Screening intrasite artifact distributions with Fourier and filtering methods

Abstract

Current approaches to the spatial analysis of intrasite artifact distributions are not concordant with the general nature of organization of archaeological records. They assume both global organization of artifacts into types of depositional sets and depositional areas, and the significance of local artifact densities as given. Instead, archaeological records typically are palimpsests, with local artifact density variation in individual artifact classes attributable to multiple formation processes—each of which may have a different, subglobal distribution. The techniques of spatial filtering, Fourier analysis, spectral analysis, and histogram equalization are introduced as screening methods, which allow the dissection of palimpsests of each artifact class into subglobal components that reflect a more homogeneous range of formation processes. Those components that are of similar nature, for multiple classes, can then be analyzed together with techniques that are concordant with their particular structure. The specific kinds of filters and sequences of application of the several methods that are useful in various formation contexts are discussed.

INTRODUCTION

In the past ten years, quantitative analysis and interpretation of spatial patterns of artifacts within archaeological sites have become increasingly sophisticated. This is evidenced in two ways. First, there has been a rapid increase in the number of *techniques* that are available to the archaeologist for spatial analysis. These include methods first developed in mathematical ecology, geography and statistics (Pielou, 1964; Clark and Evans, 1954; Berry *et al.*, 1980). Many of these techniques have been reviewed for their concordance with intrasite archaeological data elsewhere (Carr, 1984).

The second line of advance is marked by the increasing number of *models* of the spatial organization of artifacts within sites and the formation processes responsible for various forms of organization (*e.g.*, Binford, 1976; Gifford, 1978, 1980; Kent, 1983; O'Connell, 1977, 1979; Schiffer, 1976, 1983; Wood and Johnson, 1978; Yellen, 1977). These models comprise Middle Range Theory in Binford's sense (Binford, 1977; Binford and Sabloff, 1982). They allow the assignment of behavioral, geological, biological, or ecological meaning to artifact patterns found with quantitative methods. They are the product of the many ethnoarchaeological and experimental studies of cultural and natural formation processes and disturbance processes that we have witnessed this past decade.

A potentially fruitful coalescence of these two lines of advance has begun within the last five years. Some archaeologists (*e.g.*, Carr, 1984, 1985*a*; Whallon, 1984) have become more critical of the particular circumstances in which various spatial algorithms are applied. Their concern has been whether or not technical assumptions about the *expectable* form of organization of artifacts within a site are concordant with or contradict the *empirical* aspects of artifact organization that reflect human behavior. In other words, are technical assumptions *logically consistent* with the behaviorally relevant aspects of a spatial data structure? Without such concordance, those patterns that are found quantitatively within an artifact distribution may be distorted representations of behaviorally significant patterns or may reflect other, irrelevant sources of variation, such as geological, postdepositional disturbances.

The concern for bringing concordance to spatial analysis is witnessed by the attempts that archaeologists have made to develop spatial methods tailored to their medium. An example is Whallon's (1984) method of unconstrained clustering, which is useful for delimiting artifact clusters. It was designed explicitly to avoid erroneous assumptions, such as the equivalent size and density of clusters and constant patterns of covariation or association among artifact classes over a site as a whole. My own work (Carr, 1984, 1985*a*) has included the development of a battery of monothetic and polythetic association coefficients for measuring the degrees of coarrangement of artifact classes under different, specified formation contexts. The coefficients allow for diverse local patterns of asymmetry among artifact classes and permit spatial overlap of clusters.

Modification of technique, however, is only one means for bringing concordance between data and technique in spatial analysis. By itself, it often is insufficient. It also is possible to modify or select, prior to fine-grained analysis, the *data* to be operated on: the variables and observations. One can ask what dimensions or *components* of the grid densities or locations of artifact classes are relevant to the behavioral, geological, or other formation processes of interest, and then focus analysis on those components. One also can ask what *sectors* of the site are homogeneous in the kinds of processes responsible for their artifact distributions and thus are analyzable with a *single* method that makes a *single* set of assumptions about process and organization. One then would apply different appropriate methods to different sectors of the site. In other words, *one must screen one's data for the dimensions that are relevant to and the observations that are homogeneous with respect to the processes of interest, prior to fine-grained analysis*, as in any statistical design (see Carr, 1985*b*, 1985*c*; Clark, 1983).

Screening an intrasite, spatial data set for relevant dimensions and homogeneous observations minimally requires the researcher to have some *general*, a priori knowledge of the data structure and the classes of formation processes responsible for it (classes in regard to their effects on artifact organization). By general knowledge, I mean such things as the *approximate* range of scales of clusters, whether clusters overlap *typically* to any great degree, or the degree to which clusters *generally* have been smeared by postdepositional disturbance processes, as opposed to documentation of the *precise* limits and positions of specific clusters as a result of fine-grained analysis.

This general knowledge may be obtained to some extent in several ways: (1) through historical documentation in the case of some historic sites; (2) by way of analogy in ethnographically or archaeologically well-understood contexts; (3) by argumentation from principles on the effects of natural formation processes (in environmentally known contexts); (4) by visual inspection of the data for simply structured sites; or (5) by plotting the spatial distributions of various "indices" of formation processes (Schiffer, 1983).

In many archaeological circumstances, however, these approaches are not possible or are inadequate. This has encouraged the archaeologist to proceed with fine-grained analysis on *unscreened* data. At best, this is done in order to secure the information required for screening. Analysis then proceeds in an interactive manner—alternating between further fine-grained analysis and further screening—with hope for convergence in results. However, to do so may produce, at any of the iterative stages of fine-grained analysis, discordance between technique and data. Results that are irrelevant to the processes of interest or that offer little accurate insight into the general structure of the data may be derived. At worst, the results of a first pass over the unscreened data are accepted, with no further analysis or attempt to adjust for analytic discordance.

Thus, the researcher finds himself in what has been called the *methodological double bind* (Carr, 1985*b*, 1985*c*; Christensen and Read, 1977, p. 177). The researcher needs information about the general structure of the data to properly screen it (or to choose an appropriate fine-grained analytic technique), yet is unable to obtain that information except through the possibly discordant application of fine-grained analytic approaches to the unscreened data.

A general solution to the problem of the methodological double bind, which aids in choosing variables, observations, or techniques for fine-grained analysis, is the approach of *exploratory data analysis* (Tukey, 1977; Hartwig and Dearing, 1979; Clark, 1982; Carr, 1985*b*). One aspect of exploratory data analysis is the application of relatively unassuming, data-robust techniques to explore and reveal the diversity of structures that constitute a data set, as a prelude to data screening and fine-grained analysis.

This paper introduces the use of Fourier analysis, spatial filtering, spectral analysis and histogram equalization in an exploratory data analysis mode, which, along with the sources of general knowledge mentioned above, can be used to break the methodological bind that is involved in screening complex intrasite artifact distributions. It also discusses their use in subsequent fine-grained definition of cluster boundaries. The procedures that are described should not be seen as replacements of fine-grained analytic techniques currently used in intrasite studies; rather, they are screening procedures to precede the application of fine-grained methods. Also, the procedures should not be seen as a panacea. They are pertinent primarily to the preanalysis of fairly ubiquitous and densely distributed artifact classes.

PROBLEMS IN THE ANALYSIS OF UNSCREENED ARTIFACT DISTRIBUTIONS

Incongruent and congruent assumptions

The necessity of screening complex, intrasite artifact distributions with the techniques to be proposed can be understood most easily by specifying how most spatial algorithms, as currently applied to unscreened artifact distributions, are incongruent with the typical nature of organization of those distributions and their manner of formation. Congruent forms of application then are suggested in contrast to incongruent ones.

Incongruence 1. Choice of observations, implying globally uniform organization of multiple artifact classes. This incongruence pertains to the researcher's choice of relevant *sectors* of the site (observations) to be used in analysis and indirectly to the assumed manner of organization of *multiple* artifact classes in relation to each other. Most intrasite spatial analyses have involved the application of a single algorithm to a *whole* site or study area. They thus assume that artifact classes are organized in *one* manner across the study area as a *whole*, that is, *globally*, in accord with the form of patterning to which the algorithm is sensitive. Global structures are sought: *types* of "tool kits" or *types* of "activity areas"—that is, combinations of tool classes or areas of certain artifact composition, density, shape, and/or size that repeat over the whole site. The similar arrangement of artifact classes over a *number* of locales is taken to represent the regularity produced by some formation process—an activity in the form of tool manufacture, tool and raw material use (*e.g.*, butchering, cooking), caching, disposal, or postdepositional reorganization by natural processes. Likewise, the repeated composition, density, shape, and size of the areas occupied by such coarrangements is interpreted as representing one of these formation processes.

In contrast, a generally more appropriate assumption would be that artifact classes are organized in *multiple ways* over a site, each form of organization occurring in only a *portion* of the site, subglobally, or, in the extreme case, locally. For example, one might assume that patterns of covariation or association (*i.e.* organization) among artifact classes that were used and deposited together can vary from one portion of a site to another as a result of global variation in behavioral, depositional, or disturbance processes. Carr (1985*a*) documents such locally variable organization within depositional sets at a French Magdalenian site. Variation of this kind has also led Whallon (1984) to argue that searching for global types of depositional sets and depositional areas within archaeologial sites is meaningless, implying that they do not exist.

Incongruence 2. Choice of variables, implying formation of local deposits by single or parallel processes. This incongruence between mode of analysis and organization of the archaeological record in current intrasite studies pertains to the researcher's choice of relevant *dimensions* of local artifact density of *individual* artifact classes. All current studies involve the application of a pattern-searching algorithm to local artifact densities *as given*, such as raw grid cell counts or item locations. Except for factor analytic approaches (*e.g.*, Schiffer, 1975*b*), the studies assume—whether or not the researcher is aware of it—that each of the local densities for each class is meaningful as *given*. Each local density, and by extension its larger distribution, is taken to represent the effect of *one kind* of formation process, or multiple, spatially coarranged formation processes that may be tracked together as a meaningful group—what may be termed *parallel processes*. For example, each local area is assumed to be the location of deposition of a tool kit, cache, or garbage set of specific composition (one process). Or similarly, each locale is assumed to be the location of deposition of a tool kit, cache, etc., within each of which the additional process of differential preservation of artifact classes has acted similarly (multiple, parallel processes).

In contrast, a generally more appropriate assumption would be that local densities of each artifact class are the *meaningless* summation of *multiple*, spatially overlaid organizations pertaining to multiple kinds of activities or formation processes. That is, each local density of an artifact class and the artifact class distribution as a whole may be a *palimpsest*—an overlay of structures. In this case, it would be necessary to dissect the composite artifact density distribution of each class into component density distributions—one pertaining to each form of organization, reflecting one process or a homogeneous set of processes—prior to fine-grained analysis. One then would search for patterns of coarrangement and similar kinds of depositional areas using the density *components* of each class as variables, rather than the raw densities. Only in this way would there be the concordance between data structure and technical assumption necessary for a reliable analysis.

