5. Dissecting Intrasite Artifact Palimpsests Using Fourier Methods

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In the past ten years, quantitative analysis and interpretation of spatial patterns of artifacts within archaeological sites have become increasingly more sophisticated. This is evidenced in two ways. First, there has been a rapid increase in the number of techniques available to the researcher for spatial analysis. These include methods first developed in mathematical ecology and geography, such as segregation analysis (Pielou 1964) and nearest neighbor analysis (Clark and Evans 1954). More recent introductions include methods derived from statistics, such as multiple response permutation procedures (Berry et al. 1980). Many of these several kinds of techniques have been reviewed elsewhere (Carr 1984).

The second line of advance is marked by the increasing number of models of spatial organizations of artifacts within sites and the formation and taphonomic processes responsible for those forms of organization (e.g., Binford 1976; Gifford 1978, 1980; Kent 1984; 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 meaning, or of geological, biological, or ecological meaning, to artifact patterns found by quantitative methods. The models are the product of many ethnoarchaeological and experimental studies of cultural and natural formation processes and disturbance processes that we have witnessed this past decade.

During the last five years, the beginning of a potentially fruitful coalescence of these two lines of inquiry has occurred. Some archaeologists (see Carr 1984, 1985a; Whallon 1984) and ethnoarchaeologists (Newell, this volume) have become more critical of the particular circumstances in which various spatial algorithms are applied. Their concern has been whether technical assumptions about the expectable form of organization of artifacts within a site contradict or are concordant with 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 logical consistence between technique and relevant data structure, those patterns found in an artifact distribution may be distorted representations of what behaviorally significant patterns are embedded in it. They also may reflect other, irrelevant sources of variation, such as geological post-depositional disturbances.

The concern for bringing concordance to spatial analysis is witnessed in the attempts of archaeologists, themselves, 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, 1985a) 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 form of this strategy is provided in the paper by Binford in this volume. Intrasite spatial artifact data are regrouped or "framed" in different potentially relevant ways, and then analyzed with the same technique. The several results are then examined for the differences between them and for potentially insightful ambiguities.

A second approach to preanalysis data modification is presented here. This approach involves searching for dimensions or *components* of the grid densities or locations of artifact classes that are relevant to the behavioral, geological, or other formation processes of interest, and then focusing analysis on those components. It also involves searching for *sectors* of a site that are homogeneous in the kinds of processes responsible for their artifact distributions, and thus are analyzable with a single method making a single set of assumptions about process and organization. One would then apply appropriate, potentially different methods to each sector of the site. In other words, *one can screen one's data for the dimensions that are relevant to and the observations that are homogeneous in regard to the processes of interest prior to fine-grained analysis, as in common statistical analytic design* (see Carr 1985b, 1985c; Clark 1982).

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's 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 post-depositional disturbance processes, as opposed to, say, documentation of the precise limits and positions of specific clusters as a result of fine-grained analysis.

In ethnoarchaeological studies, this general knowledge sometimes can be obtained by direct visual observation of site formation or by informant interviews. In archaeological studies, it can be obtained to some extent in several ways: (a) through historical documentation in the case of some historic sites, (b) by way of analogy in ethnographically or archaeologically well understood contexts, (c) by argumentation from principles on the effects of natural formation processes (in environmentally known contexts), or (d) by plotting the spatial distributions of various "indices" of formation processes (Schiffer 1983).

However, probably in most archaeological circumstances and in some ethnoarchaeological ones (e.g., Binford, Newell, this volume), these approaches are not possible or are inadequate by themselves. This has encouraged the researcher to proceed with fine-grained analysis on mathematically unscreened data as given. At best, this is done in order to try to obtain the information required for screening. Analysis then proceeds in an iterative 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, making appropriate screening and convergence in results less likely. 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 him/herself in what has been called "the methodological double bind" (Carr 1985b, 1985c; Christensen and Read 1977:177). 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 one 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 1985b). As one of its aspects, exploratory data analysis involves the application of relatively unassuming, data-robust techniques to explore and reveal the diversity of structures that comprise 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 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 ethnoarchaeological and archaeological 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 ubiquitously and densely distributed artifact classes.

Some 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. This implies an assumption 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 that repeat over the site at large, or areas of certain artifact composition, density, shape and/or size that repeat over the 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 post-depositional reorganization by some natural process. Likewise, the repeated composition, density, shape, and size of the areas occupied by such coarrangements is interpreted as representing one of those formation processes.

In contrast, a generally more appropriate assumption (see below) 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 in the behavioral domain can vary from one portion of a site to another, as a result of subglobal variation in behavioral, depositional, or disturbance processes. Newell's Iñupiaq ethnoarchaeological spatial analysis (this volume), in which meaningful patterning was not found by searching for global associations among artifact types but was found by searching for compositional similarities among local grid units, evidences such variable organization. Similarly, I (1985a) have documented locally variable organization within depositional sets at a French Magdalenian site. Variation of this kind has led Whallon (1984) to argue that searching for global types of depositional sets and depositional areas within archaeological 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 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 1975b), 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 their larger distribution, is taken to represent the effect of one kind of formation process, or multiple, spatially coarranged formation processes that can be tracked together as a meaningful group—what can 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 (see p. 245) would be that local densities of any artifact class may be meaningless summations 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 such class into component density distributions—one pertaining to each form of organization, reflecting one 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 such classes 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 ethnoarchaeology (e.g., Binford 1977, 1983:156-157, and this volume; Gnivecki, this volume) and in archaeology (see Carr 1984 for an inventory of many) have involved the global application of procedures to raw density or point location data. As a consequence, they assume global uniformity in the organization of artifact classes and/or the formation of local deposits by single or parallel processes. These analyses include studies using 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 of importance is their application globally and 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 that are 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 archaeologically 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 assumptions of global organization of artifacts and single or parallel-process formation of deposits that arise from global application of algorithms to raw spatial data 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 generally appear more appropriate.

