types in the same depositional sets (clusters). The net result will be a decrease in the distinctness of depositional sets in the matrix of correlation coefficients. When cells are smaller than clusters, the correlations between types belonging to different depositional sets (and clusters) will not be affected. The correlations between artifact types belonging to the same depositional set may increase, stay the same, or decrease, depending on the degree and pattern of internal homogeneity of clusters, and where cells fall within the clusters encompassing them (Figure 3.11). Kershaw (1964:112) illustrates such changing patterns of correlation among clustered items of different types using ecological data.

Application of dimensional analysis of variance or Morisita's method with

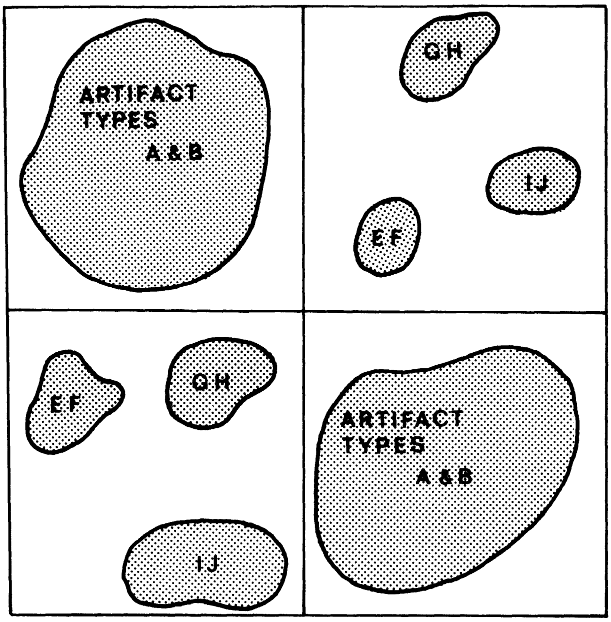


Figure 3.10. Block sizes are larger than clusters of artifacts forming depositional sets EF, GH, and IJ. Correlations between these artifact types, within different depositional sets, (E versus G, H, I, J; F versus G, H, I, J; G versus E, F, I, J; H versus E, F, I, J; I versus E, F, G, H; J versus E, F, G, H) will be inflated because items of kinds belonging to different depositional sets are lumped in the same blocks. Correlations between artifact types within the same depositional sets (E versus F, G versus H, I versus J) will not be affected by the larger block sizes.

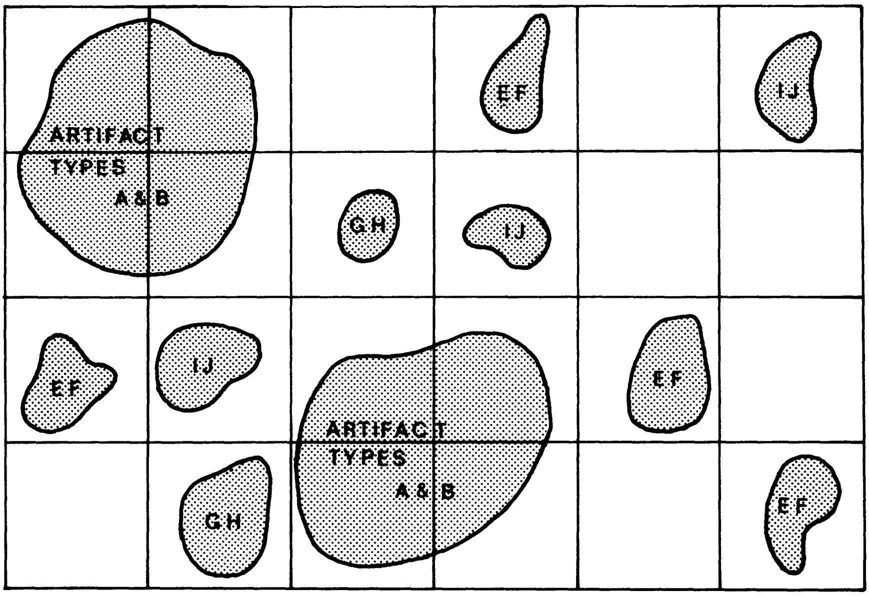


Figure 3.11. Block sizes are smaller than clusters of artifacts forming depositional set AB. Correlations between these two artifact types, within the same depositional set, may be inflated, accurate, or deflated, depending on the pattern of variation in artifact composition within clusters and where blocks fall within them.

grid expansion in two dimensions, allowing counts per arbitrarily sized grid cells to be grouped into counts per blocks approximating the scale of natural clusters, may lessen these problems, but usually will not totally circumvent them for two reasons. (1) Because the sizes of blocks in dimensional analytic techniques are *doubled* at each stage of analysis, the degree of precision with which grid cells can be scaled to clusters decreases geometrically as the size of clusters increases. Correlations between pairs of artifact types will be biased in the manner just described to the extent that they occur in clusters that are large and do not correspond in size to some multiple of the mesh of the original grid. (2) Artifacts of the same or different types may exhibit significant clustering at different scales. However, in dimensional analytic methods, only one block size, usually that at which most artifact types show significant clustering (Whallon 1973), can be used to perform the correlation analysis between all pairs of types. As a consequence, those pairs of artifact types exhibiting clustering at scales other than the chosen block size will have biased correlations.

Condition 9. Square grid cells or square or rectangular blocks, which are taken to represent one cluster or one void each, are at best crude approximations of the shapes and orientations of such natural areas. Correlations between artifact types will be biased to the extent that this is not true. When artifact types of several depositional sets form clusters that weave in and out of grid cells (Figure 3.12), correlations among types within different sets will be increased above those that would be found if the borders of clusters and cells corresponded. This results from the lumping of artifacts from different depositional sets in the same cells. Correlations among artifact types within the same depositional sets may be slightly augmented, unaltered, or slightly deflated, compared to those that would be found if the borders of clusters and grid cells corresponded, depending on the degree and pattern of internal homogeneity of the clusters. The net effect of both of these kinds of bias will be a decrease in the distinctness of depositional sets within the correlation matrix.

Condition 10. Use of gridded (unblocked or blocked) data assumes that clusters are spaced systematically with respect to each other and the grid, such that their centers fall in the centers of grid cells and each cluster occurs within only one cell. (a) If clusters, instead, fall between several grid cells (Figure 3.6), correlations between artifact types in the same depositional set may be inflated, remain the same, or be deflated, depending on the degree of internal homogeneity of clusters. Correlations between types in different sets will not be affected as long as clusters of different kinds do not fall in the same cells, as a result of off-centering. (b) If dimensional analytic techniques are applied to data where grid

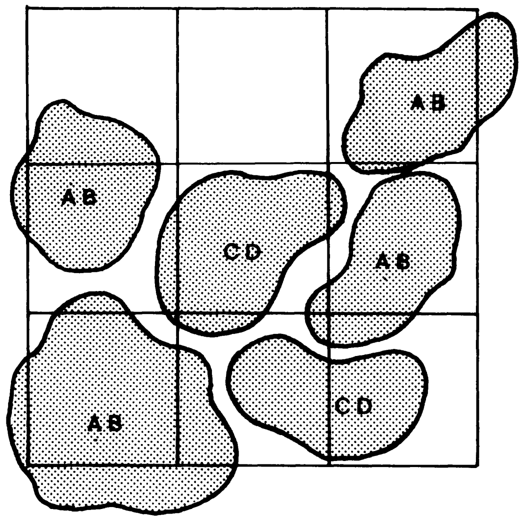


Figure 3.12. The borders of clusters do not correspond to the borders of blocks. The correlation between artifact types in different depositional sets (A versus C, D; B versus C, D) will be inflated above those that would be found if borders of clusters and blocks corresponded. As a result of the lumping of artifacts from different depositional sets in the same blocks, correlations between artifact types within the same depositional sets (A versus B; C versus D) will be only slightly affected.

and cluster spacings do not correspond, significant clustering will be found at block sizes one or more units larger than the scale of clusters (see pages 149–150). When counts are grouped at this oversized scale (Figure 3.13), correlations among types belonging to different depositional sets may be increased, whereas those among types in the same depositional sets will be unaffected. The net effect may be a decrease in the distinctness of depositional sets within the correlation matrix.

Association Analysis of Grid Cell and Block Counts

At the nominal scale of measurement, where counts of artifact types per grid cell have been reduced to presence/absence states, or dichotomized high-count/low-count states using some count threshold, patterns of association and co-arrangement among artifact types may be investigated by three means. In the realm of statistical tests, the χ^2 test of independence, using a contingency table of the form shown in Table 3.7, may be applied to original grid-cell counts or blocked data. The χ^2 statistic, with Yate's continuity correction,

$$\chi^2 - \text{stat} = \frac{(|ad - bc| - n/2)^2 n}{(a + b)(a + c)(b + d)(c + d)} \qquad (3.22)$$

where a, b, c, and d are the cell values of the contingency table, can be compared to the values of the χ^2 distribution with 1 degree of freedom to test the null hypothesis of independent arrangement of dichotomized observations. A value of χ^2 − stat greater than $\chi^2_{(1-\alpha)}$ (1) indicates significant spatial association or segregation of the pair of artifact types at the α level. To use this test, the

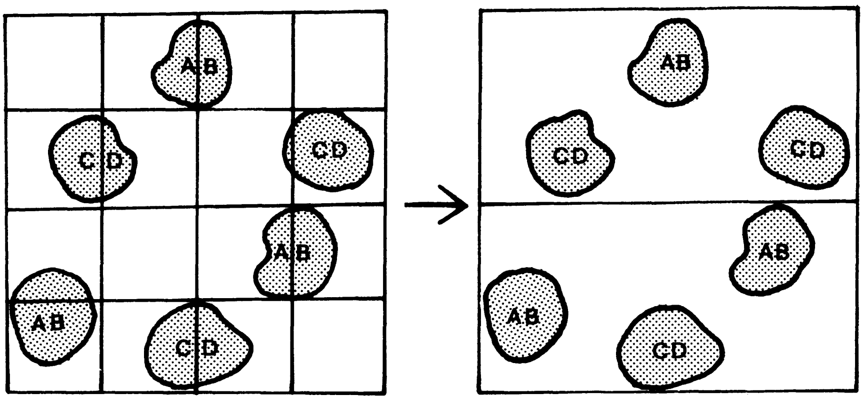


Figure 3.13. If dimensional analytic techniques are applied to data where grid and cluster spacings do not correspond, significant clustering will be found at block sizes larger than the scale of clustering. Grouping of counts of artifact types from different depositional sets within the same blocks at this oversized scale will cause correlations among types in different sets to increase, whereas those among types in the same set will be unaffected.

TABLE 3.7

Contingency Table for Generating the χ^2 Statistic, Testing Whether Artifact Types Associate

	Artifact type *Y* +	Artifact type *Y* −	Row totals
Artifact type X +	A NUMBER OF GRID CELLS WITH BOTH TYPES PRESENT	B NUMBER OF GRID CELLS WITH TYPE X PRESENT AND TYPE Y ABSENT	A + B
Artifact type X −	C NUMBER OF GRID CELLS WITH TYPE X ABSENT AND TYPE Y PRESENT	D NUMBER OF GRID CELLS WITH BOTH TYPES ABSENT	C + D
Column totals	A + C	B + D	N

expected value of counts in the *a, b, c,* and *d* cells must all be greater than 5, requiring minimally 20 grid cells for analysis. If the number of observations are fewer, a χ^2 test of independence based on information statistics (Kullback *et al.* 1962) or the hypergeometric distribution (Lieberman and Owen 1961) may be used.

The χ^2 test of independence was applied in spatial analysis originally by plant geographers (Cole 1949; Pielou 1969) and geographers (Dacey 1968). More recently, it has been applied to archaeological data by Dacey (1973), and Dekin (1976:84); and by Hietala and Stevens (1977), who employed the hypergeometric distribution. Dichotomized high-count/low-count states were used rather than presence/absence states by Dacey and by Hietala and Stevens, the former using the mean of cell counts and the latter, the median of cell counts, as the dichotomizing threshold for each artifact type.

The χ^2 test allows arrangements of *pairs* of artifact types to be tested for their independence but does not provide a way for defining depositional sets composed of only one through many artifact types. To define depositional sets, an additional step must be taken, using the second or third approach now discussed.

Cook (1976) has drawn upon the ideas of formal analysis (e.g., Brown 1971; Peebles 1971; Saxe 1970) and has developed a means for defining depositional sets using Venn diagrams as the particular ''artificial language'' (Gardin 1965) selected for analysis. A table of dichotomized states for each variable (artifact type) over a number of cases (grid cells) is used formally to construct Venn diagrams depicting a series of sets of tools that repeatedly co-occur and that may be overlapping. The method was applied by Cook to the regional analysis of tool kits distributed among sites but also is applicable to intrasite analysis. The method is not powerful, in that it requires mental pattern recognition processes to construct the Venn diagrams rather than mathematical algorithms that can focus on complex data patterning.

A third approach to spatial analysis with nominal data, allowing the definition of depositional sets, involves measuring the degree of co-arrangement of artifact types with a ''similarity coefficient'' and then grouping types into depositional sets on the basis of their similarity, using cluster analysis, multidimensional scaling, or matrix ordering. Analysis begins with the construction of a contingency table of the form used in χ^2 analysis (Table 3.7) for each possible pair of artifact types, based on dichotomized grid-cell or block counts. Using the values of the cells within each table, a ''similarity coefficient'' is calculated for each pair of artifact types, summarizing their degree of co-arrangement. The simple matching coefficient, Jaccard coefficient, indices of Dice and Bray, and others (Sneath and Sokal 1973) are among the most commonly used for this purpose. The various coefficients differ in the weights they attach to the *a, b, c,* and *d* cells of a contingency table. For intrasite spatial analysis, where many grid cells or blocks may lack all but a few artifact types and may have absent–absent paired states for many pairs of types, a coefficient that omits consideration of negative matches is desirable (Cole 1949; Sneath and Sokal 1973:131). The rationale for this is the same as that for screening double-zero cells from analysis in correlation analysis (Speth and Johnson 1976): one is concerned with the degree of similar placement of locations where artifact types occur as opposed to locations where they do not. The Jaccard similarity coefficient accomplishes this requirement

$$J_{xy} = \frac{a}{a + b + c} \tag{3.23}$$

where *a, b,* and *c* are the values of the *a, b,* and *c* cells in the contingency table for artifact types *x* and *y*.

The techniques of association analysis just described are somewhat more consistent with the organization of intrasite archaeological records than is correlation analysis. It was noted in the previous section that if an activity is performed numerous times at several locations, if the activity set used is monothetic, and if no archaeological formation processes causing depositional sets to be polythetic (other than differential breakage and discard rates) operate, then the relative frequencies of the artifact types accumulated at those locations will stabilize over time to constant proportions approaching the ratios of the discard rates of those types. Only under these constraints will correlation analysis accurately measure the strength of relationship between the types in the activity set and depositional set. With association analysis, some of these rigorous requirements can be relaxed. Archaeological formation processes that cause depositional sets to be polythetic (see pages 122–125) can operate on artifact types having moderate to high discard rates and spatial densities. When such processes operate on plentifully deposited artifact types, the relative frequencies of such types in different use-areas of like function may not approach constant proportions, but *their presence/absence states will tend toward occurrence.* Artifact types in the same activity set and depositional set will tend to co-occur repeatedly and associate over a number of use-areas of similar function. Thus, *assessment of co-arrangement of artifact types on the nominal scale of measurement is more appropriate than assessment on the ratio scale.*

Cook (1973:28) has emphasized this point:

> While the absolute and relative frequencies of occurrence of artifact types at an archaeological site [or within subareas of that site] are important facts to record, it does not follow that such facts are *ipso facto* relevant to the solution of the problem at hand [definition of activity sets as manifested in depositional sets].

The conditions required of the archaeological record in order to apply association analysis and obtain accurate definition of patterns of co-arrangement of artifact types, nonetheless, are still rigorous, making it less appropriate than some other techniques (Table 3.4).

Condition 1. As is true of correlation analysis, association analysis requires that activity sets in the behavioral domain were monothetic. Only if this is true can depositional sets be monothetic, with all artifact types used together always occurring together archaeologically. If an activity set and the depositional set derived from it are polythetic, lower associations between artifact types within the same depositional set will be found than if it were monothetic.

Condition 2. If activity areas were not used over extended periods of time, association analysis also requires that artifacts were deposited expediently in their locations of use, such that artifact types used together always occur together archaeologically. If this is not the case, the effects of differential breakage rates and curation rates and other formation processes will cause different subsets of the activity set to be deposited at different locations of its use. The associations found between the artifact types within the generated, polythetic depositional set thus will be lower than would occur if the artifacts had been deposited expediently. If activity areas were used for a long duration, however, expedient deposition need not have occurred. Despite the effects of processes causing depositional sets to be polythetic, the presence/absence states of all types in the same depositional set will tend toward occurrence in all locations of use and deposition of the types, as just described.