Incongruent applications

Almost all quantitative intrasite spatial analyses that have been undertaken in archaeology since the late 1960s (see Carr, 1984 for an inventory of many) have involved the global application of algorithms to raw-density or point-location data. As a consequence, they assume global uniformity in the organization of artifact classes and the formation of local deposits by single or parallel processes. These analyses include ones achieved with: the Poisson method, dimensional analysis of variance and covariance, Morisita's method, nearest neighbor analysis, association analysis, correlation analysis, segregation analysis, simple contouring, trend surface analysis, Whallon's nearest neighbor methods for delimiting clusters and, more recently, multiple response permutation procedures, and k-means approaches. The critical aspect of the applications of these methods, in the context of this paper, is not the nature of the algorithms used to discover patterning (although some obviously are more robust than others; see Carr, 1984). Rather, what is important is their *global* application to *undissected* artifact distributions, and the assumptions that they consequently come to embody.

Consider, for example, the method of correlation analysis applied to grid cell counts of artifacts over a site in order to discover pairs of artifact classes that are coarranged. This common approach assumes that coarranged classes have one form of organization over all locations where they occur: constant proportions among local class densities, defining the covariation of local class densities over global space. Other algorithms applied site-wide assume other organizational properties to be globally constant. For example, dimensional analysis of variance, so applied, assumes that all depositional areas are of similar size, shape, orientation and spacing. Whallon's radius approach to delimiting clusters, applied globally, assumes that all depositional areas are of similar density. (For a discussion linking mathematical aspects of such algorithms to their assumptions in archaeological material terms, see Carr, 1984.) Moreover the application of each of these algorithms to raw density or point location data implies the integrity of each local observation and the homogeneity of the observations as a population. This, in turn, implies the formation of local deposits by singular or parallel processes.

Reasons for incongruence

The two assumptions that arise from global application of algorithms to raw spatial data—global organization of artifacts, and single- or parallel-process formation—generally are untenable, given what is known about the structure and formation of archaeological records. The alternative assumptions of locally variable artifact organization and the palimpsest nature of local and global distributions appear generally more appropriate.

The assumption of global organization of artifacts is inappropriate for two reasons. (1) The organizational properties of activity areas and activity sets of similar function in the behavioral domain and of depositional areas and depositional sets of similar function in the archaeological domain can vary systematically over a site. This variation in properties results from (a) *variation in the parameters* of any of a number of formation processes across the site, or (b) *localization* of any of them. Activity areas or depositional areas of similar function can vary over a site in their size, shape, density, composition, internal homogeneity and crispness of their borders. Causative factors include whether an area occurs in a zone of limited work space or not, whether or not it is cleaned and reused, the length of time of use of the area, whether or not the activity involves the use of permanent facilities, the season of use of the area, and a long array of postdepositional disturbance processes (Carr, 1984, p. 125–132; O'Connell, 1979; Schiffer, 1983; Whallon, 1984; Wood and Johnson, 1978; Yellen, 1977). Likewise, tool kits and depositional sets of similar function can vary over a site in the magnitude and direction of asymmetry among their constituent artifact classes, resulting in variation in patterns of covariation, rank correlation, association, or polythetic association among classes. Many spatially nonuniform or localized processes can be responsible for this: the existence of alternative tool types to accomplish the same ends; optional subtasks within an activity; differential discard of large and small artifacts; differential wear and breakage rates; the length of time of use of work areas; the multipurpose nature of tools; recycling; mining; natural and cultural postdepositional disturbance processes that smear or sort artifacts; differential preservation, etc. (Ascher, 1968; Binford, 1967; Carr, 1985*a*; McKellar, 1973).

(2) The assumption of global artifact organization is generally unwarranted also because it implies that *multiple* archaeological formation and disturbance processes are *spatially correlated* and *conterminous* over the site as a whole. In every location on a site where artifacts of a given class were manufactured, used, cached or disposed of, the same formation and postdepositional disturbance processes are assumed to have occurred to the same degree. For example, breakage rates, curation rates, degree of mining and recycling of artifacts and rearrangement of artifacts by any natural or agricultural disturbances that occurred are all assumed to have operated jointly and

in a parallel manner over the site as a whole. (Only if this were true would activity areas, activity sets, depositional areas, and depositional sets of similar function have globally uniform organizational properties.) This assumption obviously is not acceptable. Different formation and disturbance processes can occur in different subareas at varying rates or to different degrees.

The second assumption—formation of local deposits of artifacts of a single class by single or parallel processes—is generally inappropriate as well. Multiple formation and disturbance processes, spatially overlaid, but not necessarily coarranged nor similar in scale, usually are responsible for local densities of an artifact class and its distribution over a site. For example, pottery might be used for multiple tasks at different locations, each task requiring different amounts of space and perhaps overlapping. Such activities might produce overlapping clusters of sherds, the clusters varying in size. The deposits then might be smeared and partially obscured by natural or human processes, such as soil creep, plowing or trampling by the site occupants. The result would be a complex, composite pottery density distribution for which sherd densities at any one location often would not reflect any single process. To achieve a meaningful analysis, it would be necessary to dissect this palimpsest into component density distributions, each reflecting more singular processes, and then to analyze only those individual components thought pertinent to the process of interest.

Fine-grained methods approaching congruence

Three spatial methods that are useful for defining depositional sets or delimiting depositional areas at the fine-grained analytic stage *approach* solving the problem of inappropriately assuming global artifact organization.

(1) Whallon's (1984) method of unconstrained clustering. This method for defining depositional areas accomodates free variation over a study area in the size, shape, and density of depositional areas. Global types of depositional areas are not sought. The method has the disadvantage, however, of assuming that the local proportions or distributions of presence-absence states of artifact classes within similar depositional areas are comparable because they are above one, globally applied similarity threshold.

(2) Gladfelter and Tiedemann's (1985) contiguity-anomaly method. This method can be applied, as suggested by Carr (1984), to delimit depositional areas free of global assumptions about their size, shape, and absolute density. It also allows one to assess the statistical signficance of their density deviations from background densities. The method has the drawback, however, of assuming that the contrast in the artifact densities of all clusters from background artifact densities lies above or below some one, global contrast threshold. A similar degree of internal homogeneity of artifact densities within all clusters and a similar crispness of the borders of all artifact clusters are also assumed.

(3) Polythetic association (Carr, 1985a). This method allows the definition of sets of globally coarranged artifact classes while admitting variation among "similar" deposits in the most fundamental organizational properties of depositional sets: the magnitude and/or direction of asymmetry among coarranged pairs of classes, and the presence-absence states of classes. The method can faulter when applied globally,

however. In this case, it will artificially pool any subglobal patterns of coarrangement that are not complementary in order to form a single summary statistic of global patterning. For example, even though types A and B might strongly associate polythetically in one stratum of a site but not in another, the two kinds of relationships would be averaged—perhaps meaninglessly so—to define a global summary of patterning. It does not make sense to average, on a site-wide basis, patterns of coarrangement in areas of primary deposition with patterns of coarrangement in areas of secondary deposition or storage, for instance. Polythetic association shares this problem of pooling potentially contradictory local patterns with all methods that attempt to define global depositional sets (as mentioned above).

All applications of the above methods have used raw, local artifact densities or point distributions as the observations for analysis. They consequently improperly assume the integrity of raw local densities. One spatial method, however, approaches solving this problem. This is factor analysis (*e.g.*, Schiffer, 1975*b*; Kay, 1980).

(4) Factor analysis. This method can be used to dissect an artifact palimpsest and local artifact densities so as to allow the definition of spatially overlaid depositional sets within overlapping depositional areas. In this strategy, each raw cell count of artifacts of a single class is envisioned as potentially the sum of counts attributable to separate dimensions and is interpretable as different formation processes (different activities, in the simplest framework). The method, however, unfortunately first requires the summarization of global patterning using correlation analysis. This basis for analysis inappropriately assumes the constant proportions of coarranged artifact classes within similar kinds of deposits and the many incongruences with formation and disturbance processes that this assumption implies (see Carr, 1984 for a long list; also Whallon, 1984). Factor approaches also involve the problem of pooling patterns, mentioned previously.

A GENERAL APPROACH FOR SCREENING ARTIFACT PALIMPSESTS

The problems and inappropriate assumptions involved in current applications of spatial techniques to unscreened artifact distributions suggest a general approach for screening spatial data and bringing greater concordance during fine-grained analysis. This approach would help the analyst overcome the typically invalid assumptions of global organization of artifact types and of the significance of their composite densities. It is not seen as a total solution, nor can it be, for it is limited in its application to classes of artifacts that are fairly numerous and widely distributed. Rather, the approach should be seen as one of a series of complementary screening procedures for identifying relevant dimensions and a relatively homogeneous population of observations within artifact distributions for fine-grained analysis. The numerous means for identifying formation processes and the observations they have affected, as summarized by Schiffer (1983), as well as ethnographic analogy, historical documentation and other means mentioned previously, are equally important screening tools.

Five successive steps constitute the general approach, which are outlined below. Some methods for achieving the approach are described after this overview.

Step 1. Do not accept the data as necessarily meaningful as given. Instead, consider the distribution of each artifact type that is fairly numerous and widely distributed to potentially be the composite result of *multiple* behavioral and natural formation and disturbance processes that *overlap* spatially, that have operated at *different scales* and that have occurred in only *segments* of a site. For example, a scatter of multipurpose knives varying in density over space might be envisioned as the result of potentially multiple kinds of activities that overlap spatially and that each require different amounts of space and produce worn or broken knives at different rates. A ubiquitous distribution of pottery sherds exhibiting localized areas of variable size with higher sherd densities might indicate the following diversity of processes: the use of pottery for multiple tasks at different locations, each task requiring different amounts of space, followed by the "smearing" (Ascher, 1968) of such clusters by natural or human processes, partially obscuring the discreteness of the clusters. Soil creep, plowing or trampling by the site occupants might account for the smearing processes.

Step 2. Dissect the density distribution. The density distribution (or point-location distribution transformed to a density distribution) of each fairly numerous and widely distributed artifact class should be dissected into component density distributions having *scales* of density variation of two general kinds: relevant and irrelevant. The first set should include components that encompass density variations of different geographic scales consistent with the expectable, inductively suggested, or documented scales of those processes that are of interest (depending on the source of general knowledge). The second set should include other components that encompass residual density variations of scales consistent with those of processes not of interest and to be removed from analysis. For example, one might dissect the composite density distribution of sherds, mentioned above, into: (a) a component representing *small-scale* density variations that (possibly) result from irrelevant, localized, unsystematic artifact recovery, differential preservation, variable rates of artifact breakage and deposition, and other such factors; (b) several components of *mid-scale* density variation, each pertaining to a restricted range of spatial scales that correspond to the space requirements of only one (possible) kind of activity and each ideally documenting one (possible) kind of activity or depositional process (*e.g.*, caching, dumping); and (c) a component representing *large-scale* density variations that (possibly) result from irrelevant, smearing processes. All of these components would be definable, despite the spatial overlap of the processes they represent, using the techniques to be introduced.