The first assumption—global organization of artifacts—is usually inappropriate for two reasons. The first reason is that 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, and (b) the 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, if it is cleaned and reused, the length of time of use of the area, whether the activity involves the use of permanent facilities, the season of use of the area, and a long array of post-depositional disturbance processes (Carr 1984:125-132; 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 between 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. These are: 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 post-depositional disturbance processes that smear or sort artifacts, differential preservation, etc. (Ascher 1968; Binford 1976; Carr 1985a; McKellar 1973).

The second reason why the assumption of global artifact organization is generally unwarranted is that it implies that multiple archaeological formation and disturbance processes are *spatially correlated* and *coterminous* 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 processes of formation of deposits and post-depositional disturbance of them are assumed to have occurred, and to have occurred to the same relative degrees. For example, breakage rates, curation rates, degree of mining and recycling of artifacts, and rearrangement of artifacts by any natural or agricultural disturbance processes that have occurred, are all assumed to have operated jointly, in a parallel manner, over the site as a whole. Only in this way will 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.

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 or similar in scale, usually are responsible for local densities of artifact classes and their 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 somewhat. 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

Four spatial methods that are useful in fine-grained analytic stages for defining depositional sets or delimiting depositional areas approach solving the problem of inappropriately assuming global artifact organization. The first two have been applied in ethnoarchaeological settings; the second two in archaeological studies.

Whallon's (1984) Method of Unconstrained Clustering. This method for defining depositional areas accommodates 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 coherent depositional areas are above some one similarity threshold applied globally to all areas. Also, the scale of the observation units (grid cells or circular neighborhoods) among which compositional similarities are sought is held constant over all space and artifact classes.

Newell's (this volume) Method of Grid Unit Clustering. This approach is algorithmically different from unconstrained clustering (statistical rather than numeric taxonomic) but follows the same general strategy of grouping observation units. Its advantages and disadvantages are very similar to those of unconstrained clustering, except that a global threshold of statistical significance rather than similarity is used to determine compositionally similar observations.

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 significance 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 also is assumed.

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 falter if 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 some 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 basic units of analysis; they consequently improperly assume the integrity of raw local densities. One spatial method, however, approaches solving this problem. This method is factor analysis.

Factor Analysis. Factor analysis 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. The method was used to dissect palimpsests first at a regional scale in the classic study of the Mousterian by Binford and Binford (1966). It since has been applied at an intrasite scale in simulation (Schiffer 1976), archaeological (Kay 1980), and ethnoarchaeological (Binford, this volume) contexts. At the intrasite scale, each raw cell count of artifacts of a single class is envisioned as potentially the sum of counts attributable to separate dimensions, interpreted as different formation processes (different activities, in the simplest framework).

However, the method 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 global pooling of potentially contradictory patterns, as just mentioned.

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 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 method 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. In archaeological studies, the numerous means for identifying formation processes and the observations they have affected, as summarized by Schiffer (1983), in addition to ethnographic analogy, historical documentation, and other means mentioned previously, are equally important screening tools. In ethnoarchaeological studies, direct observations or informant interviews may often be important.

The following five steps summarize the general approach for screening artifact palimpsests in preparation for fine-grained analysis. Some methods for achieving the approach are described after this overview.

Step 1. Do not accept the data as necessarily meaningful as given. 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 and that have operated at different *scales* and in only *segments* of a site. For example, consider a scatter of multipurpose knives varying in density complexly over space. Its distribution 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 within it 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 be the smearing processes.

Step 2. Dissect the artifact 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-ranges* 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 and whether the research is ethnoarchaeological or archaeological). 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 the aforementioned sherds into several components having relevant or irrelevant scales of variation. First might be 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. Second might be several components of mid-scale density variation, each pertaining to a restricted range of spatial scales that correspond to the space requirements of one (possible) kind of activity, alone, and ideally documenting one (possible) kind of activity or depositional process (e.g., caching, dumping). Finally, one might extract 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 assign meaning to each density component in terms of the behavioral, agricultural, or other formation or disturbance processes likely responsible for it. This can be done using any of the sources of general knowledge enumerated at the beginning of this chapter. For example, in an ethnoarchaeological study, it can be done inductively by comparing the scale-range of variation of the component and its spatial distribution to the scales and distributions of formation processes observed or documented by interview to have generated the palimpsest. In both archaeological and ethnoarchaeological studies, it 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. Finally, assigning meaning to a density component can be done deductively by comparing the scale-range 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.

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 component representing small-scale density variations and that representing large-scale density variations might be deleted from the data. This would leave for fine-grained analysis those density components of mid-scale density variations 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 to the same *one* scale-range 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. By following this procedure, 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-range 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 belonging 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 within the distributions of which they fall. 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 the 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 (such as AVDISTGM, AVDISTLP1: Carr 1985a) 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 the 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

The primary techniques that are useful to ethnoarchaeologists and archaeologists for dissecting composite, global artifact density distributions during screening stages of analysis belong to the general class of methods known as digital spatial filtering and Fourier analysis. Both families of techniques have been applied, in ways analogous to those useful to archaeologists, and 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 techniques 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 United States Space Program in image digitization, transmission, and synthesis that has increased the level of sophistication and success in their application (Gonzalez and Winz 1977:2).