Condition 3. At least one representative of each artifact type used and deposited in a use-area must have remained there. Whereas *any* amount of postdepositional disturbance (e.g., mining) of a use-area will distort the *proportions* of artifact types within it, affecting correlations among types across areas, a fair amount of disturbance of a use-area can occur without affecting the pattern of presence/absence states within it and associations among types across areas. The amount of postdepositional disturbance that is possible without altering patterns of association will be inversely related to the density of the least frequent artifact types within the use-areas.

Condition 4. The duration of use of depositional areas need not have been long, if the activity sets used within them were monothetically organized and if artifact deposition was expedient; otherwise, depositional areas must have been used for some duration, such that the presence/absence states of all artifact types within the depositional set used in the areas stabilize at presence.

Condition 5. Depositional sets and the activity sets from which they were derived must have been nonoverlapping in organization. The rationale for this requirement is the same as that given for correlation analysis (page 165, Condition 6).

Condition 6. Spatial discreteness of activity areas is not required for association analysis to depict accurately the degree of co-arrangement of artifact types, as described for correlation analysis (pages 165–166, Condition 7).

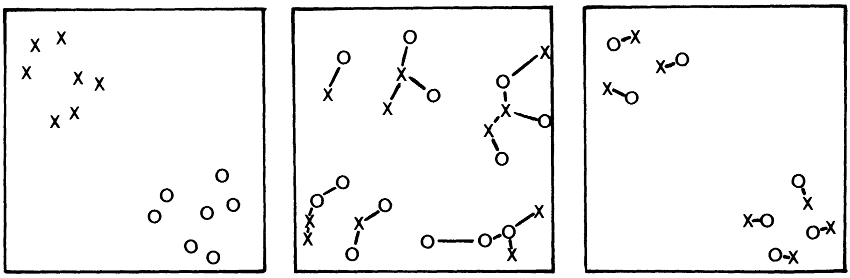
As with correlation analysis, association analysis is plagued with the problems of analysis of grid-cell counts or block counts.

Conditions 7 and 8. Clusters must be similar to each other and to the cells or blocks used to calculate associations in their sizes and shapes (usually square or rectangular).

Condition 9. Clusters must be systematically spaced so they can be encompassed within single blocks.

Condition 10. If oblong, clusters must be oriented in the direction of the grid. The effects of deviations of the archaeological record from these last four conditions on the magnitude of similarity/association found between artifact types within the same or different depositional sets are analogous to those cited for correlation analysis (see pages 166–169).

Unlike correlation analysis, association analysis runs into operational difficulties when the artifact types to be analyzed have ubiquitous distributions within which spatial patterning of high-count cells is evident. Patterning evident in the arrangement of high-count/low-count cells for each given ubiquitous type deserves investigation for its degree of co-arrangement with high-count/low-count patterns of other ubiquitously distributed types and with the presence/absence patterns of more sparcely distributed types. To do so, it is necessary to dichotomize the cell counts of ubiquitously distributed artifact types into two states, high count and low count (thereafter treated as "presence" and "absence" states), using site-wide or local threshold count values. Problematically, different thresholds chosen to dichotomize the cell counts of a ubiquitously distributed artifact type may yield different arrangements of cells with "presence" and "absence" states, producing different patterns of association between it and other types. Dichotomizing thresholds consequently must be chosen with great care, in



segregated **random** **unsegregated**

Figure 3.14. Segregated, random, and unsegregated spatial arrangements of two artifact types, X and O.

awareness of their *behavioral* significance. Some mathematical methods and logical criteria for defining thresholds will be discussed later (pages 200–201, 204–206).

Segregation Analysis

Techniques for determining the degree of co-arrangement of artifact types that operate on point locations have been used much less frequently than techniques operating on grid-cell counts. Two point location approaches that have been applied to archaeological data are segregation analysis and Whallon's "overlapping cluster approach."

Segregation analysis (Pielou 1964; Price 1975) measures the degree to which items spatially pair with others of their own class, *segregating* themselves from items of some second class; pair with items of the second class, such that the two classes associate and are *unsegregated*; or pair as often with items of their own class as with those of the second, such that the two classes randomly intermingle (Figure 3.14). To quantify these possible relationships, a tabulation is made of the number of items of each type that have as nearest neighbors items of the same type and the opposite type (Table 3.8). The *a, b, c,* and *d* cells of the resultant contingency table then can be used to calculate an index of segregation *S*.

TABLE 3.8

Contingency Table Used in Calculating Pielou's Segregation Statistic, *S*

		Base item		
		Type 1	Type 2	
Reference item (nearest neighbor)	Type 1	A	B	A + B
	Type 2	C	D	C + D
		A + C	B + D	N

$$S = 1 - \frac{b + c}{N(wz + xy)} \quad (3.24)$$

where

$$w = \frac{a + c}{N} \qquad y = \frac{a + b}{N}$$

$$x = \frac{b + d}{N} \qquad z = \frac{c + d}{N}$$

S will take the value -1 if items of the two types are completely unsegregated, pairing only with items of the opposite type. It will be zero if items of the two types randomly intermingle and pair with each other, and $+1$ if they are completely segregated, pairing only with like items.

Price (1975) extends the method by redefining S as an index of association

$$A = 1 - S \quad (3.25)$$

such that the value 1 is taken by A when two artifact types are positively associated (unsegregated), and the value -1 when they are completely negatively associated (segregated). A matrix of A coefficients for all possible couples of artifact types then is treated as a similarity matrix and subjected to a clustering algorithm, in order to define a hierarchy of types tending to associate or segregate (depositional sets).

Segregation analysis has a number of severe problems, both in what it assumes about the nature of the archaeological record and in how association and segregation are measured. In its assumptions about the organization of archaeological records (Table 3.4), segregation analysis is more stringent than correlation and association analysis. It requires that couples of artifact types belonging to the same archaeological activity set be deposited together *in pairs*, one for one, in equal numbers. For this to occur, several circumstances must pertain. (1) Activity sets must have been monothetic. (2) Activity sets must have been nonoverlapping. (3) Artifacts must have been deposited expediently at their locations of use. (4) Artifact types in the same activity set must have had the same discard rates. (5) Artifacts must not have been disturbed by postdepositional processes before excavation. (6) Artifacts must have been completely recovered and accurately classified to type. Additionally, the technique assumes (7) the nonhierarchical patterning of artifact aggregations; it examines spatial relationships between artifact types at only the smallest scale, between nearest neighbors.

When applied to archaeological circumstances where the discard rates of artifact types in the same activity sets are unequal and depositional sets are polythetic, segregation analysis will produce questionable results. The maximum value that possibly can be taken by the A statistic will be attenuated by an uncontrollable amount, depending on the degree to which artifact types in the same depositional sets occur in *unequal* numbers (Pielou 1964:259), and thus, have unequal discard rates and are polythetically distributed. Figure 3.15 illustrates the attenuation that may occur, causing artifact types that are completely, though polythetically, associated (unsegregated) to be characterized as randomly interspersed to mildly segregated.

Segregation analysis also is encumbered because it uses as its measure of association and segregation *relative* nearest neighbor distances rather than *absolute* nearest neighbor distances. Two artifact types are judged more or less associated on the basis of how often they are nearest neighbors to items of the same kind *relative to* how often they are nearest neighbors to items of the opposite kind, rather than on the basis of their geographic proximity to each other. This has two consequences. First, it represents a loss of information, a reduction of ratio-scale point-location data with known geographic distances between items to ordinal-scale relative location data (e.g., A's are closer to B's than B's are to other B's). This information loss may lead to erroneous conclusions about the degree of association of artifact types.Consider Figure 3.16. Two different pairs of artifact types, X and O, and A and B, are compared for their degrees of co-arrangement. It is clear that types X and O are highly associated, occurring together repeatedly in the same clusters and being *close in proximity.* Artifact types A and B, on the other hand, are distant from each other and unassociated. Nevertheless, segregation analysis would characterize Types A and B more associated with types X and O, because on a relative scale, A's are closer to B's than A's are to A's and B's are to B's, whereas X's segregate to

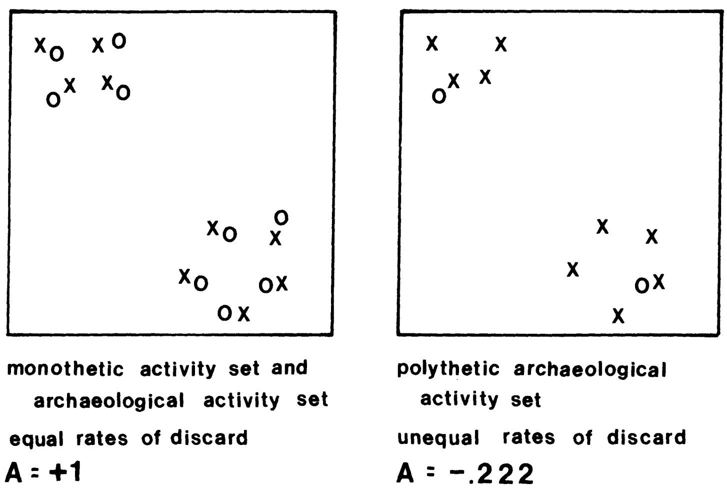


Figure 3.15. Segregation analysis assumes the monothetic organization of activity sets and archaeological activity sets, and equal discard rates for artifact types belonging to the same activity set. If this is not so, the maximum value possibly taken by the *A* statistic will be attenuated.

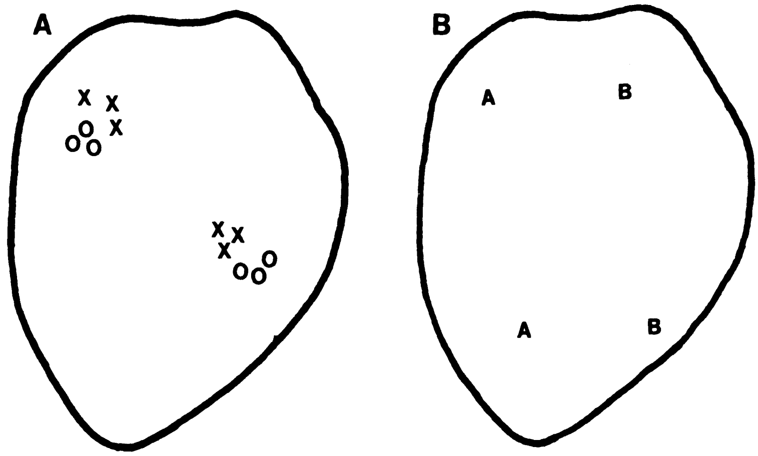


Figure 3.16. Artifact type pairs X–O, and A–B, are shown distributed on the same site. Whether pair X–O or pair A–B is judged more associated depends on whether a relative or absolute measure of proximity is used.

themselves and O's segregate to themselves within clusters. Thus, measures of coarrangement of artifact types using the relative placement of types, including the segregation statistic, may be misleading; measures of the absolute geographic proximity of items of different types are preferable (see pages 191–199). The activities that occurred on an archaeological site were performed in absolute space, not relative space.

The second consequence of using relative rather than absolute nearest neighbor distances as the measure of co-arrangement in segregation analysis is that comparability of the measure between *different couples* of types is precluded. This is so because the standard against which association of two types is assessed—the degree of association of the types with themselves—is relative and varies from one couple of types to another. For example, the degree of co-arrangement of items of two types, A and B, is judged relative to the degree to which items of type A pair with themselves and items of type B pair with themselves. Similarly, the degree of co-arrangement of items of two other types, C and D, is judged relative to the degree to which items of type C pair with themselves and items of type D pair with themselves. Comparison of the two assessments of co-arrangement is meaningless because they are based on different standards of association.

As a result of this noncomparability of multiple segregation indices (or Price's aggregation indices) to each other, it is inappropriate to apply any higher level grouping algorithm (e.g., cluster analysis, matrix ordering) to a matrix of such coefficients to define multitype depositional sets, as Price (1975) has done. Such algorithms assume the comparability of the coefficients. Although segregation analysis is poorly suited to the definition of depositional sets, the method and its problems do suggest a productive approach, to be described later (see pages 194–199).

Whallon's Overlapping Cluster Approach

The overlapping cluster approach to defining the degree of co-arrangement of artifact types, using the point locations of items, was developed by Whallon (1974). It is one of the few spatial analytic techniques currently available that has been devised by an archaeologist for archaeological purposes rather than borrowed from geography or quantitative ecology. It has been applied to several sites (Brose and Scarry 1976; Hietala and Larson 1980; Price 1975; Whallon 1974).

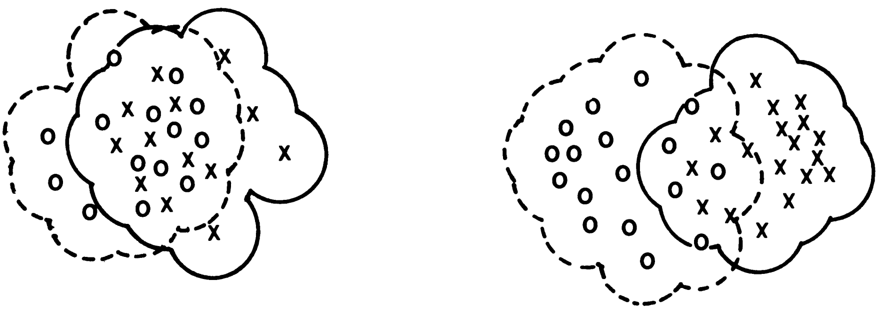
The method is algorithmically contingent upon defining the boundaries of single-type clusters. This usually is done with Whallon's radius approach (next section) but not out of logical necessity. It is desirable, then, to evaluate the requirements of these two steps separately for their concordance with the nature of the archaeological record.

The overlapping cluster approach measures the degree of similar arrangement of two artifact types, using either of two criteria. These are: (1) the amount of area shared in zones of overlap of single-type clusters having different artifact types, compared to the total union of their areas or (2) the number of items shared in zones of overlap of single-type clusters having different artifact types, compared to the total number of items in the clusters. If the area or number of items in the zones of overlap and nonoverlap are tabulated in the a, b, and c cells of a fourfold contingency table similar to that used in association analysis (Table 3.7), then a coefficient of the degree of similar arrangement of types can be calculated by

$$I = \frac{100a}{a + b + c} \tag{3.26}$$

The index varies from 0 for complete segregation of the two types to 100 for complete spatial overlap of the two types.

The method is somewhat more concordant with the nature of organization of intrasite archaeological records than are correlation and association analysis using grid cell counts (Table 3.4). No assumptions are made about the size or shape of clusters. The approach, however, still is stringent in that it requires that activity sets and depositional sets be monothetic and nonoverlapping, that artifacts be expediently deposited in their locations of use or that such location be reused often, and that artifacts not be disturbed by postdepositional processes. Only if these conditions are met will items of two different artifact types in the same activity set always occupy similar areas, maximizing the coefficient of similarity.



I high in value I low in value

Figure 3.17. Different patterns of inhomogeneity in the density of items of two types *within* a depositional area can produce different values of Whallon's item-based measure of co-arrangement, *I*.

The measure of co-arrangement using number of items shared by clusters of different kinds is more constraining than the measure using the amount of area shared. The former requires the additional condition that artifacts within single-type clusters and multitype depositional areas be homogeneously distributed in density and by extension, that depositional areas be internally homogeneous in composition and not hierarchically nested. Figure 3.17 illustrates this requirement.

Finally, Whallon's overlapping cluster approach has the drawback that determination of the degree of co-arrangement of artifact types is contingent upon the definition of single-type depositional areas. This contingency is undesirable because it limits the assessment of co-arrangement of artifact types to those exhibiting clustered patterns rather than allowing evaluation of relationships between types having any spatial pattern.

Methods for Delimiting Spatial Clusters of Artifacts

A number of standard map techniques (Davis 1973) can be used to define the spatial limits of clusters of artifacts of one type when data are in the form of densities observed over a regular grid (counts per grid cell) or item point locations that can be converted to this form. These methods include simple contouring, trend surface analysis, spatial filtering, and in certain situations, Fourier analysis (Carr 1982, 1983, 1984a). A detailed examination of these methods is beyond the scope of this chapter, although one use of spatial filtering is discussed later (see pages 204–206). It can be mentioned, however, that in using gridded data of a particular scale, all the techniques constrain the form of patterning that may be found, as a function of the chosen grid interval (Greig–Smith 1964). The techniques also require approximate homogeneity in the density of artifacts within depositional areas to define depositional areas with internal spatial continuity.

Whallon's Radius Approach

A method for delimiting clusters of artifacts of one type using item point location data directly has been devised by Whallon (1974) and applied in several circumstances (Whallon 1974; Price 1975; Brose and Scarry 1976). The method operates on the frequency distribution of nearest neighbor distances between items. The mean and standard deviation of these observations are determined, along with a "cutoff" distance of 1.65 standard deviations above the mean. Those nearest neighbor distances smaller than the cut-off threshold will represent 95% of all distances that join items separated by a potentially significant, small distance indicative of clustering, under one assumption. It is assumed that clustered patterns have unimodal, approximately normal distributions of nearest neighbor distances (Whallon 1974:23).