Step 3. Assign meaning to each density component. It is necessary to interpret each density component in terms of the behavioral, geological, agricultural or other formation or disturbance processes responsible for it. This can be done using any of the sources of general knowledge enumerated at the beginning of this article. It can be done deductively by comparing the scale of variation of the component and its spatial distribution to the expectable scales and distributions of formation processes thought likely to have generated the palimpsest, as argued from principle and contextual information. It also can be done inductively by comparing the spatial distribution of the component to the spatial distributions of various indicators of formation processes.

These indicators include such things as the dip and orientation of artifacts, abrasion and wear patterns on artifacts, patterns of refit among dispersed pieces of broken artifacts, etc. Schiffer (1983) enumerates a wealth of indices, the spatial distributions of which can be used to assign meanings to components of density variation and to test those meanings.

Step 4. Delete irrelevant components. Components that do not reflect those behavioral processes, or whatever kind of processes, that are of interest should be deleted from the data to be analyzed later with fine-grained methods. For example, in the case above, the components representing small-scale and large-scale density variations might be deleted, leaving for fine-grained analysis those density components of mid-scale density variation that possibly reflect activities or other depositional processes.

Step 5. Multiple, fine-grained analyses. Perform a separate spatial analysis for each set of relevant density components that pertain to *different* artifact classes but the same *one* scale of variability. In this way, density variation attributable to a more limited, homogeneous range of behaviors and formation processes will be encompassed in any single analysis. The erroneous assumption of spatial correlation (parallelism) among processes that actually are diverse in nature and spatially independent will largely be overcome. Also, to the extent that density components of each given scale and the formation processes they represent are restricted to a portion of the site, each analysis will be subglobal. For components representing activities and other behavioral formation processes, subglobal distribution often will be the case. Activities usually are restricted in location within sites according to their spatial requirements, as has been well documented for hunter-gatherer camps (O'Connell, 1977, 1979; Binford, 1983; Carr, 1977).

Items that belong to artifact classes that are less numerous and spatially restricted (to which the methods of dissection to be proposed are not applicable) can be included in the analyses of components having similar distribution. Different items of the same infrequent class can be analyzed with different sets of subglobal density components in different portions of the site.

Different techniques of spatial analysis that offer relatable results can be used to examine density components and the density distributions of infrequent artifact classes in different areas, depending on the structure of the distributions and the assumptions made by the techniques. In this way, the degree of congruence between data structure and technique can be maximized. For example, different coefficients of polythetic association among artifact classes (*e.g.*, AVDISTGM, AVDISTLPI; see Carr, 1985*a*) might be used to define depositional sets in different subglobal regions.

Note that the strategy of palimpsest dissection calls for the researcher to develop an understanding of the formation and disturbance processes responsible for complex artifact class distributions as part of a screening process. This process occurs *prior to* fine-grained analysis aimed at reconstructing depositional sets and depositional areas, rather than afterwards. This allows the archaeologist to choose relevant aspects of the available data, as well as appropriate techniques, for analysis. It provides the archaeologist more control over his analysis. The precise way in which this can be accomplished, without falling into the methodological bind discussed in the introduction of this paper, will become clear as the methods of dissection are discussed.

METHODS FOR DISSECTING PALIMPSESTS

Overview of the Techniques

To dissect composite, global artifact density distributions, the general classes of methods known as digital spatial filtering and Fourier analysis can be used, in ways analogous to applications in the fields of geophysical prospecting (Davis, 1973; Robinson, 1970; Zurflueh, 1967) and digital image processing (Gonzalez and Winz, 1977; Castleman, 1979; Pratt, 1978). Although these methods were employed earlier in geophysics (Holloway, 1958) and their fundamentals have been known to mathematicians, physicists and communication engineers since before this century, it has been the recent efforts of the U.S. Space Program in image digitization, transmission, and synthesis that has increased the level of sophistication and success in their application (Gonzalez and Winz, 1977, p. 2).

Both families of methods have been employed successfully in archaeologial contexts to dissect composite spatial variation in geophysical survey data and soil chemistry data into components representing natural or behavioral depositional processes (Carr, 1977, 1979, 1982*a*; Scollar, 1969*a*, 1969*b*, 1970; Linington, 1969; Weymouth, 1985). The methods have never been used to dissect artifact distributions, although this application has been proposed previously for intrasite distributions (Carr, 1982*b*) and regional distributions collected in an "off-site archaeology" format (Ebert, 1983). My (1982*a*) application of the methods to geophysical data is very similar in goal, methodology, and data structure to that proposed here for artifact data: the responses of overlapping depositional areas of different kinds and sizes were segregated from each other and from the effects of natural formation processes using simple spatial filtering methods. The primary difference between geophysical and artifact data is discussed below.

For the techniques to be applied in archaeology, each artifact type distribution must be summarized in the form of local densities at closely, regularly spaced grid points. Data recorded as counts of items in coarse grids or as item point locations can be converted to the required form using methods described below.

Artifact distributions expressed in the required manner obviously are analogous to a digital image, where each coordinate pair (pixel) in the *x-y* plane is associated with a brightness (grey level). The effects of the various analytic procedures of digital filtering and Fourier analysis on the form of an artifact density distribution, then, can be understood intuitively by examining their effects on meaningful pictures, as illustrated in texts on this subject (*e.g.*, Gonzalez and Winz, 1977; Castleman, 1979).

The key to understanding the methods of digital filtering and Fourier analysis and how they may be applied to dissect a composite artifact distribution is a mental transformation of variations in density *over space* to variations in density within the *Fourier* or *wave domain*.

Consider a two-dimensional grid of artifact density values representing (sampling) a density surface. The density values at each grid point may be envisioned as the *sum* of amplitudes of multiple cosine and sine waves having different wavelengths, amplitudes, and phase angles and oriented in two perpendicular directions (Figure 1). Broad-scale trends in density are envisioned as the sum of low-frequency (long

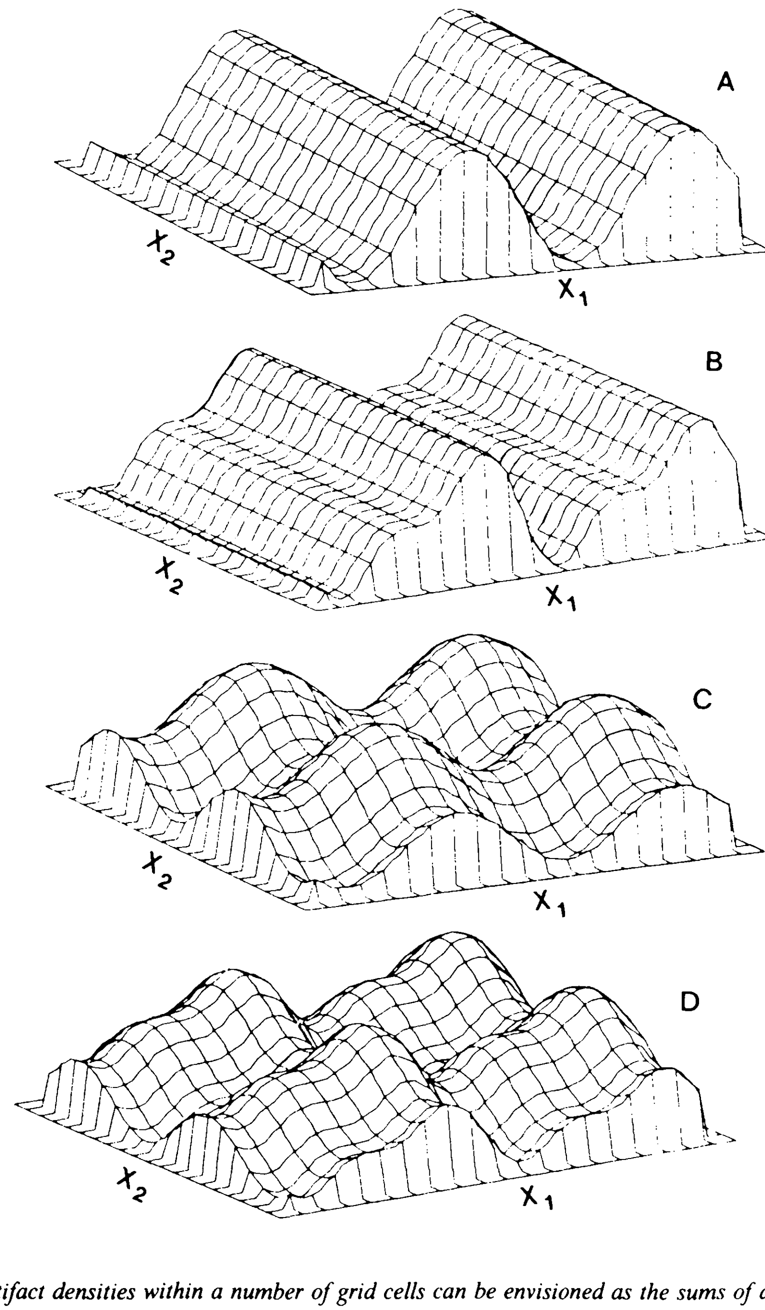

Fig. 1. Artifact densities within a number of grid cells can be envisioned as the sums of amplitudes of multiple cosine and sine waves having different wavelengths, amplitudes, and phase angles, and oriented in two perpendicular directions. (a) A single harmonic in the X_1 direction of two dimensional sine waves. (b) Two harmonics in the X_1 direction. (c) A single harmonic in both the X_1 and X_2 directions. (d) Two harmonics in both directions. [After Davis, 1973, p. 359]

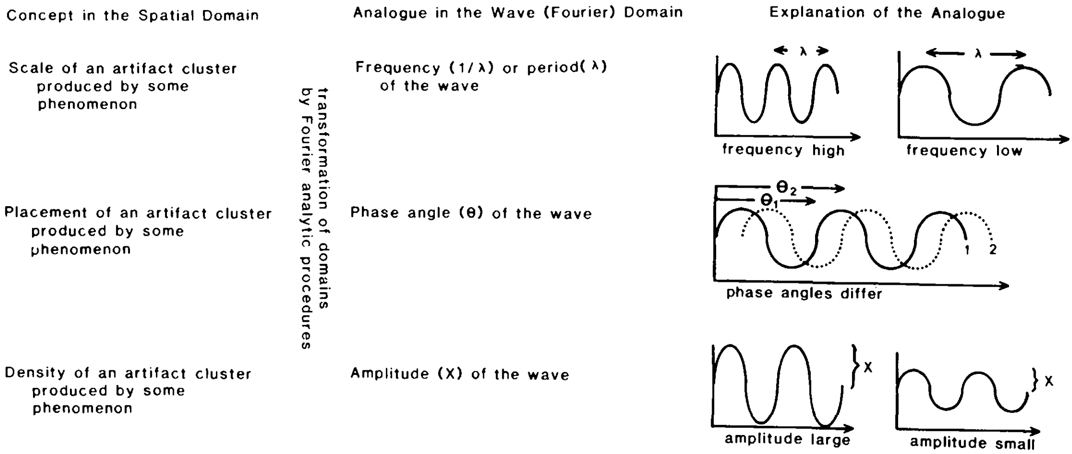

Fig. 2. Fundamental concepts in Fourier analysis as applied to artifact distributions.

wavelength) waves running through the data. Local anomalies in density are considered the result of higher-frequency (short wavelength) waves superimposed on the lower-frequency ones. Low-frequency variation might represent the blurring effect of plowing on what once were discrete clusters of artifacts. Midrange-frequency variations might represent the original clusters of artifacts. Very high-frequency variation distributed throughout the density surface could reflect variation in artifact density within clusters, or perhaps localized, unsystematic recovery of artifacts or localized postdepositional disturbance. In this way, *artifact density variations of different specific scales within a density palimpsest, each attributable to a different, limited range of formation and disturbance processes, are associated with sets of waves of specific frequency ranges*. The placement of a density anomaly in space and the magnitude of the anomaly are definable in terms of the phase angles and amplitudes, respectively, of the cosine and sine waves having wavelengths that correspond to its scale (Figure 2).