Both families of methods have been employed successfully in archaeological 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, 1982a; Scollar 1969a, 1969b, 1970; Linington 1969; Weymouth 1985). The methods have never been used to dissect artifact distributions, though this application has been proposed previously for intrasite distributions (Carr 1982b) and regional distributions collected in an "off-site archaeology" format (Ebert 1983). My (1982a) 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 techniques to be applied in ethnoarchaeology and 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 5.1). Broad-scale trends in density are envisioned as the sum of low frequency (long wavelength) waves running through the data. Local anomalies in density are considered the result of higher frequency (short wavelength) waves, superimposed on the lower frequencies. Low frequency varia-

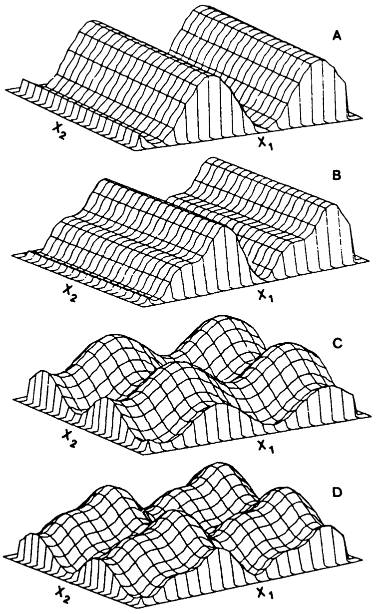

Figure 5.1 Artifact densities within a number of grid cells can be envisioned as the sums of amplitudes of multiple cosine and sine waves having different wavelengths, amplitudes, and phase angles, and oriented in two perpendicular directions. A. A single harmonic, in the X_1 direction, of two dimensional 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 1973:359.)

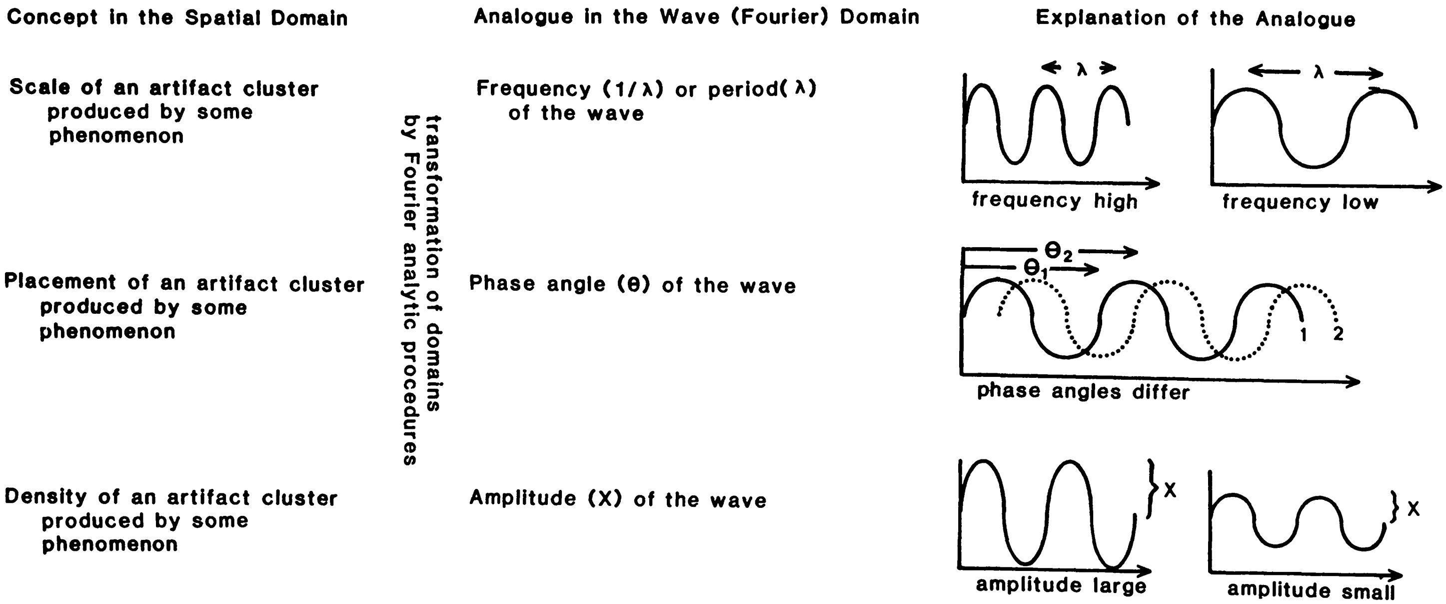

Figure 5.2 Fundamental Concepts in Fourier Analysis Applied to an Artifact Distribution

tion might represent the blurring effect of plowing on what once were discrete clusters of artifacts. Higher, mid-range frequency variations might represent the original clusters of artifacts, themselves. Very high frequency variation could reflect variation in artifact density within clusters or perhaps localized, unsystematic recovery of artifacts or localized post-depositional disturbance, these variations being distributed throughout the density surface. In this way, artifact density variations of different scale ranges within a density palimpsest, each attributable to a different, limited range of formation and disturbance processes, can be 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 respectively in terms of the phase angles and amplitudes of the cosine and sine waves having wavelengths that correspond to its scale-range (figure 5.2).

This mental transformation of data from the space to frequency domains 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 coefficients 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 ($2/\lambda$, $3/\lambda$, $4/\lambda$, . . . ; $n = 2, 3, 4$ . . .) 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 numer 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, themselves. 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 (here the artifact density surface) is simply envisioned as repeating itself infinitely over space. In other words, for a trace, its length is taken to be the period of an infinite function in the x direction in the spatial domain. For a surface, its length and width are taken to be the periods of an infinite function in the x and y directions in the spatial domain.