Next, items having nearest neighbors at distances less than the cutoff threshold are joined to define the limits of clusters. Linkage can be done in two ways. First, significantly close neighbors can be joined by lines, producing an area of minimal extent with ragged edges (Figure 3.18A). Second, circles of a radius equivalent to the cutoff threshold can be drawn around items, such that their intersecting arcs delimit an area of maximal extent with a smoother, more pleasing outline (Figure 3.18B).

Whallon's method for delimiting clusters was introduced as a "rough outline of an approach" this problem, rather than a finalized technique (Whallon 1974:23). The method has several limitations, but is a solid beginning and can be reworked into more reasonable approaches (see pages 202–206).

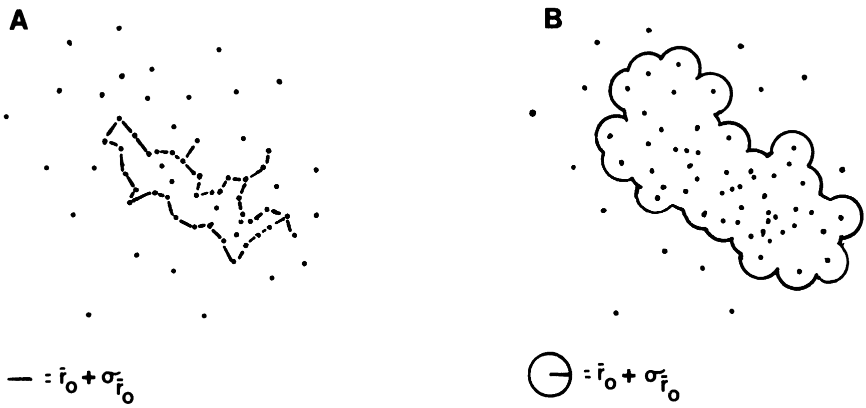


Figure 3.18. Two methods of delimiting clusters: (A) joining by lines those items separated by less than the cutoff distance $\bar{r}_0 + \sigma_{\bar{r}_0}$ and (B) circumscribing items by circles with a radius equal to the cutoff distance $\bar{r}_0 + \sigma_{\bar{r}_0}$.

The primary difficulty with the method is that it assumes the nearest neighbor distances of a clustered arrangement to be unimodal and approximately normal (Pearson's Type III distribution) in order to define an appropriate cutoff threshold. This may be true for an individual cluster, and it may also be true for multiple clusters in a scatter all having approximately the same average density and grading off in density at their broders at a similar rate. It is possible, however, for a distribution of nearest neighbor distances to be multimodal, different modes representing clusters of different average density or subportions of clusters of different densities. It also is possible for the distribution to approach a square fuction, if clusters are numerous and each varies in density over a wide range (personal observation). A hierarchical nested clustered arrangement may yield a distribution similar to an inverse function, extremely skewed to the right. The cutoff thresholds defined for these nonnormal distributions will be more or less meaningful, varying with the form of the distribution. For example, for a multimodal distribution indicating multiple clusters of differing density, obviously one threshold should be defined for each mode and different thresholds applied in delimiting different clusters, rather than defining a single threshold for the total distribution to be applied to all the clusters (see page 205). Likewise, should a distribution of nearest neighbor distances have a long tail with a few outliers, indicating scattered isolated items, these items should be eliminated from analysis to prevent the calculation of an unduely large $\bar{r}_0$ and $\sigma_{\bar{r}_0}$ and a large cutoff threshold. The latter will result in most items in the scatter being joined into one massive cluster.

Thus, as outlined by Whallon, the method is applicable to only a limited range of circumstances concordant with certain constraining assumptions. These assumptions are: (1) clusters in a scatter are all of the same average density; (2) clusters are fairly homogeneous, internally, in their artifact densities; and (3) clusters are not nested or surrounded by a low density scatter of isolated items.

Finally, the approach specifies how to define only single-type clusters; it does not detail how to construct multiple-types clusters composed of artifact types that are co-arranged, that is, use-areas.

MORE APPROPRIATE METHODS FOR INTRASITE SPATIAL ANALYSIS

None of the mathematical methods of spatial analysis available today are totally free of logical inconsistencies with the nature of organization of intrasite archaeological records. There are, however, techniques that minimize inconsistencies and that are more appropriate than the ones just described. These techniques are discussed in this section.

Methods using both grid-cell count data and item-point location data are presented, despite the obvious preferability of the latter in avoiding the problems associated with grids of set sizes, shapes, placements, and orientations (pages 175–180). Archaeological data often are recorded in only gridded form, and techniques must be offered to handle such data. For some tasks, alternative methods of analysis are presented, the different methods having different strengths and weaknesses.

Methods for Assessing Whether Artifacts Cluster in Space

N*th-Order Nearest Neighbor Analysis*

First-order nearest neighbor analysis (pages 154–161) is a relatively unconstrained approach to assessing the form of arrangement of artifacts within some natural study area. It fails, however, to provide evaluation of the possible hierarchical organization of items and the size(s) of clusters (grain of patterning).

Other methods belonging to the same family of geographic distance approaches as first-order nearest neighbor analysis also allow evaluation of form of spatial patterning but do not have these same drawbacks. Most of the techniques require at least two of the following classes of data: (1) an estimate of regional item density; (2) item-to-neighboring-item distances; and (3) randomly located point-to-item distances (Pielou 1959:607). The various methods and the aspects of arrangement (intensity, grain, hierarchical arrangement) that they are capable of evaluating are summarized in Table 3.9.

Two of the techniques—those derived by Thompson (1956) and Pielou (1959)—seem most useful to archaeologists, for they: (1) provide tests of signifi-

TABLE 3.9

Geographic Distance Methods Allowing Evaluation of Various Aspects of the Form of Arrangement of Artifact Scatters, and Their Data Requirements

Statistic for evaluating arrangement	Reference	Data required[a]	Aspect of spatial patterning measured
R	Clark and Evans (1954)	a, b	Intensity
$2\lambda_0 \sum_{i=1}^{N} r_n^2$	Thompson (1956)	a, b	Intensity, grain, hierarchy
a	Pielou (1959)	a, c	Intensity, grain
a	Mountford (1961)	a, c	Intensity, grain
z_{st}, ρ_{st}	Holgate (1965)	c	Intensity, grain
A	Hopkins and Skellum (1954)	b, c	Intensity, grain

[a] a = an estimate of regional density of items; b = item-to-neighboring item distances, or a sample of these; c = randomly located point-to-item distances, or a sample of these.

cance of departure from random arrangement in the direction of alignment as well as clustering; (2) allow estimation of the size of clusters; and/or (3) evaluate arrangement at all levels of order (individually or as a whole) in a hierarchically organized scatter of items. Thompson's method, *n*th-order nearest neighbor analysis, is summarized in this section.

*N*th-order nearest neighbor statistics allow evaluation of the form of patterning of items at each of a number of scales larger than the most detailed (the average nearest neighbor distance) by examining measurements from items to their second, third, . . . , *n*th-order nearest neighbors. The statistics generated by the method are logical analogs of those derived by Clark and Evans (1954) for first-order nearest neighbor analysis. If N is the number of items in a scatter, A the area of the scatter, m the density of items in the scatter, $\bar{r}_{0_n}$ the observed average nearest neighbor distance to *n*th-order nearest neighbors, and $\bar{r}_{e_n}$ the expected average *n*th-order nearest neighbor distance under the null hypothesis of random arrangement, then,

$$m = \frac{N}{A} \tag{3.27}$$

$$\lambda_0 = \pi m \tag{3.28}$$

$$\bar{r}_{0_n} = \sum_{i=1}^{N} r_{i_n}/\mathrm{N} \tag{3.29}$$

$$\bar{r}_{e_n} = \frac{.5642}{\sqrt{n/m}} \tag{3.30}$$

$$\sigma_{\bar{r}_{e_n}} = \frac{.2821}{\sqrt{m}} \tag{3.31}$$

The equations for determining $\bar{r}_{e_n}$ and $\sigma_{\bar{r}_{e_n}}$ hold for only large n, when the distribution of $\bar{r}_{e_n}$ approaches normality. For $n \leqq 4$, Thompson (1956:392, Table I) provides more accurate formulae.

As in first-order nearest neighbor analysis, an *n*th-order nearest neighbor statistic R_n can be calculated for each scale examined.

$$R_n = \frac{\bar{r}_{0_n}}{\bar{r}_{e_n}} \tag{3.32}$$

R_n will be approximately equal to 1 if items or *clusters*, depending on the scale of analysis, are arranged randomly within the scatter. It will tend toward 0 if items or clusters aggregate in space, and will range greater than 1 if items or clusters tend to be aligned. The maximum value of R is not determined by Thompson.

The significance of departure of a scatter of items or clusters from a random arrangement at a given scale can be tested most accurately with a χ^2 test similar to that used in first-order nearest neighbor analysis. The χ^2 statistic to be calculated is

$$\chi^2 - \text{stat} = 2\lambda_0 \sum_{i=1}^{N} r_{i_n}{}^2 \tag{3.33}$$

The form of the test is the same as that given in the section on first-order nearest neighbor statistics (see page 156), with the degrees of freedom equal to $2Nn$. Thompson also provides normal statistics for testing the significance of patterning, but these provide a more approximate solution than the χ^2 approach.

By graphing the average neighbor distances $\bar{r}_{0_n}$ against neighbor orders n, it is possible to determine a number of aspects of patterning: whether items are arranged in a nonhierarchical (uniformly random, aligned) or hierarchical (clustered) manner (including reflexive pairing); whether hierarchically organized clusters exhibit nesting; the form of arrangement of clusters at a given level of a cluster hierarchy (random, clustered, aligned); and the size of clusters. Figure 3.19 shows various aspects of such curves for nonhierarchical, hierarchical–unnested, and hierarchical–nested arrangements when the simplifying assumption of equal numbers of items in clusters at the same hierarchical level is made for illustrative purposes. Note that a nonhierarchical arrangement is characterized by a slowly rising graph, indicating measurement to increasingly distant neighbors as n increases. In contrast, the graph of a hierarchical (clustered) arrangement exhibits a ''jut,'' one neighbor order in range, indicating a change from measurement to nth-nearest neighbors *within* clusters to measurement to nth-nearest neighbors in *different* clusters, much farther away. The size of clusters, in number of items, can be determined from the neighbor order at which the jut occurs. The approximate area of the clusters can be found by graphic construction knowing the number of items that the clusters contain and the average distance between items ($\bar{r}_{0_n}$ for that n immediately before the jut), and assuming some shape for the clusters. The form of arrangement of items within clusters can be determined by calculating an nth-order nearest neighbor statistic, R_n, for some midrange neighbor order *below* the jut and by applying a χ^2 test to the neighbor distances of that order. The form of arrangement of clusters (second level patterning) can be evaluated using the same methods for some midrange neighbor order *above* the jut.

Unnested and nested clustered patterns are distinguishable (see Figure 7.19b, c) by the form of the graph below the jut. For an unnested arrangement, this segment of the graph will be a gently rising line of one slope (with some random variation). For a nested arrangement, this segment, will have multiple slopes, one for each nested level. At lower neighbor orders, the slope will be low, indicating measurement to increasingly distant neighbors within the *same hier-*

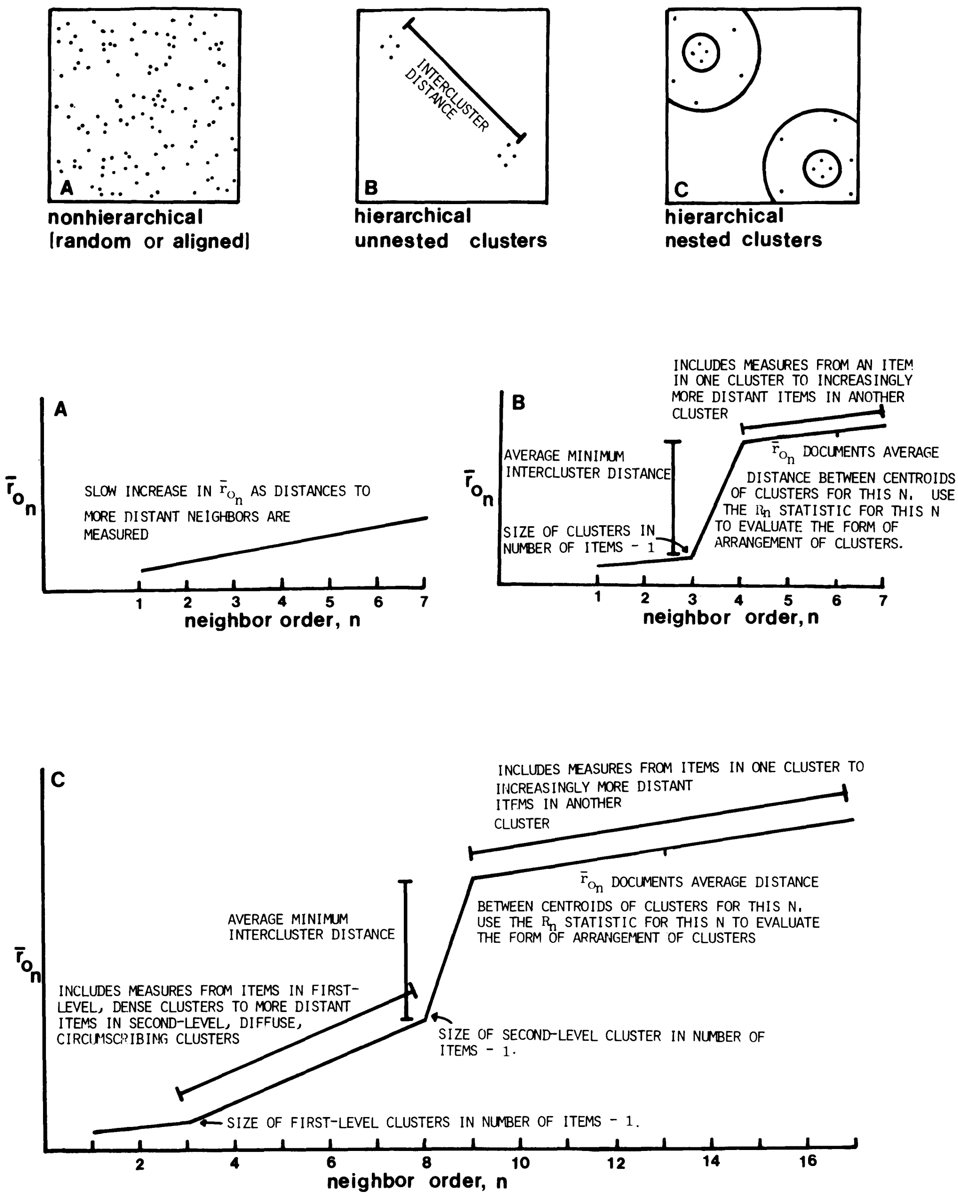


Figure 3.19. (A) Nonhierarchical arrangements (uniformly random, aligned), (B) hierarchical unnested clustered arrangements, and (C) hierarchical nested clustered arrangements have characteristically different curves of $\bar{r}_0$ against *N*. For both kinds of clustered distributions, it is possible to determine the size of clusters in number of items and the form of arrangement of clusters (second-level organization within a hierarchical pattern). It is assumed here, for simplicity, that clusters at a given hierarchical level include the same number of items and have similar densities.

archy level, of *similar density.* At higher neighbor orders, the slope will be greater, indicating the average condition of measurement to more distant neighbors in *other, less dense* (surrounding) levels of the cluster hierarchy.

The multiple slopes may manifest themselves simply as an upsweeping curve, depending on the degree of variation in interitem distances within hierarchical levels of the clusters, the intensity of the density differences between levels, the sharpness of the density gradient between levels, and whether all clusters have the same number of levels and items per level. In most archaeological circumstances, where the number of items per cluster at a given level varies from cluster to cluster, an upsweeping curve can be expected. Figure 3.20 shows generalized curves for unnested and nested clustered arrangements where clusters *vary in their number of items.* The two graphs and arrangement of types are distinguishable by the presence or absence of an upsweeping curve before the intercluster jut.

