The Dimensions of Residential Segregation*

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Abstract

This paper conceives of residential segregation as a multidimensional phenomenon varying along five distinct axes of measurement: evenness, exposure, concentration, centralization, and clustering. Twenty indices of segregation are surveyed and related conceptually to one of the five dimensions. Using data from a large set of U.S. metropolitan areas, the indices are intercorrelated and factor analyzed. Orthogonal and oblique rotations produce pattern matrices consistent with the postulated dimensional structure. Based on the factor analyses and other information, one index was chosen to represent each of the five dimensions, and these selections were confirmed with a principal components analysis. The paper recommends adopting these indices as standard indicators in future studies of segregation.

After decades of lively debate on the nature of residential segregation and how to measure it, Duncan and Duncan (1955a) ushered in a long era of peace by demonstrating that there was little information in any of the prevailing indices not contained in the index of dissimilarity and the minority proportion, a conclusion subsequently reaffirmed by Taeuber and Taeuber (1965). For more than 20 years afterwards, the dissimilarity index served as the standard segregation measure, routinely employed to measure spatial segregation between social groups.

This *Pax Duncana* came to an abrupt end in 1976, with the publication of a critique of the dissimilarity index by Cortese, Falk, and Cohen (1976). Ironically, this paper did not have a serious *direct* impact on the measurement of residential segregation. Practitioners did not take its criticisms too seriously (Massey 1978; Taeuber & Taeuber 1976), and the adjustments it proposed were never really adopted. Indirectly, however, the

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Cortese critique had a profound effect on segregation studies. After years of quiescence it sparked new thought on the issue of measurement and rekindled the fires of the old debate. Since 1976, a torrent of papers has considered a variety of definitions of segregation, proposed a host of new measures, and rediscovered several old indices. All the while the debate on the relative merits of the dissimilarity index has continued (Cortese, Falk & Cohen 1976, 1978; Falk, Cortese & Cohen 1978; Jakubs 1977, 1979, 1981; James & Taeuber 1985; Massey 1978, 1981; Morgan 1982, 1983a; Morgan & Norbury 1981; O'Connell 1977; Reiner 1972; Sakoda 1981; Steinnes 1977; Taeuber & Taeuber 1976; Van Valey & Roof 1976; White 1986; Winship 1977, 1978; Zelder 1970, 1977).

The field of segregation studies is presently in a state of theoretical and methodological disarray, with different researchers advocating different definitions and measures of segregation. There is little agreement about which measure is best to use and under what circumstances. Studies using inconsistent segregation measures are multiplying and the comparability of research has suffered. While several papers have made attempts to evaluate the various indices against one another, none has made a systematic attempt to include all candidates, and none has considered their empirical behavior over a large sample of cities. James and Taeuber (1985) consider only five measures and evaluate them using a sample of schools, not cities. White (1986) examines a larger array of indices, but still excludes many promising candidates, and he examines their behavior across only 21 SMSAs.

In this paper we attempt to bring some order to the field by undertaking a systematic methodological evaluation of 20 potential measures of residential segregation identified in a survey of the research literature. We classify these indices conceptually and explain how each corresponds to one of five basic dimensions of spatial variation. The indices are computed to measure the segregation of three minority groups from non-Hispanic whites in 60 metropolitan areas, giving 180 independent measures for each index. The indices are intercorrelated and their empirical behavior is examined using factor analysis. We find five axes that correspond to the dimensions of spatial variation we have identified. Based on this conceptual review and empirical analysis, we select a single best indicator for each dimension, and conduct a final factor analysis to confirm that the five indices provide a comprehensive, interpretable picture of residential segregation in cities.

The Dimensions of Residential Segregation

At a general level, residential segregation is the degree to which two or more groups live separately from one another, in different parts of the urban environment. This general understanding masks considerable underlying complexity, however, for groups may live apart from one another and be "segregated" in a variety of ways. Minority members may be distributed so that they are overrepresented in some areas and underrepresented in others, varying on the characteristic of *evenness*. They may be distributed so that their *exposure* to majority members is limited by virtue of rarely sharing a neighborhood with them. They may be spatially *concentrated* within a very small area, occupying less physical space than majority members. They may be spatially *centralized*, congregating around the urban core, and occupying a more central location than the majority. Finally, areas of minority settlement may be tightly *clustered* to form one large contiguous enclave, or be scattered widely around the urban area.