In this way, neither an artifact palimpsest nor its components need be periodic in structure to apply Fourier methods of dissection. A component need not, for example, be composed of equispaced clusters of similar density over a study area, and a palimpsest need not be composed of multiple components constrained in this manner. To achieve this freedom from the assumption of perodicity for components, however, each component must be represented by a set (band) of waves of multiple frequencies over a sufficient range, rather than a single wave or set of waves of one frequency. The parameter of band width thus is critical.

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 (formation and disturbance processes) that generated the palimpsest's density variations (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 palimpset's patterning that result from different formation processes. They are redescriptions of the outcomes of processes rather than models of the processes that generated those outcomes. (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 depends on the researcher's general understanding of his or her data (see below for how this problem is approached).

SPATIAL FILTERING

Dissection of 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, which might be expected 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 having 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 a specified spatial scale-range.

Spatial filters of a variety of mathematical forms, differing in the weights attached to the average 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 1958:358) or ringing (Scollar 1969a:81; Gonzalez and Winz 1977:140). 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 (as 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 the data values to be averaged in decreasing importance away from the central observation, according to some smooth function. Examples include the Butterworth, exponential, and normal filters (Gonzalez and Winz 1977:145-150; 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. Just one filter achieves this ideal: 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 1973:226) 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 controlled accurately along the principle axes of the gridded data, but are less easily managed in other directions. Distortions may accrue as a result (Scollar 1970:15).

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

$$F(u) = \frac{1}{N}\sum_{i=0}^{N-1} f(x_i)e^{-j2\pi u x_i/N}$$

$$= \frac{1}{N}\sum_{i=0}^{N-1} f(x_i)\left(\cos\left(\frac{2\pi u x_i}{N}\right) - j\sin\left(\frac{2\pi u x_i}{N}\right)\right) \qquad (2a)$$

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.,

$$F\ (u\ ) = R\ (u\ ) + I\ (u\ ); \qquad (2b)$$

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 equivalency 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

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

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 1970:10). 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 x 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 summed amplitudes in the sine array. For a single dimensional trace, this is analogous to the operation

$$S_n^2 = \alpha_n^2 + \beta_n^2 \qquad (4)$$

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

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

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 ith frequency (harmonic). Taking the square root of S_i^2 defines the amplitude of the ith frequency (harmonic).

The resulting $N \times N$ matrix of amplitudes of the *i*th harmonics in the x and y directions then is displayed as a surface. Sometimes, the low frequency origin is placed at the corner of the surface (Davis 1973:369; see figure 5.5). 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 1970:12). 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 by plowing or waterwashing 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—again simplifying to one dimension—as follows.

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

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

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 5.3. The coefficients of the filter are zero in all portions of the Fourier plane pertaining to frequencies to be obscured. They are one in all portions of the plane representing frequencies to be obtained. A low pass, ideal filter, in the two dimensional case for example, has the general form

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

where $D(u,v)$ is 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.

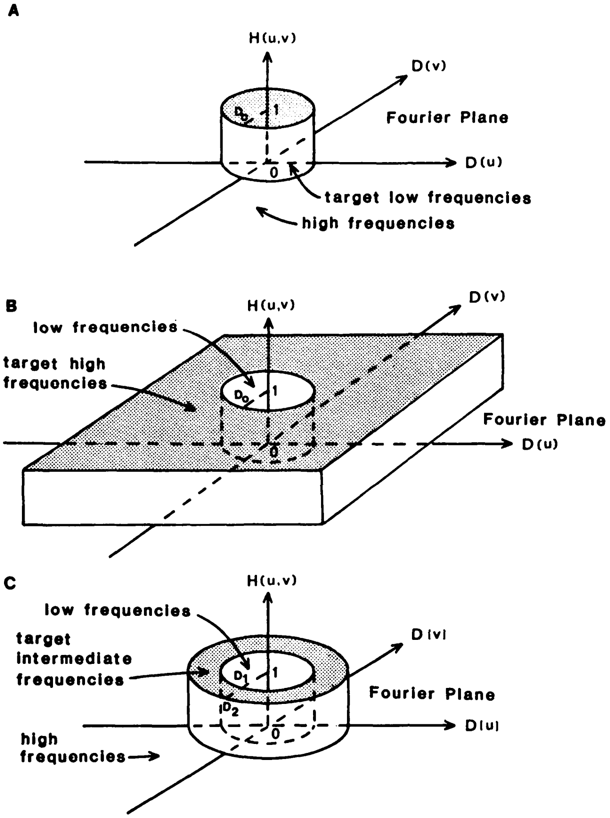

Figure 5.3 A. An ideal low pass filter in the Fourier domain; B. An ideal high pass filter in the Fourier domain; C. An ideal band pass filter in the Fourier domain.

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 5.4) is one such transfer function. In the two dimensional case, it has the general form

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

for a low pass filter, and

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

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

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

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.

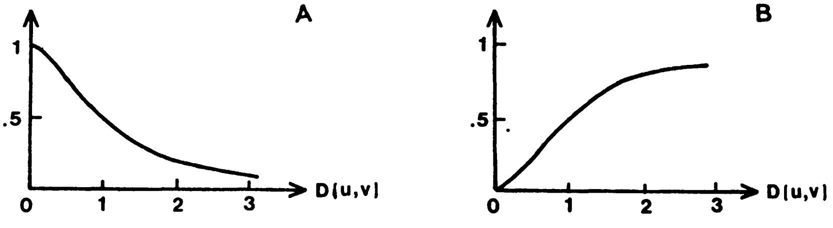

Figure 5.4 A Butterworth filter functions in the Fourier domain (radial cross section). A. Low pass filter; B. high pass filter.

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 1977:149-151, 163-166), and normal (Castleman 1979:194) 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.