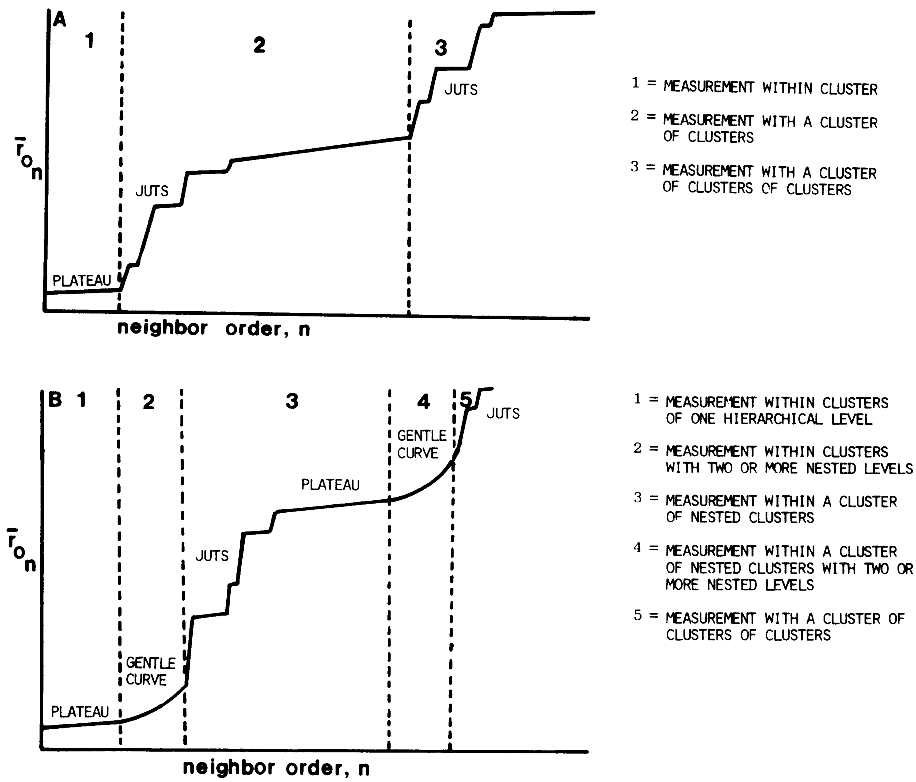


Figure 3.20. (A) Unnested and (B) nested clusters have characteristically different curves of $\bar{r}_{0_n}$ against *N,* even when the number of items per cluster at a given hierarchical level varies from cluster to cluster. Generalized curves are shown. The numbered segments of each curve pertain to the different hierarchical levels of clustering illustrated in Figure 3.5.

Finally, note that when the number of items per cluster varies, in either a nested or unnested arrangement, multiple juts occur in place of a single jut. One jut will occur for each cluster having a different number of items, reflecting the change from measurement to *n*th nearest neighbors within clusters to measurement to *n*th nearest neighbors in different clusters, *at different orders for the different sized clusters.* The juts will vary in magnitude in accordance with the different distances between clusters. Gentle slopes may precede each jut if the arrangement is a hierarchical–nested one.

*N*th-order nearest neighbor analysis is nearly consistent with the nature of organization of the archaeological record, but has several drawbacks (Table 3.4).

Problems 1 and 2. It restrictively assumes that clusters of a given hierarchical level are of similar size. It also assumes that if clusters are nested, each cluster has the same number of nested levels. As archaeological reality deviates from these conditions, the nearest neighbor statistics $\bar{r}_{0_n}$ and R_n and the χ^2 test of significance reflect mixed information on arrangement from more than one hierarchical level (e.g., within-cluster distances and between-cluster distances, simultaneously) and become less meaningful. Similarly, the graph of $\bar{r}_{0_n}$ against n becomes increasingly more complex and its diagnostic characteristics may become lost.

Problems 3 and 4. Technically, *n*th-order nearest neighbor analysis is plagued with a framing problem and a boundary problem, just like first-order nearest neighbor analysis. To avoid a framing problem, it is necessary that the area of analysis be a behaviorally meaningful entity. No solutions to the boundary problem have been offered at this time. As a consequence, the nearest neighbor statistic R_n may be inflated and indicate the scatter to be less clustered than it actually is. The χ^2 statistic also will be inflated, making the test for clustering of items more conservative and the test for systematic alignment of items more liberal.

Problem 5. *N*th-order nearest neighbor analysis requires much computation time. As the number of items within clusters increases, the amount of calculation that must be done before information on intercluster organization can be extracted rises substantially. Where clusters are large yet spatially discrete, this burden may be reduced by counting the number of items in clusters, beginning the analysis at an order greater than the numerous number of items in a cluster and searching for *n*th nearest neighbors outside of the cluster to which an item belongs. When clusters cannot be delimited clearly prior to analysis, yet are large, *n*th-order nearest neighbor analysis may simply be unoperationable.

Pielou's Point-to-Item Distance Statistics

When it is not practial or meaningful to use *n*th-order nearest neighbor analysis to evaluate the form of arrangement of items in a scatter, as when clusters are large or vary greatly in the number of items or nested hierarchical levels they contain, Pielou's (1959) point-to-item distance statistics may be employed. This approach provides a single measure and test of the form of arrangement of items within a scatter as a whole, considering simultaneously "most if not all" scales of ordering of items (Pielou 1959:608). In its sensitivity to multiple scales of arrangement, it is more informative than first-order nearest neighbor analysis. However, because it mixes information on arrangement from multiple hierarchical levels of patterning into one statistic, it is less satisfactory than *n*th-order nearest neighbor analysis. The method would be more desirable if it were known what scales of patterning have the greatest and least effect on test results, but this has not been investigated.

Pielou's method begins with the selection of a set of random points within a natural study area. The distance from each random point to the item nearest it then is measured. A measure, *a*, of the form of arrangement of items within the study area may be calculated by

$$a = \pi D \bar{r}_0^2 \qquad (3.34)$$

where D is the density of items in the study area and $\bar{r}_0$ is the average distance from the n random points to their nearest item neighbors

$$\bar{r}_0 = \frac{\sum_{i=1}^{n} r_i}{n}, \qquad (3.35)$$

r_i being one point-to-item distance. If the arrangement of items is random at all geographic scales, then a will approximately equal $(n - 1)/n$. Values of a larger than this indicate a tendency toward aggregation, whereas smaller values indicate a tendancy toward alignment.

The significance of deviation of a scatter from a random arrangement can be determined by calculating a χ^2 statistic

$$\chi^2 - \text{stat} = 2n\pi D r_0^2 \qquad (3.36)$$

and comparing its value to the χ^2 distribution with $2n$ degrees of freedom. A value of χ^2 − stat greater than $\chi^2_{(1-\alpha)}$ (df) indicates significant clustering at the α level, whereas a value less than $\chi^2_{(\alpha)}$ (df) indicates significant alignment at the α level.

When it is operationally impossible to use *n*th-order nearest neighbor analysis, Pielou's method and first-order nearest neighbor analysis can be used together to give some insight (not obtainable from the methods individually) into the form of arrangement of items at *multiple* scales. If the two techniques produce different results, then it can be concluded that the scatter of items is hierarchically arranged, with one kind of arrangement at the smallest scale and a second or more kinds at larger scales.

Although concordant with the nature of organization of intrasite archaeological records, Pielou's method has two disadvantages.

Problem 1. It does not allow evaluation of the size of clusters.

Problem 2. More seriously, it is not sufficient by itself for assessing form of arrangement. Some aggregated and regular arrangements of items have the same frequency distribution of point-to-item distances as random arrangements (Pielou 1959:613). The results of Pielou's technique must be confirmed by visual inspection of the study area.

Luton and Braun's Contiguity Method

Luton and Braun (1977) have constructed a statistical method for assessing form of arrangement that operates on grid-cell count data. The technique consciously was designed to evaluate the spatial *arrangement* of item-counts among cells, rather than their frequency *distribution*; it consequently avoids all the technical problems of Poisson-based approaches previously discussed (Table 3.4; pages 141–142, Problems 1–5).

To apply the method, the difference in cell counts at each border between all adjacent cells is calculated. The direction in which differences are calculated (left to right versus right to left; up versus down) must remain constant over the whole grid system. The mean and variance of these differences then is determined.

A relative index of arrangement of cell counts can be constructed by finding the ratio of the observed variance of cell count differences to that expected, assuming the random arrangement of cell counts. For a large number of cells, this expected variance is equal to twice the observed variance of the cell counts. The ratio will take the value 1 for a random arrangement, becoming less than 1 as the arrangement becomes more clustered and more than 1 as the arrangement becomes more dispersed.

An absolute assessment of form of arrangement can be made by applying a χ^2/df test to Luton and Braun's index of arrangement. An arrangement clustered significantly for a given α level will produce an index value less than $\chi^2/df_{(\alpha)}$; a significantly dispersed arrangement will yield an index value greater than $\chi^2/df_{(1-\alpha)}$, where df is the number of differences in counts minus one.

The theoretical basis for the method is the Central Limit Theorem applied to a convoluted function: the difference between two independent random variables. The theorem states that, for large N, this difference is, itself, a random variable with an approximately normal distribution having known moments, regardless of the form of the distribution of the two original variables. The mean of the convolved variate is equal to the difference of the means of the two original variables, and its variance is equal to the sum of their variances (Strackee and van der Gon 1962). In the context of Luton and Braun's method, the two original random variables are (1) the counts of items in a set of grid cells, where counts have a Poisson distribution and are arranged randomly, and (2) the counts of items in neighboring cells in the defined directions, also having a Poisson distribution and being arranged randomly.

Luton and Braun's method can be extended in several ways, given its robust theoretical basis. First, aggregation at specified scales larger than the area encompassed by two neighboring grid cells can be assessed simply by calculating differences between the counts of cells separated by a larger, set distance. Second, patterns of association between pairs of artifact types can be found using the differences in counts of items of different types within cells. Finally, patterns of mutual aggregation of pairs of types can be discerned using between-cell differences of the within-cell differences in their counts. The details of the latter two methods for assessing whether artifact types are co-arranged are not summarized here because they appear less appropriate to this task than does the procedure, polythetic association, which is introduced in the next section. Luton and Braun's methods assume the monothetic organization of depositional sets.

Luton and Braun's contiguity method for assessing form of arrangement is free from the technical problems of Poisson-based methods (see pages 141–142, Problems 1–5). Nevertheless, as a grid-based technique, it still is discordant with the nature of the archaeological record in most ways already discussed for Poisson methods (see pages 143–144, Problems 6–14; Table 3.4). Many of these constraints could be removed partially by applying the technique several times, using grids of different meshes, in a dimensional analytic strategy.

A Method for Assessing Whether Artifact Types Are Co-Arranged

Polythetic Association

The model of intrasite archaeological records described previously (pages 117–121), as well as the problems enumerated in using the measures of covariation, association, and segregation to assess the degree of co-arrangement of artifact types (pages 161–179), suggest some basic technical properties that an accurate measure of co-arrangement probably must have.

Property 1. The measure should use point-location data and be within the realm of nearest neighbor or item-to-point approaches, rather than use grid-cell counts. This is necessary to avoid the many restrictions on analysis posed by the methods using grids of set meshes, shapes, orientations, and placements.

Property 2. The measure should be concerned with the co-occurence *of artifacts of different types within each other's neighborhoods rather than the* covariation *of their densities.* This is necessary to avoid methodological assumptions that are inconsistent with those behavioral and archaeological formation processes that cause artifact types within the same depositional set not to covary.

Property 3. The measure of co-occurence should not be influenced by whether co-occurring artifact types are co-arranged in a more symmetrical or more asymmetrical manner (Pielou 1964). By a *symmetrical* co-arrangement of two artifact types is meant that wherever one artifact type occurs, the other always occurs, and vice versa. In nearest neighbor terms, it means that whenever one artifact type is a second's nearest neighbor, the second artifact type is always the first's nearest neighbor (Figure 3.21a). A symmetrical co-arrangement of two artifact types can occur only when they have equal densities and items of the two types can always pair. *Asymmetrical* co-arrangements of two types occur when they are scattered over the same locale, but in different densities. The items of the lower density artifact type always have items of the higher density artifact type near them, but items of the higher density type only sometimes have items of the lower density type near them. Nearest neighbor relationships are not reciprocal (Figure 3.21b–d).

A monothetic depositional set ipso facto is characterized by artifact types that are co-arranged in a symmetrical manner. Wherever an item of one type within a monothetic depositional set occurs, items of all other types in the set co-occur in the vicinity, and vice versa. A polythetic depositional set, on the other hand, ipso facto is characterized by artifact types that are co-arranged in an asymmetrical manner. Where an artifact of one type occurs, an artifact of another type in the same depositional set may or may not occur, depending on the archaeological formation processes by which the set was generated. Depositional sets that are more polythetic, as a result of the operation of more archaeological formation and disturbance processes on them, are characterized by artifact types that exhibit greater local density differentials and more asymmetry in their co-arrangement.

As a consequence, a measure of co-arrangement of artifact types, to avoid being influenced by the degree to which depositional sets are polythetic and to measure only co-arrangement, must be insensitive to (not affected in value by) whether co-arranged artifact types pattern themselves in an asymmetrical or symmetrical manner, and to variations in the degree of asymmetry of co-arrangement. Specifically, one artifact type within an activity set might have higher curation rates and lower discard rates than other types within it, causing the type to occur in lower densities, and to be *absent* at some locations where the other types occur. Also, multipurpose tools and compound tools, which participate in several activities during the course of their life histories, will be *absent* from some locations where other members of their activity sets have been deposited. *These forms of absences of an artifact type from the vicinity of other artifact types with which it often was used or deposited and with which we might expect it to occur (asymmetry) do not indicate that the missing type is not part of the depositional set represented by the types.* A measure of co-arrangement of artifact types thus should not be affected in value by such absences and asymmetry.

We may see more clearly, now, how association analysis—as a measure of monothetic, symmetrical co-occurrence of artifact types—is inappropriate for defining most depositional sets. Currently used association coefficients do not distinguish between two possible kinds of absences of a type from the neighbor-

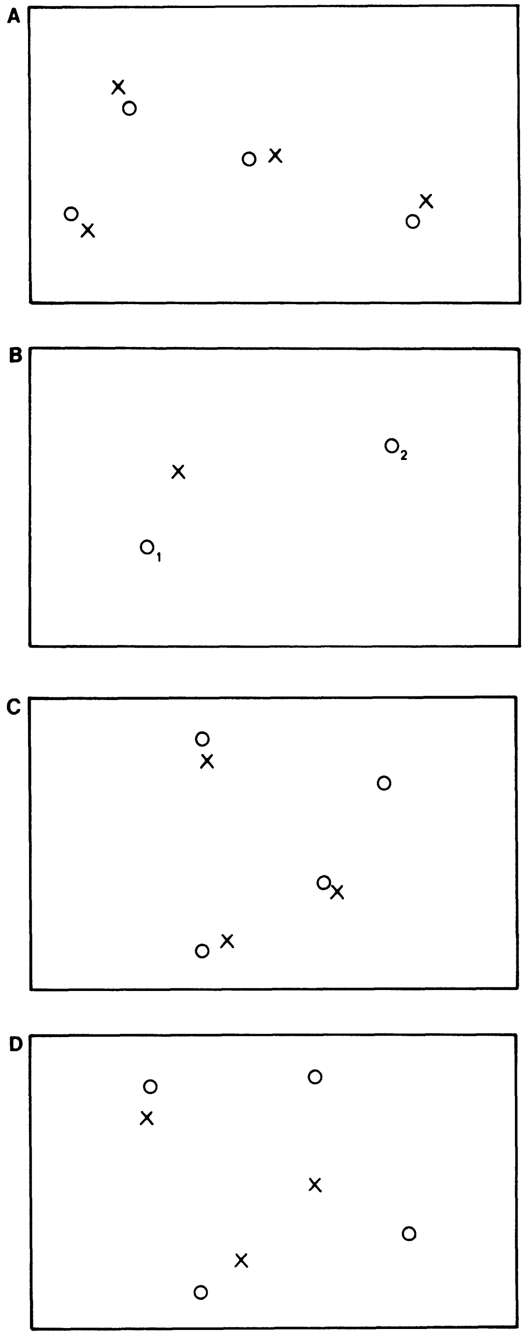


Figure 3.21. (A) A symmetrical co-arrangement of two artifact types, X and O, defining a monothetic set. (B) Asymmetry in nearest neighbors. Artifact X is artifact O_2's nearest neighbor of the opposite kind, but O_2 is not X's nearest neighbor of the opposite kind. Artifact O_1 is artifact X's nearest neighbor of the opposite kind. (C) An asymmetrical co-arrangement of two artifact types, X and O, defining a polythetic depositional set. (D) A more ambiguous asymmetrical co-arrangement of two artifact types, X and O, defining a polythetic depositional set.

hood of other artifact types: (1) absence due to the actual dissociation of the artifact type from a depositional set represented by other types (Figure 3.22), and (2) absence as a result of the polythetic organization of types among depositional sets and their asymmetrical distribution over space (Figure 3.21c–d). Mismatches (counts in the *b* and *c* cells) in fourfold contingency tables *always* are considered a measure of dissociation (Sneath and Sokal 1963:128– 135).

Property 4. The measure of co-arrangement of artifact types should not be influenced by changes over space in the *direction* of asymmetrical relationships between co-arranged types (Figure 3.23). In some neighborhoods, one artifact type within an activity set may be absent because it was not used, deposited, preserved, or recovered, whereas in other neighborhoods, other members of the set may be absent. This circumstance may arise because the factors causing artifact types within a depositional set to be co-arranged in an asymmetrical manner need not have worked uniformly over the whole site, or even within depositional areas. For example, some kinds of artifacts within an activity set may have been "mined" and recycled in some parts of a site, whereas elsewhere at the site, other kinds of artifacts within the set may have been collected.