This mental transformation of data from the space to the frequency domain can be expressed mathematically. Simplifying, for a one-dimensional density trace, the artifact density, Y_i, at any point i, would be given by the expression

$$Y_i = \sum_{n=1}^{\infty} \alpha_n \cos\left(\frac{2n\pi X_i}{\lambda}\right) + \beta_n \sin\left(\frac{2n\pi X_i}{\lambda}\right), \qquad (1)$$

where X_i is the distance of the point from the origin, λ is the wavelength of a given wave, $1/\lambda$ is the frequency of a given wave, n is an integer variable called the *harmonic number* that allows wavelength and frequency to be varied, and α_n and β_n are a set of coefficents determining the amplitudes of the waves. The series expands infinitely. It begins with a pair of cosine and sine waves having some low frequency ($1/\lambda$; $n = 1$; picked arbitrarily) called the *first harmonic* or *fundamental frequency* and continues with pairs of cosine and sine waves having higher frequencies ($2/\lambda, 3/\lambda, 4/\lambda, \ldots$; $n = 2, 3, 4 \ldots$) called the second harmonic, third harmonic, etc. Thus, artifact density at each grid point along the trace is represented by the sum of an infinite number of cosine and sine curves of various frequencies.

For a one-dimensional trace, one set of cosine and sine waves is required. For a two-dimensional surface, two sets of waves, oriented perpendicular to each other, are required.

It should be noted that the variations in the spatial domain that are modeled in the frequency domain by equation (1) need not be periodic. The Fourier theorem, of which equation (1) is the discrete form, states that any periodic function of infinite expanse (one-dimensional trace or two-dimensional surface), no matter how complex, can be constructed from the sum of amplitudes of multiple cosine and sine waves of different frequencies and amplitudes. To apply the theorem to a finite, nonperiodic trace or surface, the trace or surface simply is envisioned as repeating itself infinitely over space. In other words, the length of a trace is taken to be the period of an infinite function in the x direction in the spatial domain, the length and width of a surface are taken to be the periods of an infinite function in the x and y directions in the spatial domain.

Finally, it should be clarified that the sets of cosine and sine waves of different scale ranges that are used in combination to represent a palimpsest's artifact density variations in the Fourier domain are not *models* of the processes that generated the palimpsest's density variation (as by analogy to a regression model as a representation of a process). Rather, the sets of waves are convenient *redescriptions*—from the spatial domain to the Fourier domain—of different components of the palimpsest's patterning that result from different formation processes. The completeness of redescription depends on the number of terms in equation (1). Also, the degree to which it is possible for the researcher to associate a set of waves with its generative process will depend on the researcher's general understanding of his or her data (see below for how this problem is approached).

Spatial Filtering

Dissecting a composite density distribution into component sets of waves of specific frequencies can be achieved with mathematical operations in *either* the spatial domain or frequency domain. This one might expect from their equivalence.

In the spatial domain, dissection is accomplished with running *filter functions* or *operator functions* that "smooth" the data. To obtain low-frequency, broad-scale trends in the distribution, the density at each grid point is replaced by a weighted average of the densities at points surrounding it. The larger the neighborhood over which densities are averaged—called the *smoothing interval* or *filter width*—the smoother the resulting surface. Residual, high-frequency, small-scale density variation can be obtained by subtracting observation values of the smoothed surface from those of the original data. Intermediate frequency bands composed of waves of a specified range of wavelengths can be obtained by performing the smoothing operation twice, using running averages that have different filter widths, and then subtracting the resulting smoother surface from the resulting less well-smoothed surface. In this way, it is possible to isolate density variation of specified spatial scales.

Spatial filters of a variety of mathematical forms, differing in the weights attached to the averaged values, can be used to accomplish the smoothing operation. The simplest filter is a moving average, where all averaged points are weighted equally. This operator, however, produces undesirable results known as *polarity reversals* (Holloway, 1958, p. 358) or *ringing* (Scollar, 1969, p. 81; Gonzalez and Winz, 1977, p. 140). As the filter runs over the surface and reduces the amplitudes of higher frequency waves, it also changes some maxima of select frequencies into minima, and vice versa, *i.e.*, it alters the *phase* of some waves as well as their amplitude. Pictorially, this results in localized highs and lows being surrounded by successive rings of low and high values (like those produced by a stone thrown in a pond), with the potential for interference patterns among rings and among rings and anomalies. Thus, the image is confused.

To reduce ringing, a filter may be used that weights—according to some *smooth* function—the data values to be averaged in decreasing importance away from the central observation. Examples include the Butterworth, exponential, and normal filters (Gonzalez and Winz, 1977, p. 145–150; Holloway, 1958). The single filter that achieves no ringing whatsoever is the normal filter, where the weighting values are equivalent to the ordinates of a two-dimensional normal curve.

In addition to not introducing ringing, it is desirable that a filter extract frequencies from a palimpsest in a clean manner. When smoothing a surface, the *total amplitude* of waves of all target frequencies and *only* the target frequencies should be obtained by the filtering operation. Only one filter achieves this ideal. This is the $(\sin x)/x$ filter function.

All filter functions that provide a clean or nearly clean separation of frequencies unfortunately also produce severe ringing. Inversely, those that minimize ringing—filters with smoothly tapering weights—do not provide clean separation of frequencies. The amplitudes of waves of some target frequencies (those of greatest frequency) are reduced somewhat, and the amplitudes of waves of some undesired frequencies (those of lowest frequency) are not completely damped. The latter can be seen in that the percentage of amplitude *reduction* of waves, specified by the weights of such filters, changes only slowly and smoothly away from the central observation and with increasing wavelength.

Filtering, then, requires a compromise to be made between ideal segregation of waves of different frequencies and prohibition of ringing distortion. When operating in the spatial domain, the filters of Zurflueh (1967) and Spence and Sheppard (Davis, 1973, p. 226) provide optimal solutions.

Filtering in the Fourier domain

Although filtering in the spatial domain is easier to visualize for the novice than filtering in the wave domain, it is preferable to operate in the wave domain. Computation is simpler in this domain, now that the fast Fourier transform algorithm is available (Cochran *et al.*, 1967). Also, filtering is more accurate. The effects of filters in the spatial domain can be accurately controlled along the principle axes of the gridded data, but are less easily managed in other directions. Distortions may accrue as a result (Scollar, 1970, p. 15).

To dissect an artifact density distribution in the Fourier domain, it first is necessary to transform the spatial distribution into a wave representation. After filtering is accomplished, the altered wave representation is inversely transformed back into a spatial distribution. For a simplified, one-dimensional trace of equally spaced observations, the general equation achieving the transformation from the spatial to the wave domain is

$$F(u) = \frac{1}{N}\sum_{i=0}^{N-1} f(x_i)e^{-j2\pi ux_i/N} = \frac{1}{N}\sum_{i=0}^{N-1} f(x_i)\left(\cos\left(\frac{2\pi ux_i}{N}\right) - j\sin\left(\frac{2\pi ux_i}{N}\right)\right), \tag{2a}$$

where $f(x_i)$ is the value (artifact density) observed at a grid point x_i, i units from the origin of the spatial domain; j is the imaginary number, $\sqrt{-1}$; $F(u)$ is the sum of amplitudes, $R(u)$ and $I(u)$, of cosine and sine waves, respectively, of the one examined frequency, u, over all grid points in the spatial domain, *i.e.*,

$$F(u) = R(u) + I(u); \tag{2b}$$

and N is the number of sampled grid observations (equivalent to the number of waves of different frequencies examined). As many equations of this form as there are frequencies examined (*i.e.*, N) are needed to transform the data completely into the frequency domain. The equivalence of the exponential function with that involving the cosines and sines is given by Euler's theorem.

The general equation achieving the inverse transformation from the wave to the spatial domain is

$$f(x) = \sum_{i=0}^{N-1} F(u_i)e^{j2\pi u_i x/N} = \sum_{i=0}^{N-1} f(u_i)\left(\cos\left(\frac{2\pi u_i x}{N}\right) + j\sin\left(\frac{2\pi u_i x}{N}\right)\right), \tag{3}$$

where $F(u_i)$ is the summed amplitudes, $R(u_i)$ plus $I(u_i)$, of cosine and sine waves of frequency u_i, i units from the origin of the frequency domain (see below); $f(x)$ is the value (artifact density) observed at the one examined grid point x, corresponding to the combined amplitudes of all cosine and sine waves of all frequencies in the frequency domain; and N is the number of waves of different frequencies examined (equivalent to the number of sample grid units). Again, as many equations of this form as there are grid points examined (*i.e.*, N) are needed to transform the data back into the spatial domain.

A two-dimensional density distribution transformed into the frequency domain cannot be displayed in any convenient way that also retains all frequency, amplitude and phase information. The transformed data are represented by two two-dimensional arrays of values equivalent in size to the original grid of densities (Scollar, 1970, p.

10). The elements of one array are the summed amplitudes of pairs of perpendicularly oriented cosine waves, one sum for each combination of frequencies examined in the x and y directions ($N \times N$, total). The elements of the second array are the summed amplitudes of pairs of perpendicularly oriented sine waves.