Gridded Data. Filtering operations may be performed on a continuous surface, or a discretized representation of it constituting a sample of it (Gonzalez and Winz 1977:36-47). In the latter case, the observations must be arranged in a regular grid.

Excavation and surface survey data recorded as counts of items in grid cells are of the required format, but point-plotted artifact distributions are not. They 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.

The conversion from item point locations to gridded data can be achieved by laying a grid of points over the distribution of artifacts of the type of interest. Then the number of artifacts within a given radius of each established point is totaled. Items within the search radius conceivably may be weighted equally for their contributions to local densities, or in some inverse relation to their distances from the grid points (Davis 1973:310-317). The latter approach is more desirable in that it does not induce polarity reversals.

The length of the search radius must be chosen with care. It must be long enough to provide a semi-stable estimate of local artifact density, yet short enough to not excessively smooth out high frequency density variations that might be of interest. Usually the search radius should be several times smaller than the scale of the highest frequency density variation of interest. For example, when the goal is to extract density components of a scale equivalent to depositional areas of some one kind, the search radius for calculating local densities should be several times smaller than that scale.

Once the gridded data have been filtered, it is possible to convert the modified grid cell values of each of the *N* extracted density components back to *N* corresponding filtered point distributions. For any one component, each original item is assigned a filtered local density value. This is calculated using the filtered density values of adjacent grid points for that component, and any of a number of methods of interpolation (Yule and Kendall 1968:24; Davis 1973:310-322).

The local density value of each item, along with the item's location, may be used in various kinds of familiar point distribution analyses, but of subglobal scale. These can be achieved in either a weighted or unweighted fashion, depending on the analytic method. In the former, the filtered density values of each item for a given component is used as a weighting coefficient in the calculations of the method. Nearest neighbor analysis, Pielou's point-to-distance statistics, polythetic association, and the radius approach to delimiting clusters for example, each offer this potential. The specific means of calculation are beyond the scope of this paper. In the unweighted mode, local density values for items are used to define the simple presence or absence of the item from its location by applying some appropriate density threshold. The resulting filtered point distribution then can be analyzed with any of a number of point distribution techniques in standard ways.

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 bespeaks of 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 size) 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 the artifact distribution decreases and can be exacerbated by choice of an inappropriately large interpolative search radius. 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.

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. First, 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. Second, 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 lower is the Nyquist frequency.

When data are in the form of item point locations, the mesh of the grid to be used may be made as fine as desired during the operation of converting the artifact point locations to gridded local artifact densities. The mesh of the grid need not correspond to twice the search radius used in defining local densities; it may be smaller or larger. When the data are already in a gridded 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 5.5). This distortion of the amplitudes of lower frequencies is called aliasing error (Robinson 1970:23; Robinson et al. 1969; Gonzalez and Winz 1977:70-74). Its magnitude is determined by the combined amplitudes of the aliased frequencies.

Aliasing error occurs in all discrete data that represent a continuous surface. It is a product of sampling. No matter how accurate the values of individual grid points (the samples) are, it still will occur.

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, just as search radii should be kept small. 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.

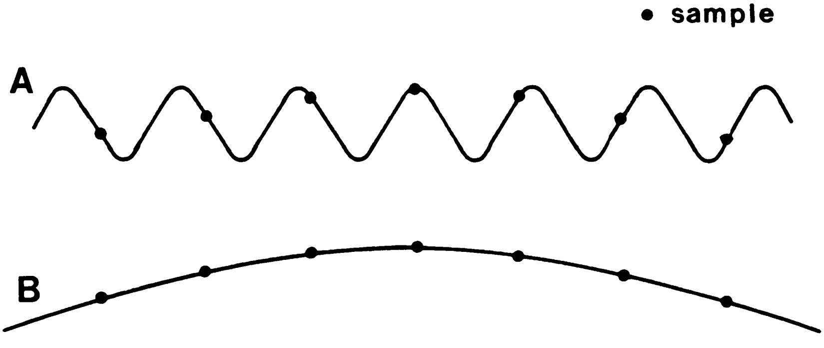

Figure 5.5 An example of aliasing error. A sinusoidal wave (A) is sampled at less than two samples per wavelength (less than the wave's Nyquist frequency), producing the aliased wave (B). (After Robinson 1970:24, fig. 4.)

Shape of the Grid. When filtering in the Fourier domain, it is necessary that the gridded representation of an artifact density distribution have 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 1977:146–148).

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 1977:61–63, 146–148, 189). When transforming a discretized distribution (gridded format) from the spatial to Fourier domains and filtering in the Fourier domain, it is assumed that the original data, their Fourier transform, and the filter function are periodic (see above). For a one dimensional trace of length A operated on by a filter function of width B, the assumed periodicity is

$$M > \mathrm{A} + B - 1 \tag{9}$$

If a trace of a length less than M is transformed into the wave domain and filtered, the high frequency waves of adjacent assumed periods of the transformed data (in adjacent assumed Fourier planes) will be included in the filtering operation and confuse it (Gonzalez and Winz 1977:61–63, 146–148, 189). To avoid this, a perimeter of zeros equal to one half the width of the filter should be appended to the original data.

SPECTRAL ANALYSIS

Appropriate decomposition of an artifact density distribution into bands of frequencies that are meaningful representations of the formation or disturbance processes of interest depends on: (a) the researcher having general knowledge of the scale-ranges and orientations of those processes and (b) the researcher designing filters concordantly. The cutoff values for each filter, its width, its sharpness of cutoff, and any asymmetry in it, must be concordant with the scale-range and orientation of the process of interest.

The general knowledge about formation processes that is required for building appropriate filters can be derived from ethnoarchaeological observations or informant interviews, historical documents, ethnographic analogy, or deductive argumentation by principle, as mentioned above. For example, in an archaeological study, one might use ethnographic information on the range of sizes of hide working areas in hunter-gatherer camps (O'Connell 1979; Carr 1977) to design filters useful in searching a palimpsest of scrapers for variability of spatial frequencies equivalent to the size-range of such areas.