Designing a Coefficient of Polythetic Association. A coefficient of co-arrangement that meets the above criteria and that is consistent with the model of intrasite archaeological records presented earlier in this chapter may be designed. To build it, first consider what a nearest neighbor measure of symmetrical, monothetic co-arrangement might look like, meeting only requisite Properties 1 and 2 just discussed.

A simple statistic comparing the arrangement of items of two artifact types is the average absolute distance between items of one type and their nearest neighbors of the second type. A *base type* and *reference type* are chosen. For each item of the base type, the Euclidean distances at which surrounding items of the reference type occur are compared until the nearest neighbor of the reference

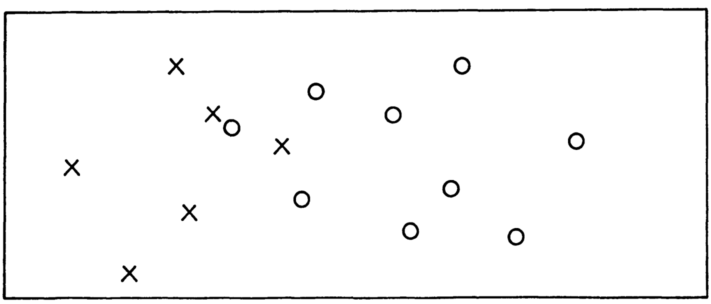


Figure 3.22. Two artifact types, X and O, that belong to different depositional sets but overlap spatially to a slight degree. Other artifact types included in the depositional sets are not shown.

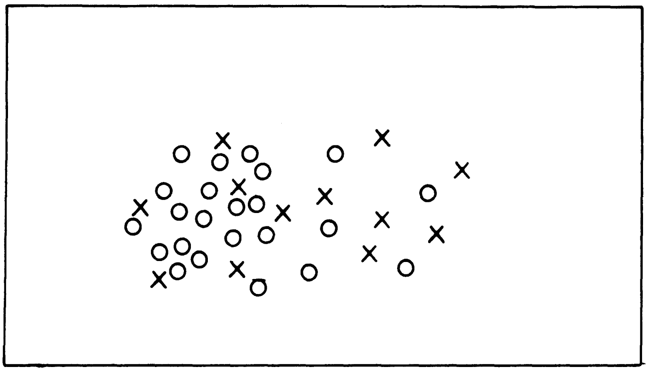


Figure 3.23. A cluster of two artifact types, X and O, that is internally inhomogeneous in the relative densities and direction of asymmetrical co-arrangement of the two types.

type is found. The same procedure then is repeated, this time using the items of the reference type as base points and the items of the base type as the satellite reference points. The average intertype distance can be computed by

$$\mathrm{AV}DISTM_{AB} = \frac{\sum_1^n \overline{AB} + \sum_1^m \overline{BA}}{n + m} \tag{3.37}$$

where n is the number of items of type A, m is the number of items of type B, $\overline{AB}$ is the distance from a given base point of type A to its nearest neighbor of type B, and $\overline{BA}$ is the distance from a given base point of type B to its nearest neighbor of type A. Note that the number of $\overline{AB}$ distances, n, and their sum, need not be equivalent to the number of $\overline{BA}$ distances, m, and their sum. This is so because the number of items of type A and B over a site may not be equal, and the pattern of co-arrangement of the types may be asymmetrical (Figure 3.21a).

The above statistic provides a measure of symmetric, monothetic association of two different types. If two artifact types are co-arranged in a symmetrical manner, such that items of one type are usually close to items of the second type and *vice versa,* defining a monothetic depositional set, both of the sums of distances, $\Sigma\overline{AB}$ and $\Sigma\overline{BA}$, will be small. The value of AVDISTM will be small, indicating that the two types are co-arranged. However, if two artifact types are co-arranged in an asymmetrical manner (similar distributions, different densities; Figure 3.21c–d), such that sometimes the less dense type is not proximate to the more dense type, defining a polythetic depositional set, then one of the sums of distances, ΣAB or ΣBA, will be large—whichever represents the sum of distances from items of the more dense type to items of the less dense type. The value of AVDISTM, consequently, will be inflated. The coefficient will erroneously indicate that the two types are less *co-arranged* than they really are because its value is influenced by the *asymmetric relationship* between the types as well as their co-arrangement.

To remove the influence of asymmetry on the statistic, it is necessary to consider only those distances from items of the more dense type to items of the less dense type. These distances truly indicate the degree of similar arrangement of the two artifact types and are not inflated by the asymmetrical nature of co-arrangement of the types. The distances from items of the more dense type to items of the less dense type, which reflect the *absence* of items of the less dense type from the neighborhood of some items of the more dense type due to asymmetry, should be ignored. This may be achieved by calculating two average interitem distances

$$\text{AVDIST1} = \frac{\sum_1^n \overline{AB}}{n}, \text{ and AVDIST2} = \frac{\sum_1^m \overline{BA}}{m} \qquad (3.38)$$

and choosing the *minimum* of the two as the measure of association of the two types

$$\text{AVDIST} = \min(\text{AVDIST1}, \text{AVDIST2}). \qquad (3.39)$$

For example, in Figure 3.21c, the average distance from type X to type O is small, because pairing between the two types is complete from the perspective of type X. The average distance from type O to type X, however, is larger, because pairing is incomplete from the perspective of type O. The smaller average distance would be chosen as the measure of association, *ignoring the effects of those absences* of items of type X from the vicinity of some items of type O that reflect the asymmetric nature of co-arrangement of the two types and that result from the various processes by which the archaeological record was formed, disturbed, and collected.

Higher values of AVDIST, indicating dissociation of two artifact types, are found only when the types tend to not pair in a *symmetrical* manner—when both types are distant from each other and most likely belong to different depositional sets (Figure 3.22).

By defining the strength of association between two artifact types in this manner, then, two *causes* for the absence of an artifact in the proximity of another are separated: (1) the *actual dissociation* of the types belonging to different depositional sets and possibly different activity sets, and (2) the numerous *archaeological formation processes* that cause activity sets and depositional sets to be polythetic in organization and that cause artifact types within a depositional set to be co-arranged in an asymmetrical manner. Only the first factor affects the value of the statistic AVDIST, as should be. The statistic AVDIST then, is a measure of the degree of *polythetic association* of artifact types.

Once a matrix of AVDIST coefficients for all possible pair-wise combinations of types has been calculated, overlapping polythetic depositional sets may be defined by using an *overlapping,* polythetic hierarchical clustering algorithm (Cole and Wishart 1970; Jardine and Sibson 1968) and *multiple* threshold distances specifying the different levels at which different portions of the generated tree may be broken into significant groupings of artifact types. An overlapping clustering algorithm must be used to allow the definition of depositional sets that may be overlapping, as specified by the model of the archaeological record presented early in this chapter. Multiple average nearest neighbor distance thresholds for defining groups of artifact types must be used because different depositional sets may occupy depositional areas of different sizes and densities. The values of the distance thresholds used in defining groups of artifact types in different portions of the tree should be less than the expectable scales or equivalent to the expectable artifact densities of *potential* depositional areas of different kinds that are *suggested* by the relationships among artifact types in the unbroken tree. Some examples of factors that should be considered in defining the expectable nature of depositional areas and appropriate distance thresholds are: the kinds of activities suggested by the potential groupings of artifact types and their space requirements, whether sweeping and cleaning of activity areas probably occurred, and whether depositional sets have been smeared by contemporary farming (in the case of surface collections).

The process of defining groups of artifact thus is an iterative one that involves examining the unbroken tree for potentially meaningful groups of artifact types; postulating expectable distance thresholds for such groups; checking to see whether the potential groups are defined by the postulated thresholds; and reexamining the unbroken tree for other potential groupings, should the first groupings not be defined by the postulated thresholds, etc. Standard procedures for defining a single, tree-wide threshold for defining clusters, although more systematic, are less concordant with the nature of the data.

If the number of artifact types to be clustered is greater than approximately 16, it may not be feasible to use overlapping polythetic clustering algorithms to define depositional sets. The computation time required on a computer may be too large (Cole and Wishart 1970:162). In these cases, multidimensional scaling techniques may be used as an alternative to represent the relationships between types in a few dimensions, and to define overlapping polythetic clusters of types.

Further Considerations of Design. The coefficient, ADVIST, satisfies the first three criteria described above as required for accurate measurement of the co-arrangement of artifact types. It does not fulfill the fourth; it is influenced by changes over space in the direction of asymmetrical relationships between co-arranged artifact types. The coefficient requires the assumption that if two artifact types are co-arranged and co-arranged asymmetrically, the direction of asymmetry is uniform across the whole area of analysis.

For pairs of artifact types having random or aligned arrangements, this assumption poses no problems. If two artifact types have random or aligned arrangements and are co-arranged asymmetrically as well, the direction of asymmetry ipso facto is uniform across the study area. However, if two artifact types have clustered arrangements and are co-arranged asymmetrically, the assumption of uniform asymmetrical co-arrangement, where asymmetry occurs, may be overly constraining. The direction of asymmetry may vary from cluster to cluster: in some clusters one type of artifact may be more plentiful, whereas in other clusters another type may be more plentiful. Direction of asymmetry also may vary within a cluster (Figure 3.23). In these circumstances, the coefficient, AVDIST, will be inflated by the effects of changes in the direction of asymmetry.

To circumvent this problem, for each pair of artifact types exhibiting clustered arrangements, it is necessary to partitioned the study region into areas that *potentially* might differ from each other in the direction of asymmetrical co-arrangement of the types (should they be co-arranged) and that are internally homogeneous for this characteristic. Then, within each uniform stratum, the coefficient AVDIST may be calculated without bias, and the average of all AVDIST statistics from all strata, weighted by the numbers of distances used in calculating them, may be used as an accurate measure of co-arrangement of the artifact types across the study area:

$$\text{AVDISTP} = \frac{\sum_{i=1}^{k} x_i(\text{AVDIST}_i)}{\sum_{i=1}^{k} x_i} \tag{3.40}$$

where AVDIST_i is that AVDIST coefficient found in the ith uniform stratum and x_i is the number of interitem distances (n or m in equation 3.38) used to calculate the AVDIST coefficient in stratum i, and k is the number of strata.

The unbiased AVDISTP coefficients for all pairs of artifact types where both types exhibit clustered arrangements, along with the AVDIST coefficients for all other possible pairs of types, then can be grouped by cluster analysis or multidimensional scaling, as previously described, to define polythetic, overlapping depositional sets not influenced by changes in the direction of asymmetrical co-arrangement over the site.

Partitioning the study area into uniform strata for a particular pair of clustered artifact types can be achieved by the following method. First, the limits of single-type clusters for both artifact types are defined, using one of the methods to be described later (pages 202–207). Second, the study area is partitioned into broad "potential zones of analysis" containing one or more single-type clusters of *both kinds* but no more than one pair of single-type clusters different in kind *that overlap spatially* (a potential use-area) (Figure 3.24). Each potential zone of

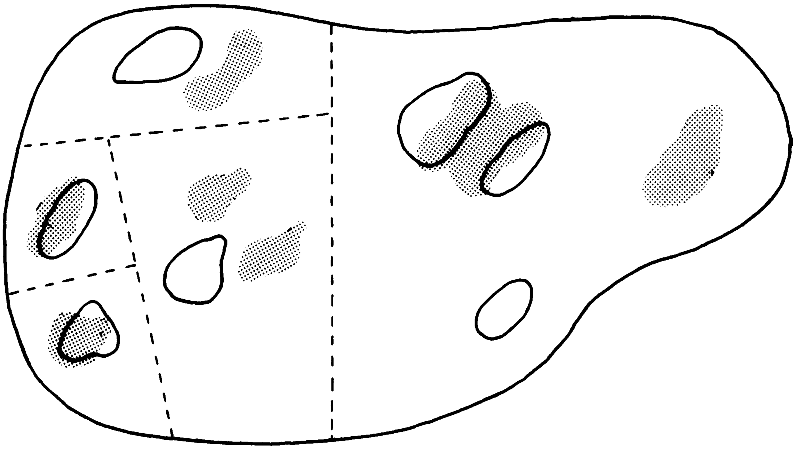


Figure 3.24. A site may be partitioned into broad zones within which different kinds of single-type clusters of artifacts are closer to one another than they are to similar single-type clusters, and within which asymmetry of co-arrangement of artifact types is uniform at the scale of the cluster.

analysis, which contains at most one co-arrangement of two types (one multitype cluster), is, by definition, uniform in the asymmetrical co-arrangement of types within it (if the types are co-arranged at all), assuming the multitype cluster is internally homogeneous in its direction of asymmetrical co-arrangement of types. Third, to insure homogeneity *within* each multitype cluster, the following remaining steps must be taken.

For the multitype cluster in question, the local densities of items of each type within the neighborhood of each item of both types is calculated. The radius of the neighborhood used to calculate local densities should be much less than the radius of the multitype cluster, but large enough to include several items of either type. Next, the multitype cluster is divided into areas of contiguous neighborhoods that similarly have greater densities of one artifact type than the other. These areas are homogeneous in the direction of asymmetry of the two types and may serve as strata within which unbiased AVDIST coefficients may be calculated. If single-type clusters also occur in the "potential zone of analysis," they must be combined with those homogeneous areas within the multitype cluster that are closest to them and that predominate in the artifact type they contain, to define the appropriate strata.

Extension of the Method to Data in the Form of Grid-Cell Counts. The method just summarized requires item point location data for the computation of geographic distances. For some data sets, however, it may be feasible to convert grid count data into a form consistent with the proposed methodology. If the archaeological site from which the data are taken is large enough, compared to the size of the collection units, and if the collection units are not larger than the expectable *minimal* dimensions of depositional areas, the centers of collection units may be used to approximate the actual provenience of the artifacts within them. This approach has been used on two data sets (Carr 1977, 1979, 1984a), giving reasonable results and allowing the investigation of polythetic patterning that otherwise would not have been possible.

Data Screening Required by the Method. Artifact types occurring *ubiquitously* across a site in *high densities* must be handled in a special way if they are not to cause analytical misrepresentations of the data. The manner in which they are handled should be consistent with their form of arrangement and with one's understanding of the activities and depositional processes by which the arrangement was produced.

Two circumstances are possible. First, the items of the ubiquitously, densely distributed artifact type might also exhibit significant *clustering*. This arrangement could result from either of two different sets of processes. It could represent the deposition of debris from an activity that produced much waste and that could be and was performed anywhere within the site, but that more often occurred in the vicinity of some preferred social gathering places (e.g., hearths) or some preferred physically attractive work areas. Whittling and knapping are examples of such activities. The arrangement also could reflect an artifact type: (1) that was disposed of at high rates; (2) that had multiple purposes, such that it was deposited at numerous locations of work or discard, producing clusters of the type; and (3) that then was ''smeared'' (Ascher 1968) by natural or human processes (e.g., soil creep or plowing) partially obscuring the discreteness of the clusters. Raw materials such as igneous rock, sandstone, and limestone, as well as pottery, in some Archaic and Woodland sites in the Eastern United States have spatial arrangements fitting this description.

As a second possible circumstance, the items of the ubiquitously, densely distributed artifact type might be scattered in a fairly *even density* over the whole site (a uniform or random arrangement). This arrangement could reflect either of the above two sets of formation processes, followed by *intensive* smearing of the artifact type so as to obscure most evidence of clustering. It might also represent debris from an activity that could be and was performed anywhere within the site, with preferred areas of performance being located differently and randomly at different times over the course of many reoccupations of the site.

Artifact types arranged in the second manner can be analyzed together, using the method of polythetic association to determine their degree of co-arrangement. They cannot, however, be analyzed with nonubiquitously distributed types without distorting the relationships between these types in the clustering routine. The ubiquitously scattered types will associate polythetically, strongly, and approximately equally with all nonubiquitously distributed types,masking the relationships between the latter (Carr 1979). Thus, two separate analyses—one for evenly, ubiquitously scattered artifact types and one for nonubiquitously scattered artifact types—must be performed. This requirement is not undesirable because the two different kinds of artifacts have different depositional patterns and can be expected to belong to different depositional sets.

Ubiquitious, clustered artifact types, too, might be analyzed with the ubiquitious, evenly scattered types and segregated in analysis from nonubiquitously scattered types to avoid distortion of relationships between the nonubiquitously scattered types. This, however, would bypass the opportunity for investigating relationships between locations where the ubiquitous types tend to cluster and locations where nonubiquitous types cluster. To investigate such patterns with accuracy, it is necessary to partition the arrangement of each ubiquitous, clustered type into its two dimensions—ubiquitous and clustered—and to analyze these dimensions separately. The clustered dimension of each type can be analyzed with artifact types that are nonubiquitously distributed. The ubiquitous dimension of each type can be analyzed with types having a ubiquitous, even arrangement.

This procedure is satisfying because it acknowledges that the arrangement of a ubiquitously clustered type is a compound result—a palimpsest—of two distinct depositional processes (e.g., the deposition of an artifact in a clustered distribution, followed by smearing) (Carr 1982).