By convention, these arrays are displayed in a *combined* form, retaining information on only the amplitudes and frequencies of the waves, and not their phases (cosine or sine). Each summed amplitude in the cosine array is squared and added to the corresponding squared and summed amplitudes in the sine array. For a single-dimensional trace, this is analogous to the operation

$$S_n^2 = \alpha_n^2 + \beta_n^2, \tag{4}$$

where α and β are the amplitudes of the cosine and sine waves of frequency n/λ defined in equation (1), or equivalently,

$$S_i^2 = R^2(u_i) + I^2(u_i), \tag{5}$$

where $R(u_i)$ and $I(u_i)$ are, again, the amplitudes of the cosine and sine waves of frequency i, summing to $F(u_i)$ in equation (3). The value, S_i^2 is called the *power* or *variance* of the i^{th} frequency (harmonic). Taking the square root of S_i^2 defines the amplitude of the i^{th} frequency (harmonic).

The resulting $N \times N$ matrix of amplitudes of the i^{th} harmonics in the x and y directions then are displayed as a surface. Sometimes, the low frequency origin is placed at the corner of the surface (Davis, 1973, p. 369). More often, it is placed at the center, with the amplitudes of particular frequency combinations mirrored symmetrically in each of the resulting four quadrats (Scollar, 1970, p. 12). A display of this form is called the Fourier plane.

Filtering in the Fourier domain is achieved by multiplying the amplitude coefficients of cosine and sine pairs of particular frequencies by some number between 0 and 1, allowing complete damping to total retention, respectively, of variability due to those frequencies. When filtering a two-dimensional surface, usually cosine and sine pairs in *both* the x and y directions are modified in the same manner, damping or retaining the same sets of frequencies in both directions equivalently. This allows variability of a particular spatial scale to be retained or supressed equally in all directions. For some occasions, however, an asymmetrical approach is preferable, allowing variability in only one direction to be altered (*e.g.*, Robinson, 1970), or altering variability in two directions in different ways. Removal of directionally-biased blurring of artifact clusters caused by plowing or water erosion is one archaeological application for which an asymmetrical approach can prove useful (see below).

Mathematically, the process of filtering in the Fourier domain can be expressed as follows. Again, simplifying to one dimension,

$$G(u) = H(u) \bullet F(u), \tag{6}$$

where $F(u)$ are the amplitudes of the cosine and sine waves of some frequency, u, as given in the equation (2a), $G(u)$ are the altered amplitudes, and $H(u)$ is the filter, or *transfer function*.

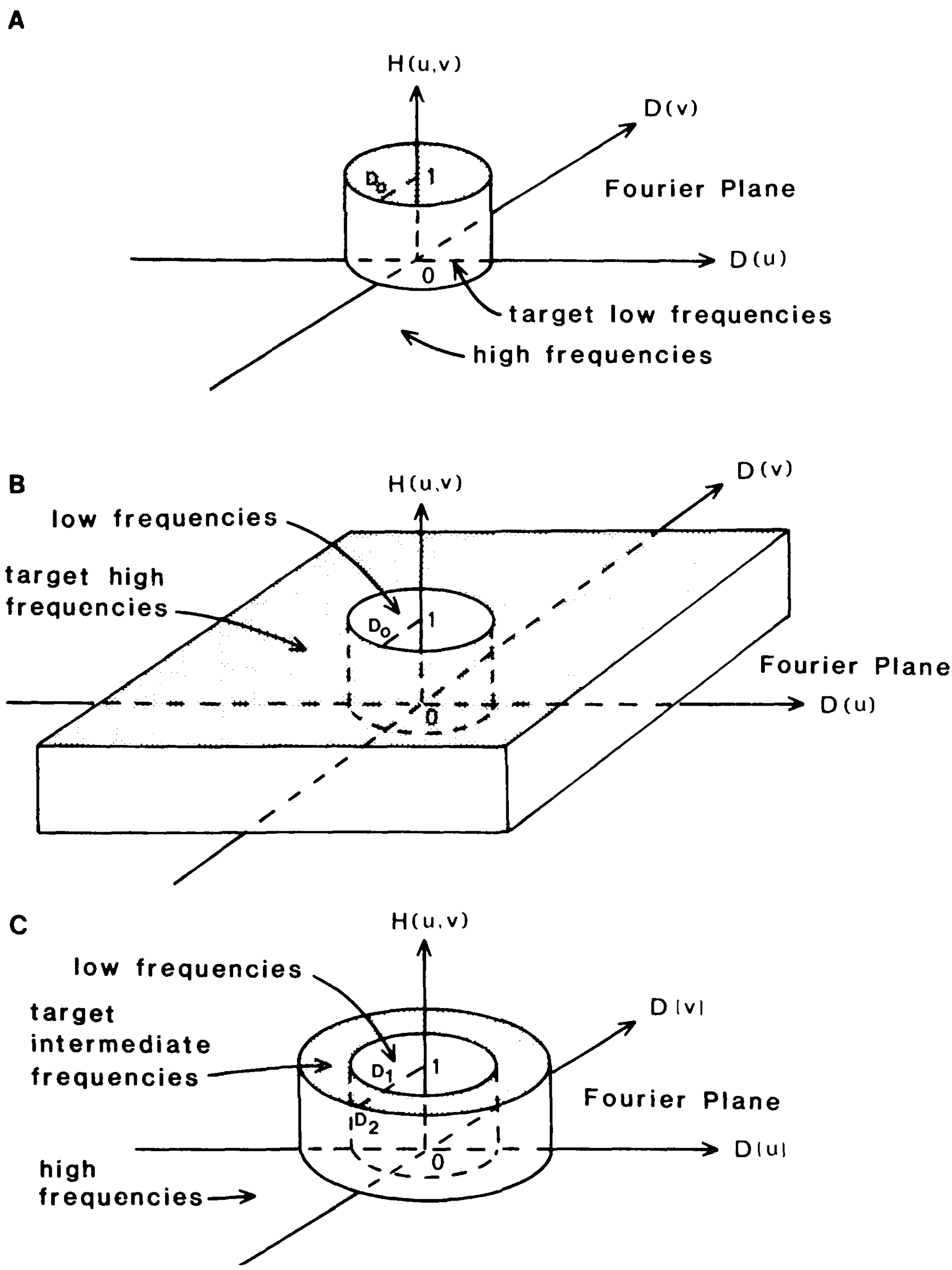

Fig. 3. (a) An ideal low-pass filter in the Fourier domain. (b) An ideal high-pass filter in the Fourier domain. (c) An ideal band-pass filter in the Fourier domain.

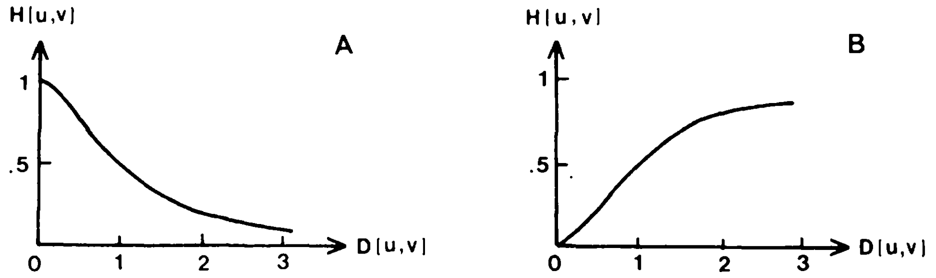

Fig. 4. A Butterworth filter function in the Fourier domain (radial cross section).

Ideal filters, giving perfectly clean separations of frequencies, passing only low frequencies, only high frequencies or a band of frequencies of some specified range, are shown in Figure 3. The coefficients of the filter are 0 in all portions of the Fourier plane that pertain to frequencies to be obscured. They are 1 in all portions of the plane that represent frequencies to be obtained. A low-pass, ideal filter, in the two-dimensional case for example, has the general form

$$H(u,v) = \begin{cases} 1 & \text{if } D(u,v) \leq D_o \\ 0 & \text{if } D(u,v) > D_o \end{cases} \tag{7}$$

where $D(u,v)$ is the distance from the origin of the Fourier plane (*i.e.*, frequency) in the u and v directions and D_o is the frequency threshold above which no higher frequency waves are to be admitted. D_o is called the *cutoff frequency*. Ideal filters of these kinds in the Fourier domain are equivalent to $(\sin x)/x$ filters in the spatial domain.

Like ideal filters in the spatial domain, those in the wave domain cause ringing. Ringing can be attenuated by using a transfer function with a smooth envelope rather than a step function. The Butterworth filter (Figure 4) is one such transfer function. In the two-dimensional case, it has the general form

$$H(u,v) = \frac{1}{1 + (D(u,v)/D_o)^{2n}} \tag{8a}$$

for a low-pass filter, and

$$H(u,v) = \frac{1}{1 + (D_o/D(u,v))^{2n}} \tag{8b}$$

for a high-pass filter. The parameter, n, determines the steepness of the function.

As is true for all smooth transfer functions, there is no sharp discontinuity in the coefficients of the Butterworth filter that establishes a clean threshold between passed and damped frequencies. The cutoff frequency, D_o, therefore is defined arbitrarily as the frequency above (or below) which amplitudes of waves are diminished more than a certain percentage. A commonly used value for the Butterworth filters is the number of waves that have their amplitudes diminished by 50%, (*i.e.*, $H(u,v) = .5$ when $D(u,v) = D_o$ (Gonzalez and Winz, 1977, p. 146).

Because the Butterworth filter does not have an abrupt cutoff frequency, separation of component frequencies is not clean. When using a low-pass filter, a certain percentage of the variability (amplitude) of waves having frequencies above the cutoff threshold is admitted along with the target, low-frequency waves. When using a high-pass filter, the opposite is true. These circumstances are the case for all smooth transfer functions. Thus, as in the spatial domain, a compromise between ideal separation of frequencies and prevention of ringing is required.

Other smooth transfer functions commonly used include the exponential, trapezoidal (Gonzalez and Winz, 1977, p. 149–151, 163–166) and normal (Castleman, 1979, p. 194) filters.

Collection and preparation of data for filtering

To be applied and to produce unbiased results, filtering techniques require data to be in a specific form.

1. Gridded data. Filtering operations may be performed on a continuous surface or its discretized representation which constitutes a sample of it (Gonzalez and Winz, 1977, p. 36–47). In the latter case, the observations must be arranged in a regular grid.

The required format for excavation and surface survey data is counts of items in grid cells. Point-plotted artifact distributions must be converted to local artifact densities at regular grid points to be filtered. After filtering, the relevant components, which also are in the form of gridded data, can be analyzed directly with fine-grained techniques appropriate to gridded data or converted back to a *filtered point distribution* for analysis with techniques using item point locations. Methods for achieving the first conversion are described by Davis (1973, p. 310–317); those for accomplishing the second are described in essence by Yule and Kendall (1968: Chapter 24), Davis (1973, p. 310–311) and Carr (1984, p. 204–205). Care must be used in choosing appropriate search radii and domains of interpolation.