In many instances, however, the approximate size of the phenomena and density anomalies/variations that are sought may not be known precisely beforehand. Or the researcher may have no knowledge whatsoever of the formation processes that generated the artifact distribution of study or of its structure. In these cases, the amplitudes of waves of each frequency within the density distribution can be examined to determine the scales and orientations of the phenomena of interest or of anomalies/variations potentially representing phenomena of interest. Filter parameters appropriate for isolating them then can be specified. The method allowing this to be achieved is called spectral analysis (Jenkins and Watts 1968; Brillinger 1975:ch. 5; Ontes and Enochson 1978:ch. 8).

In spectral analysis, the power of each frequency present within the data is calculated. For two-dimensional data, the powers of all possible combinations of frequency pairs in the x and y directions are determined. Theoretically, this can be achieved by filtering the data numerous times with band pass filters one frequency in width. Practically, however, it is done by taking the Fourier transform of the autocorrelation function (Jenkins and Watts 1968). A graph called the raw power spectrum, plotting power against frequency (for one dimensional data) or frequency pair (for two-dimensional data), then is made (figure 5.6). Usually the raw power spectrum is erradic, as a consequence of the finite sample dimensions of the surface from

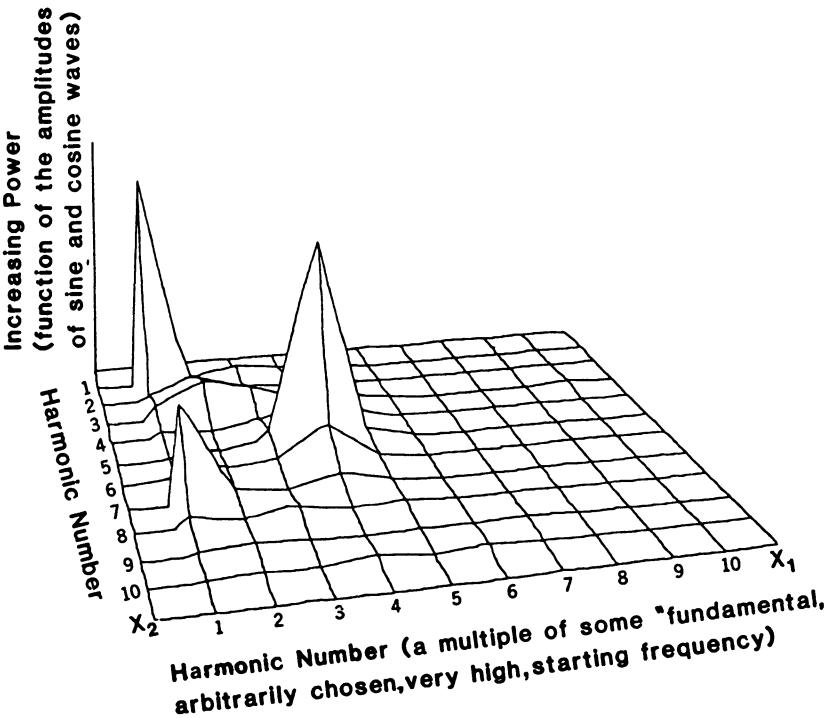

Figure 5.6 A Power Spectrum

which it is derived (Davis 1973:269). It must be smoothed with some kind of running weighted average (e.g., a Hanning filter) of small width ("window").

The smoothed power spectrum can serve to guide the researcher in designing filters with cutoff frequencies, widths, sharpness, and degree and orientation of asymmetry that are concordant with the phenomenon of interest when either of two circumstances are true: (a) the anomalies caused by each phenomenon of interest comprise a significant percentage, areally, of the original gridded surface; or (b) the anomalies, though infrequent, are of intense magnitude. If either condition is true, the frequencies in both the *x* and *y* directions that correspond to the scales of each phenomenon of interest will be represented by a maximum in the power spectrum. The scales and orientations of the phenomena therefore will be identifiable and the cutoff frequencies, widths, and orientations and degrees of asymmetry of filters that are appropriate for isolating each phenomenon will be designable. The degree of difference in the scales of the phenomena, corresponding to the amount of separation between peaks in the power spectrum, also can be estimated. This will permit the researcher to determine how sharp the cutoff thresholds of filters must be to segregate variability from each source, while at the same time keeping the filters as smooth as possible to discourage ringing.

As an example, suppose an artifact density palimpsest is composed of a number of approximately round clusters of waste flakes within a random, low density scatter of waste flakes. The landscape might represent flint knapping that was performed in some preferred locations (e.g., around hearths, under shade trees), plus occasionally at fortuitous loci. The smoothed power spectrum of this distribution would be trimodal. One mode would occur at moderate frequencies having wavelengths corresponding to the size range of clusters. The second mode would occur at very high frequencies having wavelengths corresponding to the small sizes of localized, random density anomalies within the low density scatter. Strong power in the very high frequencies also would be attributable to artifact density variation within clusters. Finally, the power spectrum would be strong in the very low frequencies as a result of the relatively ubiquitous nature of the random scatter. Thus, it would be possible from the peaks within the spectrum to determine the approximate scales of the two kinds of knapping areas of interest and the differences in their scales. Filters of appropriate parameters could be designed to isolate these different kinds of density variation.