To partition a ubiquitous, clustered arrangement of artifacts into its two dimensions, the techniques of spatial filtering or Fourier analysis (Carr 1982, 1983, 1984a; Davis 1973) can be applied. These techniques allow the construction of a smoothed surface of broad-scale spatial trends in artifact density variation (representing the ubiquitous dimension) and the calculation of small-scale, local deviations in artifact density from the trend (representing the clustered dimension). A complete detailing of the procedures of spatial filtering using grid-count and item-point location data is beyond the scope of this chapter. However, specific procedures for isolating items belonging to the clustered dimension of a compound artifact arrangement using point location data are discussed in the next section on delimiting clusters.

Evaluation of Polythetic Association. The technique of polythetic association is consistent with the organization of intrasite archaeological records with one exception (Table 3.4). The method is capable of determining the degree of co-arrangement of artifact types at only the most local scale of analysis, represented by interitem distances; it leaves broader-scale co-arrangements uninvestigated. Thus, although the approach is adequate for defining sets of artifact types that repeatedly occur in *close proximity* to each other and represent depositional sets, broader scale, hierarchical relationships between depositional sets and between clusters, describing patterns of activity organization and community structure, cannot be assessed. This limitation might be overcome by seeking relationships among *n*th-order nearest neighbors, a route of analysis that remains to be investigated.

A trial application of *some* of the aspects of polythetic association previously described is given by Carr (1979). The depositional sets defined by its application were intuitively meaningful. More rigorous testing of the full set of procedures is under way (Carr 1984a).

Methods for Delimiting Spatial Clusters of Artifacts

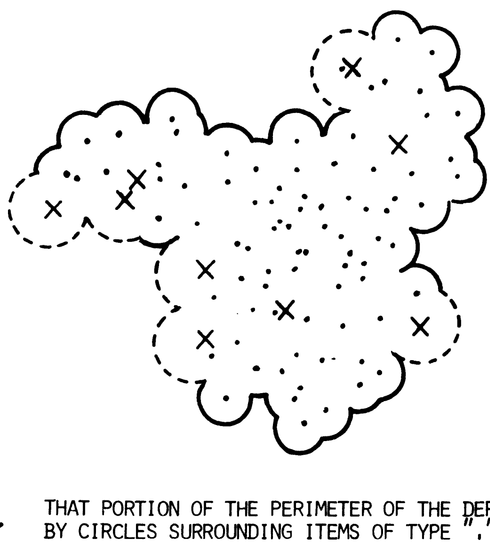
Modified Radius Approach I

Two techniques for defining single-types clusters and multiple-type clusters (depositional areas) can be designed by modifying Whallon's (1974) "radius approach" (see pages 181–182). Both require data in the form of item point locations.

The first method begins with a series of histograms of interitem nearest neighbor distances, one histogram for each artifact type showing significant clustering by one of the methods previously described (see pages 183–189). If the histograms exhibit large outliers, these must be eliminated, to prevent their inordinate effect on the statistics to be calculated in later steps. This screening process is acceptable because isolated single items corresponding to such large nearest neighbor distances are not of consequence in defining clusters of items. If the histograms are multimodal, they should be partitioned into their component modes by visual, graphic, or numerical methods (e.g., Bhattacharya 1967). The different modes of nearest neighbor distances in a histogram hopefully pertain to items within *different clusters of different densities,* there being minimal dispersal of the interitem distances of items in *one* cluster among several modes. This may be checked for each individual mode by plotting on a map all the item-pairs to which the nearest neighbor distances within that mode pertain. Most of the item-pairs should cluster spatially into one cluster or several clusters of similar density, for a given mode. If the histogram of nearest neighbor distances for an artifact type is multimodal but does not show this correspondence between the items to which a mode pertains and spatial clusters of those items, the method outlined here is inappropriate.

Next, the mean and standard deviation of the nearest neighbor distances in each frequency distribution, if it is unimodal (or each mode, if it is multimodal), is determined. A cutoff distance of 1.65 σ above the mean is defined for each unimodal distribution and mode, encompassing those 95% of all nearest neighbor connections that are more likely to occur within rather than between clusters. For each artifact type, a map is then made, showing the locations of all items of that type. Circles are drawn around each item, the radius of the circle being equivalent to the cutoff distance of the mode and type to which the item belongs. The intersecting circles for items of the same type and mode should define one or more clusters of items of the same type and of similar density. Types having histograms of nearest neighbor distances with multiple modes will have multiple clusters of different densities, at least one cluster for each mode.

Once spatial clusters for each type have been delimited on the maps of items of single types, the maps can be overlaid to define depositional areas. Depositional areas will be indicated by the similar placement of clusters of items of *those types that previously have been shown to form depositional sets.* Clusters of items that overlap but contain types that do not form depositional sets simply reflect different depositional areas that happen to overlap in *some* cases. The *exact* perimeter of a depositional area should be defined by the *union* of the areas ocurring within the clusters having similar placement and having types within the same depositional set, as opposed to the *intersection* of such areas (Figure 3.25). *This procedure accommodates the polythetic arrangement, within and between depositional areas, of items of different types in the same depositional set* (e.g., artifact types with different discard rates and densities).



THAT PORTION OF THE PERIMETER OF THE DEPOSITIONAL AREA DEFINED BY CIRCLES SURROUNDING ITEMS OF TYPE "." WITH A SMALL CUTOFF RADIUS

THAT PORTION OF THE PERIMETER OF THE DEPOSITIONAL AREA DEFINED BY CIRCLES SURROUNDING ITEMS OF TYPE "X" WITH A LARGER CUTOFF RADIUS

Figure 3.25. Depositional areas can be defined by the *union* of areas within clusters containing artifacts of types previously shown to form depositional sets.

The modified radius approach is concordant with the nature of organization of the archaeological record with two exceptions (Table 3.4). (1) Clusters must be fairly homogeneous internally in local artifact density, to the extent that clusters of different average densities do not share a large proportion of subareas with similar local density. (2) Clusters may not be hierarchically nested to the extent that they are internally heterogenous in artifact density and that the first condition holds. Either condition may cause items associated with nearest neighbor distances in single modes of a multimodal histogram not to cluster spatially, prohibiting the definition of meaningful cutoff distances. For these situations, the second modified radius approach may be used to delimit depositional areas.

Modified Radius Approach II

The second approach for defining depositional areas, modified from Whallon's (1974) method, again involves the definition of single-type clusters, followed by the overlaying of clusters of two or more types.

To begin, for each artifact type showing significant spatial clustering by some method, a data matrix is assembled. Each data matrix lists the two dimensional coordinates of each item of the type in question and the distances of the items from their nearest neighbors of the same type. The information contained in each matrix defines a surface of nearest neighbor distance values, which also may be interpreted as a surface of local item density values.Each matrix then is analyzed using digital spatial filtering techniques (Gonzalez and Wintz 1977; Carr 1982) to isolate: (1) large-scale geographic trends in the values of nearest neighbor distances—trends in item density—and (2) local deviations of nearest neighbor distance values and item density from the broader trends. The latter, if negative in value, may be interpreted as locations of significant artifact density/clustering.

Spatial filtering of a surface represented by irregularly spaced nearest neighbor distance values at the locations of items first requires the rediscription of the surface as a regular, fine-meshed grid of distance values. The values of each such grid point can be determined by interpolation from the values of the original observations surrounding it (Davis 1973:310–317).

A smoothed surface of nearest neighbor distance values representing large-scale density trends then is obtained by replacing each grid value with a weighted average of the grid values surrounding it. The particular smoothing *operator* or *filter function* used to accomplish this task can vary in the weighting scheme used and the distance (*filtering interval, search radius*) over which averaging occurs (Davis 1973:225–227). A generalized filter of the form specified by Zurflueh (1967) is preferable over other generalized operators in most cases where the specific structure of the data is not known, and is recommended. The filtering interval used in generating the smoothed surface should be slightly greater than the *maximum* expectable size of artifact clusters, in order to define trends sufficiently broad that they do not include local variations in density attributable to the clustering of artifacts. Different artifact types may be analyzed with filters having different interval widths, according to the expectable maximum size of their clusters.

Local deviations of nearest-neighbor distances and item density from broader density trends can be found with two steps. First, a smoothed value at each of the original, irregularly spaced item locations is found by interpolation from the smoothed values of adjacent grid points. Second, the smoothed value at each item location is subtracted from its original value. The resulting residual values define a map of locations where nearest-neighbor distance values are less than the expectable local norm (item density is anomalously high) and greater than the expectable local norm (item density is anomalously low). The former, *negative* nearest-neighbor distance anomalies are of interest as locations of significantly high artifact density that comprise single-type artifact clusters.

To define the perimeter of such clusters, a map is constructed with circles drawn around those items having anomalously low nearest-neighbor distances, the radius of each circle equal to the smoothed nearest neighbor distance of the item it is drawn around. Intersecting circles in the map should define one or more clusters having items of the same type but in variable average densities that are greater than the local norm.

The same filtering and mapping operations are repeated for each artifact type showing significant clustering. The perimeters of multitype depositional areas may be defined, as before, by the union of areas within those clusters containing artifacts of types previously shown to be co-arranged.

Those steps of this method involving the use of spatial filtering techniques to define a smoothed surface and a surface of local deviations can also be achieved using Fourier analysis (Carr 1982, 1983, 1984a; Gonzalez and Winz 1977). Although more complex, Fourier analysis can provide a technically cleaner definition and separation of large-scale trends and local deviations when filter functions are carefully designed.

The method just outlined is very nearly concordant with the nature of organization of intrasite archaeological data (Table 3.4). Its primary drawback is that it requires, prior to analysis, an estimate of the maximum expectable size of artifact clusters of each type, in order to generate the smoothed surface of nearest neighbor values for each artifact type. The estimate may be made on the basis of visual inspection of the spatial data prior to analysis or a priori behavioral considerations, including ethnographic documentation of the sizes of use-areas of kinds expected to be found.

The method also does not allow objective analysis of the hierarchical organization of depositional areas. Although it is possible to delimit different levels of a cluster hierarchy using different filters with smoothing intervals of different widths, choice of the widths requires a priori knowledge of the scales of the different levels of the cluster hierarchy. This knowledge usually is obtainable only through visual inspection of the data, in which case analytical results represent only technical verification of what already has been subjectively observed.

The Contiguity-Anomaly Method

The contiguity-anomaly (CA) method was designed by Gladfelter and Tiedemann (1980, 1984), with aid from B. Hole (Tiedmann *et al.* 1981). Like the modified radius approach II, it evaluates local variability in some measure independent of regional trends, using a running operator function. However, this method additionally provides an assessment of the *significance* of local variability, which the radius approach does not.

The CA method uses grid-count data. It aims at locating "interesting" grid cells—cells having values (e.g., artifact densities) that are significantly different from or similar to the values in adjacent cells, compared to expectation. Using the numerator of Geary's C statistic of auto-correlation (Geary 1968) as a basis, the difference of a cell from its k neighboring cells for some variable is defined as

$$SSD = \sum_{i=1}^{k} (x_i - x_0)^2 \qquad (3.41)$$

where x_0 is the value of the variable in the cell of concern, and the x_i are the values in the k surrounding cells. This deviation then is used in either of two ways to determine whether the value in a particular cell, relative to those in surrounding cells, is expectable, significantly different, or significantly similar. (1) The mean and variance of all deviations in the study area is determined. A particular cell value is classified significant if its deviation is greater than some number of standard deviations above the mean or less than some number of standard deviations below the mean. (2) Through Monte Carlo simulation, the cells within the study area can be rearranged a number of times, and the cumulative distribution of deviations estimated. A given cell value then is classified as significant if its deviation is greater or less than that associated with a prespecified percentage of cells in the cumulative distribution.

To enhance the sensitivity of the method to more subtle local deviations, it is necessary to identify extreme outliers in the histogram of cell values and remove them from consideration. This can be done with a number of standard statistical or graphic methods.

Once interesting cells have been identified, they may be classified along two dimensions: (1) by whether they represent significantly large or small local deviations, and (2) by the value of their observations (high, medium, low, etc.) compared to the mean of cell observations in the study area. Using this classification, the study area can be mapped for areas having significant localized maxima and minima; for planar surfaces composed of cells with significantly similar values; and for significant slopes between planar surfaces of different average value.

The CA method is intended by its designers to be used with grid cells of the size of the phenomenon of interest, to allow definition of the locations of the phenomenon. In the case of the analysis of intra-site artifact distributions, grid cells of artifact counts would be constructed to the expected size of depositional areas. This approach allows the locations of clusters of artifacts and areas of very low artifact density (e.g., cleaned work areas) to be pinpointed, as Gladfelter and Tiedemann (1984) illustrate. It does not, however, lead to a precise delimitation of the boundaries of depositional areas.

It is possible to modify the approach slightly, in order to define the borders of depositional areas, by using grid cells much smaller than the areas. When this is done, cells within the inferior of a depositional area will have significantly similar artifact counts (high or low, depending on whether the area is a location of artifact clustering or vacancy), provided the area is relatively homogeneous in artifact density. The borders of the depositional areas, where artifact counts change most rapidly from cell to adjacent cell, will be composed of cells classified as significant slopes, provided the area has artifact densities sufficiently anomalous compared to background artifact densities.

Upon defining the limits of single-type artifact clusters and voids, multitype clusters and voids representing depositional areas may be defined by the union of such areas having similar placements and having types within the same depositional set, as discussed previously (page 203).

The CA method, as adapted here to the problem of delimiting depositional areas, is discordant with the organization of the archaeological record in three ways.

Discordance 1. It assumes that each artifact cluster or void is either (1) relatively homogeneous internally in its artifact densities compared to other zones within the study unit, or (2) is fairly anomalous in its average artifact density such that artifact densities change rapidly at its borders. If neither of these conditions occurs, the deviations of cells comprising the area and its boundary will not be classified as significantly interesting (similar and different, respectively). Although the CA method provides some control over these problems by allowing the threshold values defining the significance of local deviations to be varied, the response of the method has limits.

Discordance 2. Closely related to the first discordance, the CA method assumes that all depositional areas are similar in their degree of internal homogeneity of artifact densities and in their density changes at their borders. Also, background artifact density variation is assumed uniform over the density area. These assumptions derive from the fact that the significance of local deviations is defined using *one* frequency distribution or cumulative frequency distribution of deviations pertaining to the whole study area.

Discordance 3. The CA method, as all spatial techniques using grid-cell count data for one grid system, may produce variable results, depending on the mesh of the grid in relation to the scale of archaeological anomalies.

The modified radius approach II is not encumbered by any of these problems or erroneous assumptions.

The contiguity-anomaly approach has several advantages over the modified radius approach II. (1) It allows patterns of local anomalies to be assessed objectively for their significance in addition to being discovered. (2) It does not require a continuous area of study. A number of discontinuous neighboring areas (e.g., a series of block excavations), each with multiple grid cells of equal mesh, may be examined as a unit. (3) The CA method allows the definition of nested cluster perimeters of a cluster hierarchy, so long as levels of the hierarchy are relatively internally homogeneous in density and have crisp boundaries.

Unconstrained Clustering

Unconstrained clustering is a method designed by Whallon (1979, 1984) explicitly to delimit multitype clusters (depositional areas) without violating their nature. The approach is best viewed as a *general strategy* that may involve a number of alternative algorithms and indices at the different stages of analysis, rather than a specific technique. Consequently, in discussing and evaluating it, it is necessary to keep separate those comments pertinent to the general strategy from those relevant to the way Whallon has operationalized it.

The method accomodates either grid-count or item-point location data. In either case, the first step in analysis is to represent the distributional data for each artifact type as a generalized pattern that does not restrict the size and shape of zones of different artifact density. The use of a contour map of each artifact type for such a representation is suggested. It can be constructed using any of a number of interpolation and data-smoothing methods (Cole and King 1968; Davis 1973), such as a running operator function defining the local density of artifacts of a given type within a stated search radius, or a two-dimensional running mean. The constructed surface is theoretically continuous, but in practice is represented by a fine-meshed grid of smoothed artifact densities.

Next, the smoothed densities of artifacts of each type at the *original* item locations or grid points (or some arbitrary grid of points) are determined. For a given type, its density at a data location is obtained by interpolation from its smoothed artifact densities at the nearest four grid points among the many representing its contour surface.

The similarity of each pair of original item or grid locations to each other with respect to their local artifact inventories then is measured using some similarity coefficient (e.g., a Euclidean distance or a Jaccard coefficient), operating on some measure of the artifact inventory of each data location (e.g., relative artiface type densities, the presence/absence states of types). Data locations then are grouped according to their similarity into sets using some unweighted, polythetic agglomerative clustering algorithm (e.g., average linkage, Ward's method). Sets of similar locations, defined by some similarity threshold, are plotted on a map, their distribution indicating the spatial arrangement of localities of similar artifact composition. If clusters that are internally homogeneous in their artifact composition occur within the study area, locations similar in their artifact inventories will aggregate spatially, defining the limits of the clusters. Clusters similar in artifact composition will be allocated to the same set of data locations, indicating their like nature.

Unconstrained clustering, as a *general* strategy, has several problems but also offers an advantage over the modified radius approach II (Table 3.4).