The necessity of using interpolation methods to transform item point location data to gridded observation data (and sometimes back) reflects perhaps the most critical way in which archaeological applications of Fourier and filtering procedures differ from geophysical and digital image processing applications. It indicates a difference between the spatial structure of an archaeological artifact distribution, which is discontinuous, and that of geophysical phenomena (*e.g.*, soil resistivity, magnetic susceptibility) or an image, which define a continuous surface. In geophysical and digital image applications, the problem is not one of choosing a relevant search radius for *interpolating* observation values within discontinua, but rather, choosing a relevantly sized unit of observation (volume of soil measured for its resistivity or magnetic susceptibility, pixel) over which continuous variation is *averaged* ("measured") to define a discrete observation. Thus, artifact distributions generally have a lower resolution or coarser structure than geophysical phenomena or an image relative to the anomalies of interest (*e.g.*, depositional areas, soil anomalies, features in an image) and a potentially greater susceptibility to aliasing error (see below). This circumstance becomes more problematic as the density of an artifact distribution decreases and can be exacerbated by choice of an inappropriately large interpolative search radius.

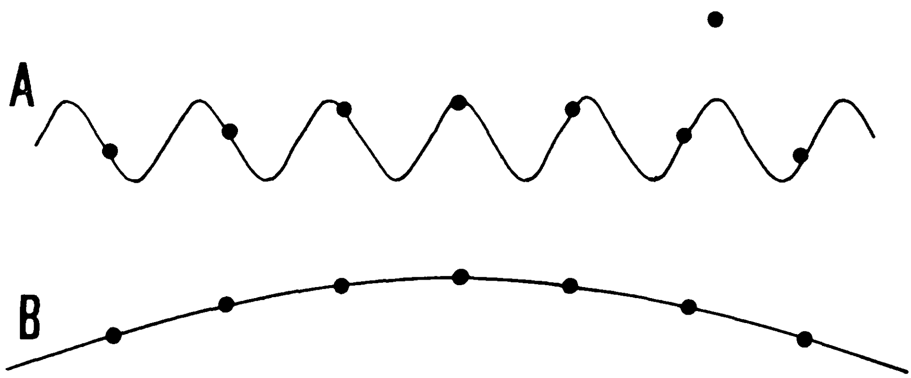

Fig. 5. An example of aliasing error. A sinusoidal wave (A) is sampled at less than two samples per wavelength (less than the wave's Nyquist frequency), producing the aliased wave (B). [After Robinson, 1970, p.24, Figure 4]

It can cause distortion in an archaeological Fourier and filtering analysis that would not occur in an otherwise analogous application to geophysical, image, or other continuous phenomena.

2. Grid interval. The higher the frequency of waves/density variations to be sought in an artifact distribution, the finer the spacing between grid points must be. This limitation of grid mesh on the frequencies capable of being extracted occurs for two reasons, depending on whether one is filtering in the spatial domain or wave domain. (a) In the spatial domain, filters must be composed of a reasonably large number of weighting coefficients if they are to produce a controlled response. This limits the minimum width of the filter, the minimum number of observations that can be smoothed and, thus, the upper frequency of waves that can be obtained with a low-pass filter. (b) When filtering in either the Fourier or spatial domain, the highest frequency that can be calculated theoretically from a data set has a wavelength of two times the grid interval, *i.e.*, a wave defined by only three observations. This frequency is called the *Nyquist frequency*. The farther apart grid points are, the greater is the Nyquist frequency.

When data are in the form of item point locations, the mesh of the grid to be used can be made as fine as desired during the operation of converting the artifact point locations to gridded local artifact densities. When the data are already in grid format, the grid can be made finer using the methods of interpolation just referenced. The process of making a finer grid, in the case of converting item point location data to gridded data, eases both limitations discussed above. It makes continuity and precision possible in the filtering process when filtering in the spatial domain. It also increases the Nyquist frequency. The process of making a fine grid from a coarse grid through interpolation, however, eases only the first limitation related to controlled filtering. It will not increase the upper limit on the frequency of waves that can be extracted from the data: no information on higher frequency variations is added by the interpolation process.

Variations greater in frequency than the Nyquist frequency, although not detectable, add false variability to lower frequency variation in a data set (Figure 5). This distortion of the amplitudes of lower frequencies is called *aliasing error* (Robinson, 1970, p. 23; Robinson *et al.*, 1969; Gonzalez and Winz, 1977, p. 70–74). Its magnitude is determined by the combined amplitudes of the aliased frequencies. Thus, when filtering in either the spatial or Fourier domain, grid observations should be spaced several times more closely than the scale of variation of interest. For example, for an artifact distribution, this might be several times smaller than the diameter of depositional areas expected or known to occur in the data.

3. Shape of the grid. When filtering in the Fourier domain, it is necessary that the gridded representation of an artifact density distribution has rectangular dimensions. Irregularly shaped areas of interest may be filled out to rectangular dimensions by adding zero densities to grid locations without observations, with no deleterious effects on the analysis (Gonzalez and Winz, 1977, p. 146–148).

4. Circumscribing the grid with null observations. Even when the original distribution of artifact densities and its gridded representation have rectangular dimensions, it is necessary that a perimeter of zero densities of a specified width be placed around it when filtering in the Fourier domain. This is necessary to avoid what is called *wraparound error*: the confusion of a filtering operation by its encompassing high-frequency variation from assumed Fourier planes adjacent to that of interest (Gonzalez and Winz, 1977, p. 61–63, 146–184, 189).

Spectral analysis

Decomposition of an artifact density distribution into bands of frequencies that are meaningful in representing the formation or disturbance processes of interest depends on: (1) the researcher having general knowledge of the scale and orientations of those processes and (2) the researcher designing filters concordantly. The cutoff values, width, sharpness of cutoff, and asymmetry of each filter must be concordant with the scale and orientation of the process of interest.

The general knowledge that is required to build appropriate filters may be derived from historical documents, ethnographic analogy, or deductive argumentation from principle and site context. When these approaches are insufficient, it is possible to examine the amplitudes of waves of *each* frequency within the density distribution to determine the scales and orientations of the phenomena of interest or of anomalies/variations potentially representing phenomena of interest and, thus, the filter parameters appropriate for isolating them. The method allowing this to be achieved is called *spectral analysis* (Jenkins and Watts, 1968; Brillinger, 1975, Chapter 5). Standard approaches are adequate when either: (a) the anomalies caused by each phenomenon of interest constitute a *significant percentage, areally*, of the original gridded surface, or (b) the anomalies, though infrequent, are of *intense magnitude*. When these conditions are not met, nonstandard procedures of Fraser (1966, p. 1069–1073) may be used.

Successful application of spectral analysis to an artifact palimpsest requires that it be *stationary*, *i.e.*, that there are no broad-scale trends in artifact density over its expanse. To ensure that this assumption is met, it is only necessary to filter the palimpsest with a high-pass filter having a cutoff frequency of several times the maximum likely scale of variability of interest. This operation will remove any broader trends from the data, leaving a residual, stationary representation of the palimpsest.

Histogram equalization

Filtering operations and spectral analyses are one set of related techniques by which selected aspects of the variability within an artifact palimpsest can be segregated or "enhanced". Another group of methods allowing this fall under the heading of *histogram modification*, used primarily for digital image processing (Gonzalez and Winz, 1977, p. 114–136; Castleman, 1979, p. 68–83).

The purpose of histogram modification techniques is to bring greater contrast between the values of observations representing different phenomena in a surface when the contrast between them is low (*e.g.*, as in an under-exposed or over-exposed photograph). This is achieved by expanding the *dynamic range* of the observations differentially over their range so that their histogram and image contrast is altered advantageously. The most effective approach, called *direct histogram specification* (Gonzalez and Winz, 1977, p. 127–136), usually cannot be realized in archaeological applications because of insufficient knowledge of the surface's structure, and the suboptimal technique called *histogram equalization* or *histogram linearization* must be used. In this technique each observation is multiplied by the cumulative frequency of all observations of lower value. In other words, the transformation function required to equalize the histogram of a surface is its own cumulative frequency distribution. If observation values are in the form of grouped data and the actual values of individual observations are unavailable for computation, the histogram of a surface can be equalized only approximately (Gonzalez and Winz, 1977, p. 125).

POTENTIALS FOR APPLICATION TO ARTIFACT PALIMPSESTS

Spectral analysis, various kinds of filtering procedures, and histogram equalization can be used to reveal and dissect the structure of an artifact palimpsest. The particular kinds of filters and the order of application of methods that are most useful for this depend on the structure of the palimpsest. To give the reader some feeling for the flexibility of the approach and when various filters and sequences of application are appropriate, six ideal models of artifact distribution that differ in their structure are presented, along with appropriate methods of analysis (Table 1). Some formation and disturbance processes that could be responsible for the structural attributes of the models are listed in Table 2. It is assumed here, for illustrative purposes, that the goal of spatial analysis is to isolate density variation attributable to depositional areas of different functions and scales, as opposed to that attributable to natural or other formation processes.

Distribution 1. None of the proposed methods need be used to screen this distribution. Depositional areas of different kinds, and the processes responsible for them, are spatially segregated and apparent. Local artifact densities are not a mixture of component variations in density. A distribution of this kind would seldom, if ever, occur archaeologically. Minimally, there is always undesirable high-frequency variation present in a distribution, attributable to one or more of the processes listed in Table 2.

TABLE 1. ARTIFACT DISTRIBUTIONS HAVING VARIOUS STRUCTURAL ATTRIBUTES AND THE TECHNIQUES APPROPRIATE TO THEIR DISSECTION

STRUCTURE OF PALIMPSEST

Distributions of various structural attributes	Depositional areas are of several kinds, varying in scale*	Depositional areas do not overlap spatially	Depositional areas overlap spatially	High-frequency noise absent	High-frequency noise present, due to**	Good contrast in artifact density between depositional areas	Low contrast in artifact density between depositional areas, due to**	Boundaries of depositional areas crisp	Boundaries of depositional areas blurred, due to**	Power spectrum of noise and signal known	Power spectrum of noise and signal not known	*TECHNIQUES TO BE USED, IN ORDER OF OPERATION*
1	X	X		X		X		X			X	Methods described not needed
2	X		X	X		X		X			X	Spectral analysis → band filters
3	X		X		X	X		X			X	Spectral analysis → low-pass filter with a gradient threshold → band pass filters
4	X		X		X		X	X			X	Spectral analysis → low-pass filter with a gradient threshold → histogram equalization → spectral analysis → band pass filters
5	X		X		X		X		X		X	Spectral analysis → low-pass filter with gradient threshold → high-pass filter → histogram equalization → spectral analysis → band pass filters
6	X		X		X		X		X	X		Spectral analysis → low-pass filter with a gradient threshold → Wiener estimator filter histogram equalization → spectral analysis → band pass filters

*Depositional areas include not only *clusters* of artifacts representable by mid-frequency waves, but also broader scatters and background density levels representable by low frequency waves.