When the phenomenon of interest (behavioral or otherwise) occupies only a small area of the original gridded surface and is not represented by anomalies of intense magnitude, it may not be apparent in the power spectrum. The peak in power associated with it may be emersed in the peak associated with noise of that scale. An example would be one or a few small activity areas having low artifact density within a random scatter of the same kind of artifacts. If this circumstance is suspected from an ambiguous power spectrum, nonstandard spectral procedures similar to those suggested by Frasier et al. (1966:1069–1073) can be used.

The procedures allow the number of anomalies, their locations, sizes, and orientations to be determined.

Successful application of spectral analysis to an artifact palimpsest requires that the palimpsest be stationary; i.e., that there are no broadscale 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. It is best if filtering is done in the Fourier domain. This will avoid a loss of data at the edge of the palimpsest equivalent to half the width of the high pass filter that would otherwise occur if filtering were done in the spatial domain.

Once spectral analysis of an artifact distribution has been completed and significant components of variation within it have been isolated through filtering, there remains the task of identifying the nature of the components—the formation processes responsible for each. This can be achieved by comparing the spatial distribution of each component to the distribution of various "indicators" of formation processes (Schiffer 1983), as discussed previously.

HISTOGRAM EQUALIZATION

Filtering operations and spectral analyses are one set of related techniques by which select aspects of the variability within an artifact palimpsest may 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 1977:114–136; Castleman 1979:68–83). Whereas the former achieve segregation and enhancement explicitly in accord with the scales of the components of variation within a palimpsest, the latter do so only indirectly. Methods of histogram modification operate on the magnitude of variation of *all* frequencies comprising *individual* observations rather than the magnitude of variations of *specific* frequencies over *all* observations. Nevertheless, they supplement filtering techniques in a very important way and can aid in the effectiveness of filtering techniques, as will be shown below.

An artifact density surface, or any digital image, is partially characterized by its frequency distribution, or histogram, of observation values falling in classes of various magnitude. Observations having values falling in different classes may represent different phenomena within the surface, perhaps also differing in their scale. For example, consider the distribution of waste flakes discussed above, composed of clusters with various high densities of flakes resulting from flint knapping in prefered locations, and a low density background scatter of flakes resulting from occasional knapping at fortuitous locations. The histogram for this arrangement might have a shape similar to a Poisson distribution with additional positive outliers. The Poisson portion of the curve would represent one phenomenon—the random, low density background scatter; the higher magnitude outliners would represent another phenomenon—the high density clusters.

The purpose of histogram modification techniques is to bring greater contrast between the values of observations representing different phenomena within a density surface when the contrast between them is low (e.g., as in an underexposed or overexposed photograph). This is achieved by expanding the dynamic range of the observations, but differentially over their range so that their histogram and image contrast are altered advantageously. Specifically, the range of observation values pertaining to different phenomena is expanded much, while the ranges of observation values comprising the same phenomena are expanded less. For instance, suppose the clusters of waste flakes in the example above were of several different kinds, but they differed only slightly in average artifact density from each other and from the lower density background scatter of flakes. A histogram of local artifact density observations for this arrangement would have little dynamic range, all observations falling within narrow limits. To bring greater contrast between the observations representing clusters of different kinds and between observations representing the clusters and their background, the dynamic range of observed local densities could be increased differentially. The number of histogram classes and the numeric range of observations falling between the outliers, or between them and the body of the Poisson portion of the histogram, could be greatly increased. The number of histogram classes and the numeric range of observations defining each of the outliers and the Poisson portion of the histogram might be increased only slightly.

The most effective approaches to histogram modification require a priori knowledge of the different phenomena within the surface, and their corresponding densities. A desirable form of histogram for the surface, increasing contrast between phenomena, is modeled, and the empirical distribution is transformed to fit the model. This approach is called direct histogram specification (Gonzalez and Winz 1977:127–136).

In archaeological and some ethnoarchaeological applications, where the density surface is unknown in nature and the goal is to define its structure, the a priori knowledge required for direct histogram specification is not available. In this case, the suboptimal technique called histogram equalization or histogram linearization must be used. Contrast between different phenomena is increased simply by equalizing the number of observations falling in each class of the histogram. For the above example, this transformation would increase the number of classes representing clusters of different kinds, the background scatter, and the antimodes between these, bringing greater contrast between clusters and between the clusters and the background scatter, in their densities. However, the contrast achieved would not be as great as that which might be obtained with a transformation designed specifically to augment the target classes discussed above. And of course, if two phenomena were well differentiated in a surface, histogram equalization would decrease the contrast between them. Histogram equalization must be used with discretion.

Histogram equalization is achieved by multiplying each observation by the cumulative frequency of all observations of lower value than it. 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 1977:125).

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 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 5.1). Some formation and disturbance processes that could be responsible for the structural attributes of the models are listed in table 5.2.

The linked models of archaeological organization, processes responsible for them, and appropriate techniques of analysis, comprise a series of primitive "entry models" as defined by Carr (1985b). These are useful in aiding the analyst in selecting techniques that concord with data structure.

It is assumed here, for illustrative purposes, that the goal of the 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 to 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 5.2.

Distribution 2. The overlap of despositional areas of various functions in this form of artifact distribution requires that density variation 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 undesirable 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 5.2) 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 to be used 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

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

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 $f(x_n,y_n)$; $\nabla f(x,\mathrm{y})$ 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

Table 5.1 Artifact Distributions Having Various Structural Attributes and the Techniques Appropriate to their Dissection

	Structure of Palimpsest											*Techniques to be Used, in Order of Operation*
Distributions of various structural attributes	*Depositional areas are of several kinds, varying in scale*[a]	*Depositional areas do not overlap spatially*	*Depositional areas overlap spatially*	*High frequency noise absent*	*High frequency noise present, due to*[b]	*Good contrast in artifact density between depositional areas*	*Low contrast in artifact density between depositional areas, due to*[b]	*Boundaries of depositional areas crisp*	*Boundaries of depositional areas blurred due to*[b]	*Power spectrum of noise and signal known*	*Power spectrum of noise and signal not known*	
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 equilization → spectral analysis → band pass filters*
5.	X	X	X	X		X		X	*Spectral analysis → low pass filter with gradient threshold → high pass filter → histogram equilization → 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 equilization → spectral analysis → band pass filters*

[a] 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.