Problem 1. The method is based on the unwarranted assumption that depositional areas are fairly homogeneous, internally, in their artifact compositions. In particular, variation in composition within an area deriving from the polythetic arrangement of items of different types is not accomodated. To the extent that subsectors of a depositional area vary in their artifact inventories as a result of polythetic-causing formation processes, recovery methods, or artifact classification (Figure 3.23), data locations within different subareas may be characterized as dissimilar and allocated to different sets by the clustering routine, obscuring the integrity or altering the boundary of the depositional area.

The aspect of unconstrained clustering responsible for this circumstance is the nature of the similarity coefficients available for defining the degree of similarity in the artifact composition of two localities. As was discussed previously (see pages 192–196), such coefficients assume monothetic organization; the maximum degree of similarity they can specify between observations *attenuates* as the attributes they operate on (here, artifact types within locales) become more polythetically distributed.

This problem is somewhat alleviated by clustering *smoothed* estimates of local artifact densities rather than local artifact densities, themselves. Local occurrences of an artifact type in frequencies less than expectable, or unexpected absences of it, resulting from polythetic causing factors, are subdued within depositional areas by the smoothing operation.

Problem 2. In a similar manner, different clusters that are polythetically alike in their artifact compositions may be misrepresented as dissimilar, compositionally, by the monothetic similarity coefficients used in the clustering procedure. This problem is not diminished by the preclustering smoothing operation.

Problem 3. The artifact inventories characterizing data locations and the pattern of similarity found between pairs of data locations will vary with the width of the running operator function used to construct the contour maps of each type and the degree to which the original data thus are smoothed. No criterion is offered to suggest the appropriate scale at which patterning should be sought. This is the same problem that dimensional analytic techniques were devised to circumvent (see pages 145–147, 151–153).

Problem 4. As Whallon (1979:12) points out, the strategy does not admit overlap among spatial clusters. Overlapping clusters are represented by a series of discrete sets of locations defining a gradational change in artifact composition. This results because the clustering algorithms used to define sets of similar points do not allow the construction of overlapping sets. Although overlapping clustering routines do exist (Jardine and Sibson 1968), they are too limited in the number of observations they can process to be useful to this method. This circumstance is not a problem to the extent that overlapping areas can be identified by inspection of the maps produced by the method.

To the good, unconstrained clustering allows the investigation of the potentially multilevel, hierarchically nested organization of depositional areas within sites. To delimit clusters at various levels of a cluster hierarchy, it is only necessary to vary the criterion of how similar two data locations must be to be considered members of the same set of similar locations. This is achievable by adjusting the threshold similarity coefficient value used to define sets of similar locations within the dendrogram of locations. The multiple, appropriate thresholds will be evident in the dendrogram or the plot of dissimilarity values against fusion step generated by the clustering procedure. In contrast, using the modified radius approach II, hierarchically nested organization of clusters can be defined only with iterative procedures (repeated adjustment of filter widths).

Finally, at the level of *specific operationalization* of unconstrained clustering, there is one problem with Whallon's application of the strategy. As a measure of the artifact inventories of each datum location to be clustered, Whallon used the relative frequencies (proportional densities) of artifact types. This, coupled with the requirement of internal homogeneity of clusters dictated by his use of a monothetic Euclidean distance coefficient, implies the assumption that within clusters, and between clusters of a similar nature, the *ratios* of artifact types remain constant. He also states this assumption as likely (Whallon 1984). As shown previously (pages 162–165), such an assumption is discordant with the expectable nature of the archaeological record, implying monothetic organization of depositional sets, expedient artifact deposition, and a number of the other problems discussed for correlation analysis. To circumvent these problematic assumptions, it is necessary to use (1) some other measure of the artifact inventories of data locations, and/or (2) some nonstandard similarity coefficient unaffected in value by the polythetic distribution of artifact types within and between clusters.

Unconstrained clustering is a very flexible strategy for defining depositional areas. It is likely that with further experimentation with the approach, reasonable solutions to its problems will be found.

CONCLUSION

The scientific process by which method and theory are advanced so as to improve our understanding of complex phenomena is a stepwise one. It involves repeated comparison between data, pattern-searching techniques, and interpretive models for their degree of logical consistency, and repeated alteration of model and techniques to bring them closer in line with data structure.

Our understanding of the structure of archaeological deposits and archaeological spatial data has improved over the past 10 years as the nature of human behavior and archaeological formation processes has been investigated and become apparent. The mathematical search techniques that we use to define the spatial organization of artifacts and facilities within sites, however, have not changed much during this time; they are logically inconsistent in various ways with the understanding we now have of the organization of the archaeological record and its causes. It is hoped that the proposed model of archaeological deposits and the evaluations of currently used spatial analytic techniques reviewed in this chapter will make archaeologists aware of these inconsistencies and suggest means by which they may be overcome. The alternative techniques presented here are a step in the right direction of eliminating discordance between data structure and method, but much more work is needed.

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This chapter owes much of its form to Robert Whallon, who taught me as a graduate student to question actively the appropriateness of applying particular techniques in analyzing particular kinds of data structures—to ask what assumptions about the data the techniques make, and whether those assumptions are justifiable in light of the nature of the phenomenon of interest. To him I am most indebted and very thankful. Michael Schiffer and a number of anonymous reviewers provided very constructive comments that helped me rephrase or add to certain critical arguments I have made in the paper. These I greatly appreciate, and have incorporated. P. Greig-Smith graciously read the manuscript for mathematical errors and currency. I am thankful for the heavy time commitment he undertook and his careful screening, though I remain responsible for the chapter's content.

REFERENCES

Adams, R. McC., and H. J. Nissen
1972 *The Uruk countryside.* Chicago: University of Chicago Press.

Ahler, S. A.
1971 Projectile point form and function at Rodgers Shelter, Missouri. *Missouri Archaeological Society, Research Series* 8.

Ammerman, A. J., and M. W. Feldman
1974 On the making of an assemblage of stone tools. *American Antiquity* **39**(4, Pt. 1):610–616.

Anderberg, M. R.
1973 *Cluster analysis for applications.* New York: Academic Press.
Anderson, D. C., and R. Shutler
1977 Interpreting the major cultural horizons at the Cherokee sewer site (13CK405): A preliminary assessment. Paper presented at the 35th Plains Conference, Lincoln, Nebraska.
Ascher, R.
1968 Time's arrow and the archaeology of a contemporary community. In *Settlement Archaeology,* edited by K. C. Chang. Palo Alto: National Press Books. Pp. 47–79.
Balout, L.
1967 Procedes d'analyse et questions de terminologie dans l'etude des ensembles industrials du Paleolithique Inferieur en Afrique du Nord. In *Background to evolution in Africa,* edited by W. W. Bishop and J. D. Clark. Chicago: University of Chicago Press.
Battle, H. B.
1922 The domestic use of oil among southern Aborigines. *American Anthropologist* **24**:171–182.
Behrensmeyer, A. K.
1975 The taphonomy and paleoecology of Plio-Pleistocene vertebrate assemblages east of Lake Rudolf, Kenya. *Museum of Comparative Zoology* Bulletin 146(1).
Bhattacharya, C. G.
1967 A simple method of resolution of a distribution into Gaussian components. *Biometrics* **23**:115–135.
Binford, L. R.
1972 Directionality in archaeological sequences. In *An archaeological perspective,* by L. R. Binford. New York: Seminar Press. Pp. 314–326.
1976 Forty–seven trips. *In* Contributions to anthropology: The interior peoples of northern Alaska, edited by E. S. Hall, Jr. National Museum of Man, Mercury Series, Archaeological Survey of Canada Paper 49.
1978 *Nunamiut archaeology.* New York: Academic Press.
Binford, L. R., and S. R. Binford
1966 A preliminary analysis of functional variability in the Mousterian of Levallois facies. *American Anthropologist* **68**(2):238–295.
Binford, L. R., *et al.*
1970 Archaeology at Hatchery West. Society for American Archaeology, *Memoirs* 24.
Bordes, F.
1961 *Typologie du Paleolithique Ancien et Moyen.* Bordeaux: Imprimeries Delmas.
1968 *The Old Stone Age.* New York: McGraw–Hill.
Brown, J. A.
1971 Dimensions of status in the burials at Spiro. *In* Approaches to the social dimensions of mortuary practices edited by J. A. Brown. Society for American Archaeology, *Memoirs* 25.
Brown, J. A., and L. Freeman
1964 A UNIVAC analysis of sherd frequencies from the Carter Ranch pueblo, eastern Arizona. *American Antiquity* **31**:203–210.
Brose, D. S., and J. F. Scarry
1976 The Boston Ledges shelter: comparative spatial analysis of early Late Woodland occupations in Summit county, Ohio. *Midcontinental Journal of Archaeology* **1**(2):179–228.
Carr, C.
1977 The internal structure of a Middle Woodland site and the nature of the archaeological

record. Preliminary examination paper, Department of Anthropology, University of Michigan.
1979 Interpretation of resistivity survey data from earthen archaeological sites. Unpublished Ph.D. dissertation, Department of Anthropology, University of Michigan.
1981 The polythetic organization of archaeological tool kits and an algorithm for defining them. Unpublished paper presented at the annual meetings of the Society for American Archaeology, San Diego.
1982 Dissecting intra-site artifact distributions as palimpsests. Paper presented at the annual meetings of the Society for American Archaeology, Minneapolis.
1983 A design for intrasite research. Unpublished paper presented at the National Park Service Research Seminar in Archaeology. Fort Collins, CO.
1984a Alternative models, alternative techniques: variable approaches to intra-site spatial analysis. In *Analysis of archaeological data structures,* edited by C. Carr. New York: Academic Press, (In press.)
1984b Getting into data: philosophies on the analysis of complex data structures. In *Analysis of archaeological data structures,* edited by C. Carr. New York: Academic Press. (In press.)

Christensen, A. L. and D. W. Read
1977 Numerical taxonomy, R-mode factor analysis, and archaeological classification. *American Antiquity* **42**:163–179.

Clark, J. G. D., and M. W. Thompson
1954 The groove and splinter technique of working antler in the Upper Paleolithic and Mesolithic, with special reference to the material from Star Carr. *Prehistoric Society, Proceedings* **19**:148–160.

Clark, P. J., and F. C. Evans
1954 Distance to nearest neighbor as a measure of spatial relationships in populations. *Ecology* **35**:445–453.

Clarke, D. L.
1968 *Analytical archaeology.* London: Methuen.

Cole, A. J., and D. Wishart
1970 An improved algorithm for the Jardine–Sibson method of generating overlapping clusters. *Computer Journal* **13**(2):156–163.

Cole, J. P., and C.A.M. King
1968 *Quantitative Geography.* New York: John Wiley.

Cole, L. C.
1949 The measurement of interspecific association. *Ecology* **30**:411–424.

Collins, M. B.
1975 The sources of bias in processual data: an appraisal. In *Sampling in archaeology,* edited by J. W. Mueller. Tucson: University of Arizona Press. Pp. 26–32.

Cook, T. G.
1973 Koster: a lithic analysis of two Archaic phases in west-central Illinois. Unpublished Ph.D. dissertation draft, Department of Anthropology, Indiana University.
1976 Koster: an artifact analysis of two Archaic phases in westcentral Illinois. Northwestern University Archaeological Program *Prehistoric Records* 1, Evanston.

Cowgill, G. L.
1972 Models, methods, and technique for seriation. In *Models in archaeology,* edited by D. L. Clarke. London: Methuen. Pp. 381–424.

Crabtree, D. E.
1967 Notes on experiments in flintknapping, 3. The flintknapper's raw materials. *Tebiwa* **10**:8–25.

1968 Mesoamerican polyhedral cores and prismatic blades. *American Antiquity* **33**: 446–478.
1972 An introduction to flintworking. Idaho State University Museum *Occational Papers* 28.

Crabtree, D. E., and E. H. Swanson
1968 Edge–ground cobbles and blade making in the Northwest. *Tebiwa* 11:50–58.

Craytor, W. B., and L. R. Johnson, Jr.
1968 Refinements in computerized item seriation. *University of Oregon Museum of Natural History,* Bulletin 10.

Dacey, M. F.
1968 Order neighbor statistics for a class of random patterns in multidimensional space. *Annals of the Association of American Geographers* 53:505–515.
1973 Statistical tests of spatial association in the locations of tool types. *American Antiquity* **38**:320–328.

David, F. N., and P. G. Moore
1954 Notes on contagious distributions in plant populations. *Annals of Botany* (London, N. S.) **18**:47–53.

Davis, J. C.
1973 *Statistics and data analysis in geology.* New York: Wiley.

de Heinzelin de Braucourt, J.
1962 *Manuel de typologie des industries lithique.* Bruxelles: L'Institute Royal Des Sciences Naturelles De Belgique.

Driver, H. E.
1961 *Indians of North America.* Chicago: University of Chicago Press.

Earle, T. K.
1976 A nearest neighbor analysis of two Formative settlement systems. In *The early Mesoamerican village,* edited by K. V. Flannery. New York: Academic Press, Pp. 196–223.

Ebdon, D.
1976 On the underestimation inherent in the commonly used formulae. *Area* **8**:165–169.

Ellis, H. H.
1940 *Flint working techniques of the American Indians: an experimental study.* Columbus: Ohio State University Bureau of Business Research.

Evans, F. C.
1952 The influence of size of quadrat on the distributional patterns of plant populations. University of Michigan, *Cont. Lab. Vert. Biol.* **54**:1–15.

Freeman, L., and K. W. Butzer
1966 The Acheulean station of Torralba (Spain). A progress report. *Quarternaria* **8**:9–21.

Gardin, J. C.
1965 On a possible interpretation of componential analysis in archaeology. *In* Formal semantic analysis, edited by E. A. Hammel. *American Anthropologist, Special Publication* 67:9–22.

Geary, R.
1968 The contiguity ratio and statistical mapping. In *Spatial analysis: a reader in statistical geography,* edited by B. Berry and D. Marble. Englewood Cliffs, New Jersey: Prentice–Hall.

Getis, Q.
1964 Temporal land-use pattern analysis with the use of nearest neighbor and quadrat methods. *Annals of the Association of American Geographers* **54**:391–399.

Gifford, D. P.
1978 Ethnoarchaeological observations of natural processes affecting cultural materials. In *Explorations in ethnoarchaeology*, edited by R. A. Gould. Alburquerque: University of New Mexico Press. Pp. 77–101.
1981 Taphonomy and paleoecology: a critical review of archaeology's sister disciplines. In *Advances in archaeological method and theory,* (Vol. 4), edited by M. B. Schiffer. New York: Academic Press. Pp. 365–438.

Gladfelter, B. G., and C. E. Tiedemann
1980 A computer program for evaluating archaeological spatial data. Paper presented at the annual meetings of the Society for American Archaeology, Philadelphia.
1984 The contiguity–anomaly technique of spatial autocorrelation. In *Analysis of archaeological data structures*, edited by C. Carr. New York: Academic Press. (In press.)

Gonzalez, R. C., and P. Wintz
1977 *Digital image processing*. Reading, Massachusetts: Addison–Wesley.

Goodall, D. W.
1974 A new method for the analysis of spatial pattern by random pairing of quadrats. *Vegetatio* 29:135–146.

Goodyear, A.
1974 The Brand site: a techno–functional study of a Dalton site in northeast Arkansas. Arkansas Archaeological Survey, *Research Series* 7.

Gould, R. A.
1971 The archaeologists as ethnographer: a case from the Western Desert of Australia. *World Archaeology* **3**(2):143–178.
1978 *Explorations in ethnoarchaeology*. Albuquerque: University of New Mexico Press.

Gould, R. A., D. A. Koster,and A. H. L. Sontz
1971 The lithic assemblage of the western desert Aborigines of Australia. *American Antiquity* **36**(2):149–169.

Graybill, D. A.
1976 New analytical strategies for spatial analysis. Paper presented at the Annual Meetings of the Society for American Archaeology, St. Louis.

Greig-Smith, P.
1952a Ecological observations on degraded and secondary forest in Trinidad, British West Indies. II. Structure of the communities. *Journal of Ecology* **40**:316–330.
1952b The use of random and contiguous quadrats in the study of the structure of plant communities. *Annals of Botany* (London, N. S.) **16**:293–316.
1961 Data on pattern within plant communities. *Journal of Ecology* **49**:695–702.
1964 *Quantitative plant ecology*. London: Methuen.

Haggett, P.
1965 *Locational analysis in human geography*. London: Arnold.

Hartigan, J. A.
1975 *Clustering algorithms*. New York: Wiley.

Hempel, C. G.
1966 *The philosophy of natural science*. Englewood Cliffs New Jersey: Prentice–Hall.

Hietala, H. J., and R. E. Larson
1980 Intrasite and intersite spatial analyses at Bir Tarfawi. In *Prehistory of the eastern Sahara*, edited by F. Wendorf and R. Schild. Pp. 379–388. New York: Academic Press.

Hietala, H. J. and D. S. Stevens
1977 Spatial analysis: multiple procedures in pattern recognition. *American Antiquity* **42**(4):539–559.