**See Table 2 for a list of causal formation processes.

TABLE 2. SOME PROCESSES GOVERNING THE STRUCTURE OF INTRASITE ARTIFACT DISTRIBUTIONS

Processes that can cause high-frequency variation (noise) in an artifact density distribution

1. areally unsystematic, incomplete recovery of artifacts
2. areally unsystematic, misclassification of artifacts
3. a large series of formation processes that cause depositional sets to be polythetic (not all artifacts belonging to a set occur in every location where they are expected) as discussed by Carr (1982):

   a. curation (Binford, 1976)
   b. recycling of broken artifacts into new kinds of tools
   c. the multipurpose nature of some tools
   d. the fact that tools constituting the same activity set may be discarded in their separate locations of manufacture, use, storage, or discard, but not all locations need coincide
   e. "mining" of already deposited artifacts by occupants of a site or contemporary artifact collectors

The above processes are discussed at length by Binford (1974) and Schiffer (1972, 1973, 1975*a*, 1975*b*, 1976, 1977)

Processes that can cause low contrast in the densities of depositional areas of different kinds

1. ephemeral use of the areas
2. various processes blurring/smearing the contents of a cluster over a wider area, as given below

Processes that can cause blurring/smearing of the boundaries of depositional areas

1. plowing, if the artifact distribution comes from a surface survey (Roper, 1976; Trubowitz, 1981; Lewarch and O'Brien, 1981)
2. trampling by the occupants of the site (Ascher, 1968)
3. water washing
4. pedoturbations by the burrowing actions of mammals, insects, and earthworms (Stein, 1980)
5. tree falls
6. soil creep
7. solifluction
8. cryoturbations
9. aquiturbations

Processes 4 through 9 are discussed at length by Wood and Johnson (1978)

Distribution 2. The overlap of depositional areas of various functions in this form of artifact distribution requires that density variations attributable to each kind of area (and to the formation processes responsible for them) be segregated. Spectral analysis is used to determine the spatial scales of areas of different nature. Either standard techniques, or the approach of Fraser *et al.* (1966) might be used, depending on the areal expanse of the depositional areas and their artifact densities relative to background densities. Band filters with cutoff frequencies and sharpness of cutoff that are adequate to segregate variability of the different scales and types then are designed on the basis of the spectral analysis. Note that for the method to be successful, the areas of different function must differ also in scale. Again, a distribution of this kind would not likely occur archaeologically; it lacks high-frequency variation.

Distribution 3. This artifact distribution is identical to Distribution 2, with the exception that undesirable, high-frequency density variations of various causes (Table 2) occur within it. Spectral analysis is used to assess the frequencies in which variations attributable to noise and to depositional areas of different kinds are isolated. The first filtering operation must eliminate noise. This can be accomplished with a low-pass filter having an upper cutoff frequency equivalent to the lowest frequency of noise that can be removed without loss of meaningful variation attributable to depositional areas.

The low-pass filter cannot be of the standard form. It must include a threshold option stating that high-frequency density variation at an observation will be removed only if the local *gradient* (slope) in artifact density is less than some threshold. When filtering in the spatial domain, an operator of this kind would have the form

$$g(x_n, y_n) = \begin{cases} h(x,y) \bullet f(x,y) & \text{if} \nabla f(x,y) < T \\ f(x_n, y_n) & \end{cases}$$

where $g(x_n, y_n)$ is the filtered observation; $f(x_n, y_n)$ is the original observation; $h(x,y)$ is the spatial filter (set of weighting coefficients) convolved with the original surface $f(x,y)$, in the neighborhood of $f(x_n, y_n)$; $\nabla f(x,y)$ is the gradient of the original surface, in the neighborhood of $f(x_n, y_n)$; and T is the chosen threshold. This conditional filtering is necessary to preserve the crispness of the borders of depositional areas (assumed in the model). Sharp borders between areas of different average values within a surface constitute high-frequency variation. If a standard, low-pass filter is used to remove high-frequency noise within a surface, meaningful variation attributable to borders, as well as noise, will be obscured, blurring the discontinuity (Gonzalez and Winz, 1977, p. 138; 154–161). The appropriate threshold, T, must be obtained by trial and error. The neighborhood over which a local gradient is assessed must be greater in scale than that of the noise present in the surface, as determinable from its power spectrum.

Once high-frequency noise has been removed as best as possible from the artifact distribution, the remaining variability may be partitioned into components attributable to different kinds of depositional areas, using band pass filters. The appropriate parameters of the filters can be determined from the spectral analysis.

Distribution 4. This model surface presents the problems of: (a) spatial overlap of depositional areas of different sizes; (b) presence of high-frequency noise; and (c) low contrast in the densities of depositional areas of different kinds. The distribution has the same structure of Distribution 3, with the exception of the additional, last source of difficulty.

The operations necessary to successfully dissect components of density variation attributable to depositional areas of different kinds are nearly the same as those used in Distribution 3, with the additions of histogram equalization and a second spectral analysis, as shown in Table 1. Histogram equalization is used to increase the density contrast between depositional areas. It should occur only after high-frequency noise has been eliminated from the surface, so that the amplitudes of these undesirable frequencies are not emphasized. The second spectral analysis is performed after histogram equalization to reassess the differentiation of depositional areas by scale, taking advantage of the increase in their contrast and the clarity of their power spectra achieved through the histogram equalization. On the basis of the second spectral analysis, filters for isolating density variations attributable to depositional areas of different scale and function are designed. The order of operations given in Table 1 must be followed to ensure successful filtering.

Distribution 5. Often, the processes that cause low contrast in the artifact densities of depositional areas of different kinds also cause blurring of their borders (Table 2). For example, repeated plowing of a site will reduce the densities of artifacts within depositional areas and the contrast between them by smearing their contents over a wider area.

If the problem of blurring of depositional areas is added to those in Distribution 4, the sequence of operations necessary to successfully dissect the palimpsest is as follows. First, a spectral analysis is performed to aid in the design of appropriate filters. As before, a low-pass filter with a gradient threshold is used to remove undesirable, high-frequency noise. Next, the borders of depositional areas are sharpened using a high-pass filter with a lower cutoff frequency that is slightly less than that equivalent to the largest-scale depositional areas sought. This will preserve in the density surface all variation of the frequencies in the depositional areas and will attenuate very low to low frequencies that model smearing around the areas. It is important that the filter have a tapering tail that admits some low frequencies, in order to retain the internal integrity of the depositional areas, despite the consequent preservation of some blurring. High-pass filtering often is used in this manner to sharpen images (Gonzalez and Winz, 1977, p. 161 – 166). The two operations of low-pass and high-pass filtering can be reversed without disrupting the analysis.

Histogram equalization then follows, as before, to increase the contrast in densities between depositional areas. Although histogram equalization often is used after high-pass filtering to improve image quality by supressing the effects of high-frequency noise (Gonzalez and Winz, 1977, p. 166), it is not used here for this purpose. Most high-frequency noise is removed prior to this stage of analysis.

Finally, a second spectral analysis, which assesses the greater differentiation of depositional areas achieved by the above operations, is performed. Filters isolating depositional areas of various scales and functions are designed with the aid of the power spectrum.

Distribution 6. The o Distribution 5 provide as effective dissection as can be achieved, given the kinds of information typically available to the archaeologist and assumed here. They do not, however, provide the most optimal solution possible. If the power spectrum of either the combined sources of noise or the combined depositional areas (signal) is known, filters other than the generalized, low-pass filters described above may be used to optimally separate noise and signal. These filters, all of which are employed in the Fourier domain, include the Wiener estimator, the power spectrum equalizer and the generalized class of geometric mean filters (Castleman, 1979, p. 199 – 207, 278 – 282).

In the future, as we gain experience in the form of power spectra of archaeological noise, we may be able to estimate the noise of signal spectra of artifact density distributions and employ these estimates to build optimal filters. This has been done in the field of archaeological magnetometry surveying (Scollar, 1970), but is not feasible in the study of artifact density distributions at present.

RELATION OF THE SCREENING METHODS TO FINE-GRAINED ANALYSIS

It should be apparent that the proposed methods allow one to do more than explore the structure of and screen an artifact density palimpsest for components that pertain to a relatively homogeneous range of formation processes, that are potentially subglobal in nature, and that are potentially relevant. They also, in the process, allow one to define the limits of depositional areas using single artifact classes. In this regard, they grade into methods of fine-grained analysis.

To screen spatial data and to delimit depositional areas in a more *multivariate* fashion, it also is possible algorithmically to apply the techniques not just to surfaces that represent the absolute local densities of one artifact class, but also to surfaces that represent relative local density relationships among two or more classes. Measures of density relationships among classes that can be used for this include: local proportional densities of two classes; measures of local equibility in the densities of multiple artifact classes; measures of local total density of multiple, select classes of similar function or depositional history; etc. At this time, the use of the proposed methods and measures in a multivariate mode to explore an artifact density distribution for components that represent formation processes and to use their spatial distributions to define subglobal sets of homogeneous observations seems promising. Use of the methods and measures to delimit clusters seems less promising because their *proper* use would require detailed knowledge about an artifact palimpsest that typically is not available prior to fine-grained analysis. Such knowledge would be required to: (1) choose a multivariate measure that pertains to some meaningful process, and (2) select artifact classes that reflect the same process and have mutually reinforcing spatial patterns. The application of unconstrained clustering (Whallon, 1984) to delimit clusters seems more promising.

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C. CARR
Department of Anthropology
Arizona State University
Tempe, Arizona 85287
USA

SUMMARY

Current approaches to the spatial analysis of intrasite artifact distributions are not concordant with the general nature of organization of archaeological records. They assume: (1) the global organization of artifacts into types of depositional sets and depositional areas, and (2) the significance of local artifact densities as given.

Instead, archaeological records typically are palimpsests, with local artifact density variation in individual artifact classes attributable to multiple formation processes, each of which may have a different, subglobal distribution.

Subglobal variation across a site in the properties of depositional areas (*e.g.*, their size, shape, artifact density, composition, internal heterogeneity, and crispness of their borders) can result from variation in a large number of factors. These include: whether or not an area occurs in a zone of limited work space; whether or not it is cleaned and reused; the length of time of use of the area; whether or not the activity involves the use of permanent facilities; season of use; and many postdepositional disturbance processes. Subglobal variation in the organization of depositional sets (their definability by patterns of covariaton, rank correlation, association, or polythetic assocation among artifact classes) also arises from many factors. These include: the existence of alternative tool types to accomplish the same ends; optional subtasks within an activity; differential discard of large and small artifacts; differential wear and breakage rates; the length of time of use of areas; the multipurpose nature of tools; recycling and mining behaviors; and postdepositional disturbance processes, such as differential preservation.