[b] See table 5.2 for a list of causal formation processes.

Table 5.2 Some Processes Governing the Structure of Intrasite Archaeological Records

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

1. areally unsystematic, incompete 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 (1984).
    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 compromising 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, 1973a, 1973b, 1975a, 1975b, 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)

model). Sharp borders between areas of different average values within a surface constitute high frequency variation. If a standard, low pass filter 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 1977:138, 154–161). The appropriate threshold, *T*, must be obtained by trial and error. The neighborhood over which the 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 can 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 undesirable high frequency noise; and (c) low contrast in the densities of depositional areas of different kinds. The distribution has the same structure as 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 kind 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 5.1. 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 5.1 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 5.2). 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 comprising depositional areas, and attenuate very low to low frequencies that represent 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 1977:161–166). The two operations of low pass and high pass filtering can be reversed in order 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 suppressing the effects of high frequency noise (Gonzalez and Winz 1977:166), it is not used here for that purpose. Most high frequency noise is removed prior to this stage of analysis.

Finally, a second spectral analysis, to assess 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 operations described for Distribution 5 provide as effective dissection as can be achieved, given only 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 1979:199–207, 278–282).

In the future, as we gain experience in the form of power spectra of achaeological noise, we may be able to estimate the noise or 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 presently not feasible in the study of artifact density distributions.

Relation of the Screening Methods to Fine-Grained and Multivariate Analysis

It should be apparent, now, that the proposed methods are useful not simply in a screening capacity and that they allow one to do more than just explore the structure of an artifact density palimpsest. They additionally permit the analyst to dissect a palimpsest into components that pertain to a relatively homogeneous range of formation processes and that potentially are subglobal in nature. They also, in the process of screening, allow one to define the limits of depositional areas using single artifact classes. In this regard, they grade into methods of fine-grained analysis.

It also is possible to delimit depositional areas in a more multivariate fashion. The techniques may be applied 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. Some 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. Such a multivariate approach to defining depositional areas theoretically can have an advantage over a univariate one, to the extent that depositional processes manifest themselves as mutually reinforcing patterns in several artifact classes—a common circumstance.

At this time, however, the extended use of Fourier and filtering procedures and multivariate measures to finely delimit clusters does not seem promising. The success of such an approach depends on the degree to which the researcher can: (a) choose a multivariate measure that pertains to some meaningful process, and (b) select artifact classes that reflect the same process and have mutually reinforcing spatial patterns. The knowledge required to make such choices typically is not available prior to fine-grained analysis in archaeological studies, though it may be in some ethnoarchaeological ones. At this time, the application of unconstrained clustering (Whallon 1984) to components of single-class density distributions (and raw density distributions representing homogeneous sets of processes) seems more appropriate.

On Methodological Abuse

Fourier and filtering procedures, like all methods of exploratory data analysis, can be easily abused and produce misleading results (Carr 1985d). To be worthwhile, the approach requires the researcher to make a number of appropriate methodological choices, such as: filter width; filter cut-off value; sharpness of filter cut-off; degree of filter asymmetry, if any; whether histogram equalization should be applied; and, sometimes, the search radius used in transforming point distributions to gridded data. These choices determine the degree of concordance between technical assumptions about the structure of the artifact distribution and its actual structure. They determine the accuracy and meaningfulness of screening results.

To be optimal, each of these choices must be based on some general knowledge of the structure of the distribution to be dissected, or less optimally, on expectations about its probable structure. Such knowledge can be obtained from more standard sources, such as ethnoarchaeological observations, ethnographic analogy, and archaeological indices of site formation processes, or alternatively, from the results of spectral analysis and their relationship to the former, during the course of the screening process. While the level of information required to choose appropriate Fourier and filtering screening procedures is less than that required to choose appropriate post-screening, fine-grained analytic procedures, this aspect of preanalysis should not be slighted. It is the researcher's responsibility to *justify* the array of methods to be used for screening in relation to relevant aspects of the data's structure, just as fine-grained analytic methods must be justified (Carr 1985b).

In a similar manner, the researcher must justify whether Fourier and filtering procedures should be applied at all. Though the spatial distribution of an artifact class may be a composite of many processes and require dissection for fine-grained analysis, Fourier and filtering methods may be technically inappropriate for the task: the artifact distribution may be too sparce in density, relative to the scale of the phenomenon of interest, to allow accurate dissection.

Conclusion

In the last twenty years, the emphasis of analysis in American archaeology has shifted from the classification of behavioral and archaeological variability to the partitioning of it and the examining of relationships among dimensions of it (e.g., Binford 1965; Binford and Binford 1966; Willey and Sabloff 1980). This trend has been a natural part of a larger reorientation of the field toward theory building, requiring the statement of relationships among variables rather than objects. Only recently, however, has this basic change in philosophy of analysis been suggested for the study of intrasite artifact distributions (Whallon 1984; Gladfelter and Tiedemann 1985). To date, most quantitative intrasite spatial analyses have aimed at the summarization of global patterning through the definition of site-wide types of depositional areas and depositional sets rather than the isolation of diverse formation processes and the investigation and interpretation of their interrelationships in processual terms. It is hoped that the analytical framework and the techniques introduced in this paper, aimed at partitioning variability, provide one means for archaeologists to practice processual archaeology quantitatively at the intrasite level.

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