Hill, A. P.
1975 Taphonomy of contemporary and late Cenozoic East African vertebrates. Unpublished Ph.D. dissertation, Department of Anthropology, University of London.

Hill, J. N.
1970 Broken K. pueblo: prehistoric social organization in the American Southwest. University of Arizona, *Anthropological Papers* 18.

Hodder, I. R.
1972 Locational models and the study of Romano–British settlement. In *Models in archaeology,* edited by D. L. Clarke. London: Methuen. Pp. 887–909.

Hodder, I. R., and M. Hassal
1971 The non-random spacing in Romano–British walled towns. *Man* **6**:391–407.

Hodder, I. R., and C. Orton
1976 *Spatial analysis in archaeology.* Cambridge: Cambridge University Press.

Hole, F., and M. Shaw
1967 Computer analysis of chronological seriation. *Rice University Studies, Monograph in Archaeology* **53(4).**

Holgate, P.
1964 Some new tests of randomness. *Ecology* **53**:261–266.

Hopkins, B., and J. G. Skellam
1954 A new method for determining the type of distribution of plant individuals. *Annals of Botany,* **18**:213–227.

Hsu, S., and C. E. Tiedemann
1968 A rational method of delimiting study areas for unevenly distributed point phenomena. *Professional Geographer* **20**:376–381.

Jardine, N., and R. Sibson
1968 The construction of hierarchic and non-hierarchic classifications. *Computer Journal* **11**(2):177–184.

Jones, E. W.
1955 Ecological studies on the rain forest of southern Nigeria, IV. The plateau forest of the Okomu Forest reserve. *Journal of Ecology* **43**:564–594.
1956 Ecological studies on the rain forest of southern Nigeria, IV. The plateau forest of the Okomu Forest reserve, (continued). *Journal of Ecology* **44**:83–117.

Joslin-Jeske, R.
1981 The effects of curation on the archaeological record. Paper presented at the 46th annual meetings of the Society for American Archaeology, San Diego.

Kay, M.
1980 Features and factors: activity area definition at Rodgers shelter. *In* Holocene adaptations within the lower Pomme de Terre river valley, Missouri, edited by M. Kay. Pp. 561–622. Unpublished report to the U. S. Army Corps of Engineers, Kansas City district, contract DACW41-76-C-0011. Springfield: Illinois State Museum.

Keeley, L. H.
1977 The functions of Paleolithique flint tools. *Scientific American* **237**:108–126.

Kendall, M. G.
1948 *Rank correlation methods.* London: Griffin.

Kershaw, K. Q.
1957 The use of cover and frequency in the detection of pattern in plant communities. *Ecology* **38**:291–299.
1964 *Quantitative and dynamic ecology,* Chapter 6, the Poisson series and the detection of non-randomness. New York: American Elsevier. Pp. 96–113.

Kimball, R., R. N. Shepard, and S. B. Nerlov (editors)
1972 *Multidimensional scaling,* (Vol. 1 and 2). New York: Seminar Press.

Kraybill, N.
1977 Pre-agricultural tools for the preparation of foods in the Old World. In *Origins of agriculture,* edited by C. A. Reed. The Hague: Mouton. Pp. 485–522.
Kruskal, J. B., and M. Wish
1978 *Multidimensional Scaling.* Sage University.
Kullback, S. M., M. Kupperman, and H. H. Ku
1962 An application of information theory to the analysis of contingency tables. *Journal of Research, National Bureau of Standards—B., Mathematics and Physics.* **66**B(4): 217–228.
Lange, F. W., and C. R. Rydberg
1972 Abandonment and post-abandonment behavior at a rural central American house-site. *American Antiquity* **37**:419–432.
Leechman, D.
1951 Bone grease. *American Antiquity* **16**:355–356.
Lewarch, D. E., and M. J. O'Brien
1981 Effects of short term tillage on aggregate provenience surface pattern. *In* Plowzone archaeology: contributions to theory and technique, edited by M. J. O'Brien and D. E. Lewarch. Vanderbilt University, *Papers in Anthropology.*
Lieberman, G. J., and D. B. Owen
1961 *Tables of the hypergeometric probability distribution.* Stanford: Stanford University Press.
Luton, Robert M., and David P. Braun
1977 A method for testing the significance of aggregation and association in archaeological grid cell counts. Unpublished paper presented at the annual meetings of the Society for American Archaeology.
Marquardt, W. H.
1978 Advances in archaeological seriation. In *Advances in archaeological method and theory,* (Vol. 1), edited by M. B. Schiffer. New York: Academic Press. Pp. 257–314.
Mason, O. T.
1889 Aboriginal skin–dressing: a study based on material in the U.S. National Museum. United States National Museum, *Annual Report* 553–590.
1895 *The origins of invention.* London: Walle Scott.
1899 The man's knife among the North American Indians: a study in the collections of the United States National Museum. Smithsonian Institution, *Annual Report for the Year* 1897:727–742.
McCarthy, F. D.
1967 *Australian Aboriginal stone implements.* Sidney: V. C. N. Blight, Government Printer, New South Wales.
McKellar, J.
1973 *Correlations and the explanation of distributions.* Manuscript on file, Arizona State Museum Library, Tucson.
McNutt, C. M.
1981 Nearest neighbors, boundary effect, and the old flag trick: a general solution. *American Antiquity* **46**(3):571–591.
Miles, C.
1973 *Indian and Eskimo artifacts of North America.* New York: Bonanza Books.
Moorehead, W. K.
1912 Hematite implements of the United States together with chemical analyses of various hematites. *Phillips Academy, Bulletin* 6. Andover.
Morisita, M.
1959 Measuring the dispersion of individuals and analysis of the distributional patterns.

Kyushu University, *Memoires of the Faculty of Science, Series E (Biology)* **2**:215–235.

1962 I_δ-index, a measure of dispersion of individuals. *Research in Population Ecology* 4:1–7. Fukuoka: Kyushu University.

Mountford, M. D.

1961 On E. C. Pielou's index of non-randomness. *Journal of Ecology* **49**:271–276.

Nero, Robert W.

1957 A "graver" site in Wisconsin. *American Antiquity* 22(3):300–304.

O'Connell, J. E.

1977 Room to move: contemporary Alyawara settlement patterns and their implications for Aboriginal housing policy. Manuscript on file, Australian Institute of Aboriginal Studies, Canberra.

1979 Site structures and dynamics among modern Alyawara hunters. Paper presented at the Annual Meetings of the Society for American Archaeology, Vancouver.

Odell, G. H.

1977 The application of micro-wear analysis to the lithic component of an entire prehistoric settlement: methods, problems, and functional reconstructions. Unpublished Ph.D. dissertation, Department of Anthropology, Harvard University, Cambirdge, Massachusetts.

Odell, G. H., and F. Odell-Vereecken

1980 Verifying the reliability of lithic use-wear assessments by 'blind tests': The low power approach. *Journal of Field Archaeology* **7**(1):87–121.

Osborne, C. M.

1964 The preparation of Yucca fibers: an experimental study. In *Contributions of the Wetherill Mesa archaeological project,* assembled by D. Osborne. Society for American Archaeology, *Memoirs* 19:45–50.

Paynter, R., G. W. Stanton, and H. M. Wobst

1974 Spatial clustering: Techniques of discrimination. Paper presented at the annual meetings of the Society for American Archaeology.

Peale, T. R.

1871 On the use of the brain and marrow of animals among the Indians of North America. *Smithsonian Institution, Annual Report for* 1870:390–391.

Peebles, C. S.

1971 Moundville and the surrounding sites: some structural considerations of mortuary practices, II. *In* Approaches to the social dimensions of mortuary practices, edited by J. A. Brown. Society for American Archaeology, *Memoirs* 25.

Pielou, E. C.

1959 The use of point-to-plant distances in the study of pattern of plant populations. *Journal of Ecology* **47**:607–613.

1960 A single mechanism to account for regular, random, and aggregated populations. *Journal of Ecology* **48**:575–584.

1964 Segregation and symmetry in two-species populations as studied by nearest neighbor relationships. In *Quantitative and dynamic ecology,* edited by K. A. Kershaw. New York: American Elsevier. Pp. 255–269.

1969 *An Introduction to mathematical ecology.* London: Methuen.

1975 *Ecological diversity.* New York: Wiley.

1977 *Mathematical ecology.* New York: Wiley.

Pinder, D. A.

1971 The spatial development of the Luton Hat Industry in the early twentieth century. *Southampton Research Series in Geography* 6. University of Southampton, England.

Pinder, D., I. Shimada, and D. Gregory
1979 The nearest neighbor statistic: archaeological application and new developments. *American Antiquity* **44**:430–445.

Plog, F.
1974 Settlement patterns and social history. In *Frontiers of anthropology,* edited by M. J. Leaf. New York: Van Nostrand. Pp. 68–91.

Price, T. D. II
1975 Mesolithic settlement systems in the Netherlands. Unpublished Ph.D. dissertation, Department of Anthropology, University of Michigan, East Lansing.

Reid, J. J.
1973 Growth and response to stress at Grasshopper pueblo, Arizona. Unpublished Ph.D. dissertation, Department of Anthropology, University of Arizona.

Riddell, F., and W. Pritchard
1971 Archaeology of the Rainbow Point site (4–Plu–594), Bucks Lake, Pumas County, California. *In* Great Basin Anthropological conference 1970: selected papers, edited by C. M. Aikens. University of Oregon, *Anthropological Papers* 1:59–102.

Roper, D. C.
1976 Lateral displacement of artifacts due to plowing. *American Antiquity* **41**(3):372–375.

Rummel, R. J.
1970 *Applied factor analysis.* Evanston: Northwestern University Press.

Saunders, J. J.
1977 Late Pleistocene vertebrates of the western Ozark highland, Missouri. Illinois State Museum, *Reports of Investigation* 33. Illinois State Museum, Springfield.

Saxe, A. A.
1970 *Social dimensions of mortuary practices.* Unpublished Ph.D. dissertation, Department of Anthropology, University of Michigan, East Lansing.

Schiffer, M. B.
1972 Archaeological context and systemic context. *American Antiquity* **37**:156–165.
1973 Cultural formation processes of the archaeological record: applications at the Joint site, east central Arizona. Unpublished Ph.D. dissertation, Department of Anthropology, University of Arizona, Tucson.
1975a Behavioral chain analysis: activities, organization, and the use of space. *Fieldiana: Anthropology* **65**:103–120.
1975b The effects of occupation span on site content. *In* The Cache River archeological project, assembled by M. B. Schiffer, and J. H. House. Arkansas Archeological Survey, *Research Series* 8:265–269.
1975c Factors and "tool kits": evaluating multivariate analysis in archaeology. *Plains Anthropologist* **20**:61–70.
1976 *Behavioral archeology.* New York: Academic Press.
1977 Toward a unified science of the cultural past. *In* Research strategies in historical archeology, edited by S. South. New York: Academic Press. Pp. 13–40.
1982 Identifying the formation processes of archaeological sites. Manuscript on file, Department of Anthropology, Arizona State Museum Library, Tucson.

Schiffer, M. B., and W. L. Rathje
1973 Efficient exploitation of the archaeological record: penetrating problems. In *Research and theory in current archeology,* edited by C. L. Redman. New York: Wiley. Pp. 169–179.

Semenov, S. A.
1964 *Prehistoric technology: an experimental study of the oldest tools and artifacts from traces of manufacture and wear.* London: Cory, Adams, and MacKay.

Shipman, P.
1981 *Life history of a fossil: introduction to taphonomy and Paleoecology.* Cambridge: Harvard University Press.

Simpson, E. H.
1949 Measurement of diversity. *Nature* **163**:688.

Sneath, P. H., and R. R. Sokal
1973 *Numerical Taxonomy.* San Francisco: Freeman.

Sollberger, J. B.
1969 The basic tool kit required to make and notch arrow shafts for stone points. *Texas Archaeological Society, Bulletin* 40:231–240.

Speth, J. D.
1972 Mechanical basis of percussion flaking. *American Antiquity* **37**:34–60.

Speth, J. D., and G. A. Johnson
1976 Problems in the use of correlation for investigation of tool kits and activity areas. In *Cultural change and continuity,* edited by C. Cleland. New York: Academic Press, Pp. 35–75.

Stein, J.
1983 Earthworm activity: a source of potential disturbance of archaeological sediments. *American Antiquity* **48**(2):277–289.

Stiteler, W. M., and G. P. Patil
1971 Variance-to-mean ratio and Morisita's index as measures of spatial patterns in ecological populations. In *Statistical ecology, (Vol. 1): spatial patterns and statistical distributions,* edited by G. P. Patil, E. C. Pielou, and W. E. Waters. University Park: Pennsylvania State University Press. Pp. 423–452.

Strackee, J., and J. J. D. van der Gon
1962 The frequency distribution of the difference between two Poisson variates. *Statistica Neerlandica* **16**:17–23.

Svedberg, T.
1922 Ett bidrag till de statistika metodernas användning inom vaxbiologien. *Svensk bto. Tidskr.* **16**:1–8.

Swanton, J. R.
1946 Indians of the southeastern United States. *Bureau of American Ethnology* Bulletin 137.

Thomas, D. H., and R. Bettinger
1973 Notions to numbers: Great Basin settlements as polythetic sets. In *Research and theory in current archeology,* edited by C. L. Redman. New York: Wiley. Pp. 215–237.

Thompson, H. R.
1956 Distribution of distance to nth neighbor in a population of randomnly distributed individuals. *Ecology* **37**:391–394.
1958 The statistical study of plant distribution patterns using a grid of quadrats. *Australian Journal of Botany* **6**:322–342.

Tiedemann, C. E., B. G. Gladfelter, and B. Hole
1981 The contiguity–anomaly method: a nonstandard approach to spatial autocorrelation. Paper presented at the annual meetings of the Society for American Archaeology, San Diego.

Tixier, J.
1963 *Typologie de l'Epipaleolithique du Maghref.* Paris: Arts et Metiers Graphiques.

Trubowitz, Neal
1978 The persistence of settlement pattern in a cultivated field. In *Essays in northeastern anthropology in memory of Marian White,* edited by W. Engelbrech, and D. Grayson. Rindge, New Hampshire: Franklin Pierce College.

1981 Settlement pattern survival on plowed northeastern sites. Paper presented at the annual meetings of the Society for American Archaeology, San Diego.

Voorhies, M. R.

1969a Sampling difficulties in reconstructing late Tertiary mammalian communities. *Proceedings of the North American Paleontological Convention,* September 1969, Part E:454–468.

1969b Taphonomy and population dynamics of an early Pliocene vertebrate fauna, Knox County, Nebraska. University of Wyoming. *Contributions to Geology, Special Paper* 1.

Wandsnider, L. A., and L. R. Binford

1982 Discerning and interpreting the structure of Lazaret cave. Paper presented at the annual meetings of the Society for American Archaeology, Minneapolis.

Washburn, D. K.

1974 Nearest neighbor analysis of Pueblo I–III Settlement patterns along the Rio Puerco of the east, New Mexico. *American Antiquity* **39**:16–34.

Watanabe, H.

1972 *The Ainu ecosystem.* Seattle: University of Washington Press.

Wahugh, F. W.

1916 Iroquois foods and food preparation. Canada Department of Mines, *Geological Survey Memoir* 86, Anthropological Series 12.

Whallon, R.

1973 Spatial analysis of occupation floors I: application of dimensional analysis of variance. *American Antiquity* **38**:320–328.

1974 Spatial analysis of occupation floors II: the application of nearest neighbor analysis. *American Antiquity* **39**:16–34.

1979 Unconstrained clustering in the analysis of spatial distributions on occupation floors. Paper presented at the 44th Annual Meetings of the Society for American Archaeology, Vancouver.

1984 Unconstrained clustering for the analysis of spatial distributions in archaeology. In *Intrasite Spatial Analysis,* edited by H. J. Hietala. Cambridge: Cambridge University Press. (In press.)

Wheat, Joe Ben

1972 The Olsen–Chubbuck site: a Paleo-Indian bison kill. Society for American Archaeology, *Memoirs* 26.

Wilmsen, E. N.

1970 Lithic analysis and cultural inference: A Paleo–Indian case. University of Arizona, *Anthropological Papers* 16.

Winters, H. D.

1969 *The Riverton culture.* Illinois State Museum (Springfield) and Illinois Archaeological Survey (Urbana).

Wood, R. W., and D. L. Johnson

1978 A survey of disturbance processes in archaeological site formation. In *Advances in archaeological method and theory,* vol. 4, edited by M. B. Schiffer. New York: Academic Press. Pp. 315–381.

Yellen, J. E.

1974 The !Kung settlement pattern: an archaeological perspective. Unpublished Ph.D. dissertation, Department of Anthropology, Harvard University, Cambridge, Massachusetts.

1977 *Archaeological approaches to the present.* New York: Academic Press.

Zubrow, Ezra
1971 Carrying capacity and dynamic equilibrium in the prehistoric Southwest. *American Antiquity* **36**:127–138.

Zurflueh,
1967 Applications of two dimensional linear wavelength filtering. Geophysics 32:1015–1035.