The techniques of spatial filtering, Fourier analysis, spectral analysis, and histogram equalization are introduced as screening methods. They allow the dissection of palimpsests of each artifact class into subglobal components that reflect a more homogeneous range of formation processes. Those components that are of similar nature, for multiple classes, then may be analyzed together with techniques concordant with *their particular structure*.

Optimal filtering is a compromise between obtaining clean separation of frequencies present in the data and minimizing interference patterns known as polarity reversals or ringing. Filtering in the Fourier domain is preferable to filtering in the spatial domain; the former allows more control over the effects of filters in directions other than their principle axes.

The requirements of filtering include: grid count data; fine spacing of grid points, which may be obtained by interpolation of values; the filling out of irregularly shaped grids to rectangular dimensions with a border of zero count cells; and circumscribing of grids of all shapes with a border of zero count cells having a width proportional to the maximum filter width used, in order to avoid wrap around error.

Spectral analysis allows exploratory investigation of a spatial data set and provides information necessary to design filters with appropriate widths, sharpness of cutoff, asymmetry and orientation. It requires the stationariness of the data set—the lack of any trends in it—which may require high-pass filtering.

Histogram modification allows contrast between different phenomena in a spatial data set to be enhanced. This is done by expanding the "dynamic range" of observations differentially over their range, altering their frequency distribution.

Six models of archaeological records are presented along with the techniques and sequences of application of techniques appropriate for their dissection. The models differ in whether or not depositional areas vary in scale, depositional areas overlap spatially, high-frequency noise due to enumerated formation processes is present, areas contrast well in their artifact densities, the power spectra of noise and signal is known, and the crispness of the borders of areas.

RÉSUMÉ

Les travaux actuels portant sur l'analyse spatiale de distributions d'artefacts à l'intérieur de sites ne sont pas conformes à la nature générale de l'organisation des constatations archéologiques. Ils supposent: (1) l'organisation globale d'artefacts en types d'ensembles de dépôts et surfaces de dépôts et (2) que la signification de la densité d'artefacts locaux soit connue. Au contraire, les constatations archéologiques sont typiquement de palimpsestes offrant une variation de densité d'artefacts locaux suivant les différentes classes d'artefacts, variation dépendant de processus multiples de formation dont chacun peut avoir une distribution différente, subglobale.

La variation subglobale à travers un site dans ses propriétés d'aires de dépôts (par exemple, leur dimension, forme, densité, composition, hétérogénéité interne et netteté des limites) peut résulter de la variation d'un grand nombre de facteurs. Parmi ceux-ci, citons: le fait qu'une surface se trouve ou non dans une zone permettant seulement un travail limité; le fait que cette surface a été nettoyée et réutilisée; la durée d'utilisation; le besoin pour une activité d' installations permanentes; la saison d'utilisation; les nombreux processus ayant pu déranger le dépôt après sa formation. La variation subglobale dans l'organisation des dépôts (leur possibilité d'être définis par des grilles de covariation, leurs liaisons hiérarchiques, association ou l'association polythéthique parmi des classes d'artefacts) dérive également de nombreux facteurs. Nous citons: l'existence de types d'outils alternatifs pour accomplir une même tâche; des options de diverses tâches subordonnées dans une même activité; le rejet différencié d'artefacts de grande ou de petite taille; des taux de casse et d'usure différentiels; la longueur du temps d'utilisation des surfaces; l'usage polyvalent des outils; des comportements de recyclage ou d'extraction; des processus de dérangement après dépôt comme la conservation différenciée.

Les techniques de filtrage spatial, l'analyse de Fourier, l'analyse spectrale et l'égalisation des histogrammes servent de méthodes d'écran. Elles permettent la décomposition des palimpsestes de chaque classe d'artefact en composants subglobaux reflétant un domaine plus homogène de processus de formation. Les composants de nature similaire, pour des classes multiples, peuvent dès lors être analysés ensemble au moyen de techniques adaptées à leur *structure particulière*.

Le filtrage optimal est un compromis entre l'obtention d'une séparation nette des fréquences attestées par les données et une réduction des phénomènes d'interférence connus sous le nom de cercles polarisants. Il est préférable de filtrer dans le domaine Fourier plutôt que dans le domaine spatial; la première méthode permet un meilleur contrôle sur les effets des filtres dans des directions différentes de leur axe principal.

Les exigences du filtrage comprennent: des données comptées en grille; un espacement fin des points de grille que l'on peut obtenir par l'interpolation de valeurs; le remplissage de grilles aux contours irréguliers jusqu'à des dimensions rectangulaires, avec une bordure de cellules à compte zéro; et un cadrage des grilles de toutes formes au moyen d'une bordure de cellules à compte zéro avec une largeur proportionnelle à la largeur maximale des filtres employés afin d'éviter des erreurs dues au voisinage.

L'analyse des spectres permet l'investigation exploratoire d'un ensemble de données spatiales et fournit l'information nécessaire pour déterminer la largeur des filtres, la finesse des sections de découpage, l'asymétrie et l'orientation. Cette analyse de-

mande la stabilité de l'ensemble des données, l'absence de tendances à l'intérieur, ce que peut impliquer un filtrage de haut niveau.

La modification d'histogrammes permet de renforcer les contrastes entre différents phénomènes dans un ensemble de données. Ceci est obtenu en augmentant le rayon d'action "dynamique" des observations de manière différenciée et en changeant leur fréquence de distribution.

Six modèles de constatation archéologique sont présentés en même temps que les techniques et les séquences d'applications adéquates pour leur découpage. Les modèles varient selon que les surfaces de dépôt varient en échelle, selon que les surfaces se recouvrent partiellement; selon qu'un bruit de forte fréquence dû à des processus d'énumérations est présent; selon que les surfaces sont bien contrastées par leur densité en artefacts; selon que la netteté des bords de surface et selon que les spectres de pouvoir de bruits et signaux sont connus.

ZUSAMMENFASSUNG

Die gegenwärtigen Ansätze der räumlichen Analyse von Fundverteilungen innerhalb der Fundstellen stimmen nicht mit dem allgemeinen Aufbau der Organisation archäologischer Befunde überein. Sie unterstellen: (1) eine globale Organisation der Artefakten in Typen von Hinterlegungsweisen und Hinterlegungsarealen; (2) die Signifikanz der lokalen Artefaktdichten. Archäologische Befunde sind jedoch typische Palimpseste, wobei die lokale Artefaktdichte der individuellen Artefaktklassen Schwankungen unterworfen ist, die den verschiedensten Formationsprozessen zugeschrieben werden können, von denen jeder eine eigene unterschiedliche, sub-globale Verteilung aufweisen kann.

Sub-globale Unterschiede zwischen den Hinterlegungsarealen (z. B. Umfang, Form, Artefaktdichte, Zusammenstellung, interne Heterogenität, Schärfe der Abgrenzungen) können aus Variationen einer großen Anzahl Faktoren resultieren. Diese schließen ein: ob sich ein Areal in einer Zone abgesteckter Arbeitsplätze befindet; ob das Areal gereinigt oder erneut aufgesucht wurde; die Zeitdauer, die das Areal in Gebrauch war; ob die Aktivität den Gebrauch permanenter Einrichtungen erfordert; Jahreszeit des Aufsuchens des Areals; und eine Vielzahl von Prozessen nach der Hinterlegung der Artefakte. Sub-globale Unterschiede der Organisation der Hinterlegungsweisen (die Möglichkeit zu ihrer Definition durch die Struktur der Kovariation, Rangkorrelation, Assoziation, oder polythetische Assoziation unter Artefaktklassen) können ebenfalls durch viele Faktoren hervorgerufen werden. Diese schließen ein: die Existenz eines alternativen Werkzeugtypes mit dem gleichen Verwendungszweck; mögliche anderweitige Beschäftigungen während des Arbeitsprozesses; unterschiedliche Abfallbeseitigung von großen und kleinen Artefakten; unterschiedliche Abnutzungs- und Bruchraten; die Zeitdauer, die die Areale in Gebrauch waren; Vielzweckwerkzeuge; Rohstoffgewinnung und Recycling; Prozesse nach der Hinterlegung der Artefakte wie z. B. unterschiedliche Konservierungseigenschaften.

Die Techniken des räumlichen Filterns, die Fouriersche Analyse, die Spektralanalyse, die Gleichschaltung von Histogrammen werden als Sichtungsmethoden vorgestellt. Sie erlauben eine Entschlüsselung der Palimpseste jeder Artefaktklasse in

sub-globale Komponenten, die gleichartige Formationsprozesse reflektieren. Diejenigen Komponenten, die für mehrere Artefaktklassen Ähnlichkeiten aufweisen, können gemeinsam mit den Techniken analysiert werden, die ihrer jeweiligen Struktur entsprechen.

Optimales Filtern ist ein Kompromiß zwischen dem sauberen Trennen der Frequenzen, die den Daten eigen sind und dem Minimalisieren der Interferenzstrukturen. Das Filtern in der Fourier-Domäne ist dem Filtern in der räumlichen Domäne vorzuziehen, da man beim Erstgenannten eine größere Kontrolle über Nebenwirkungen des Filters bei Abweichungen von den Hauptachsen behält.

Zum Filtern benötigt man: Datenzählung in einem Koordinatensystem; kurze Abstände zwischen den Koordinatpunkten, die aus einer Interpolation der Originalwerte gezogen werden; das Ergänzen der unregelmäßigen Zellen zu rechtwinkligen Strukturen mit einer Umgrenzung von Null-Zellen; ungeachtet der Form der Struktur müssen am Rand Null-Zellen von einem Umfang liegen, der sich proportional zum maximalen Umfang des verwendeten Filters verhält.

Die Spektralanalyse erlaubt eine vorläufige Untersuchung des räumlichen Datensatzes und vermittelt nötige Informationen zur Gestaltung der Filter mit einem angemessenem Umfang, Randschärfe, Asymmetrie und Orientierung. Sie benötigt einen stationären Datensatz ohne irgendwie geartete Trends; für diese wäre ein "high pass filtering" nötig.

Die Modifizierung von Histogrammen erlaubt die Verstärkung des Kontrasts zwischen verschiedenen Phänomenen in einem räumlichen Datensatz. Dies erreicht man durch ein unterschiedliches Ausweiten des "dynamic range" der Beobachtungen über die Variationsbreite, wobei ihre Frequenzverteilung geändert wird.

Sechs Beispiele archäologischer Befunde werden mit den Techniken und der Rechenfolge der Anwendung der Techniken, die zur Entschlüsselung geeignet sind, angeführt. Die Beispiele unterscheiden sich darin, ob die Hinterlegungsareale von verschiedener Größe sind, ob sie sich räumlich überlappen, ob ein "Rauschen" durch mehrere Formationsprozesse verursacht wurde, ob die Areale verschiedene Artefaktdichten besitzen, ob die Stärkenspektra des Rauschens und des Signals bekannt sind und in der Schärfe der Abgrenzungen.