Over the years, researchers have proposed a variety of indices to measure each of these distributional characteristics, and have often argued for the adoption of one index to the exclusion of others. We argue that this sort of argument is fruitless; our survey of the research literature leads us to conclude that segregation should be measured not with one index, but with several. Specifically, we hold that residential segregation is a global construct that subsumes five underlying dimensions of measurement, each corresponding to a different aspect of spatial variation: evenness, exposure, concentration, centralization, and clustering. Each of these distributional characteristics has different social and behavioral implications and each represents a different facet of what researchers have called "segregation." A group that is highly centralized, spatially concentrated, unevenly distributed, tightly clustered, and minimally exposed to majority members is said to be residentially "segregated." Although the five dimensions overlap empirically—a group segregated on one dimension also tends to be segregated on another—they are conceptually distinct. Researchers interpret the constellation of outcomes on the five spatial dimensions as segregation, but this interpretation is an abstraction of empirical reality, not reality itself. Groups may be separated from one another in many different ways, corresponding to various combinations of the five distributional characteristics.

In the remainder of this section, we survey the methodological literature to consider indices associated with each of the five dimensions we have identified. We define each dimension conceptually and illustrate its logical independence from the others. We link each index to its appropriate dimension of spatial variation and describe how each captures the distributional trait in question.

1. EVENNESS

Evenness refers to the differential distribution of two social groups among areal units in a city. A minority group is said to be segregated if it is unevenly distributed over areal units (Blau 1977). Evenness is not measured in any absolute sense, but is scaled relative to some other group.

Evenness is maximized and segregation minimized when all units have the same relative number of minority and majority members as the city as a whole. Conversely, evenness is minimized, and segregation maximized, when no minority and majority members share a common area of residence.

The most widely used measure of residential evenness is, of course, the index of dissimilarity. It measures departure from evenness by taking the weighted mean absolute deviation of every unit's minority proportion from the city's minority proportion, and expressing this quantity as a proportion of its theoretical maximum (James & Taeuber 1985). This index varies between 0 and 1.0, and, conceptually, it represents the proportion of minority members that would have to change their area of residence to achieve an even distribution, with the number of minority members moving being expressed as a proportion of the number that would have to move under conditions of maximum segregation (Jakubs 1977, 1981). One formula for the dissimilarity index is:

$$D = \sum_{i=1}^{n} [t_i|p_i - P|/2TP(1-P)] \tag{1}$$

where t_i and p_i are the total population and minority proportion of areal unit i, and T and P are the population size and minority proportion of the whole city, which is subdivided into n areal units. Taeuber and Taeuber (1965) and Lieberson (1981) provide simple computational examples to illustrate the use of the index as a measure of segregation.

The dissimilarity index can be derived from the Lorenz curve, which plots the cumulative proportion of minority group X against the cumulative proportion of majority group Y across areal units, which are ordered from smallest to largest minority proportion. D represents the maximum vertical distance between this curve and the diagonal line of evenness. Among its properties, the dissimilarity index is strongly affected by random departures from evenness when the number of minority members is small compared to the number of areal units (Cortese, Falk & Cohen 1976; Massey 1978; Winship, 1977, 1978) and it is insensitive to the redistribution of minority members among areal units with minority proportions above or below the city's minority proportion (James & Taeuber 1985; White 1986). Only transfers of minority members from areas where they are overrepresented (above the city's minority proportion) to areas where they are underrepresented (below the minority proportion) affect segregation as measured by the dissimilarity index. The index thus fails what is known as the "transfers principle" (James & Taeuber 1985; White 1986; Winship 1978). Examples of the index's relationship to the Lorenz curve are given in Duncan and Duncan (1955a) and James and Taeuber (1985).

A second measure of evenness is closely related to the index of dissimilarity. The Gini coefficient is the mean absolute difference between minority proportions weighted across all pairs of areal units, expressed as a proportion of the maximum weighted mean difference, which occurs when minority and majority members share no area in common. Like the index of dissimilarity, it varies between 0 and 1.0 and may be derived from the Lorenz curve. It represents the area between the Lorenz curve and the diagonal of evenness, expressed as a proportion of the total area under the diagonal. However, unlike the dissimilarity index, it is sensitive to all transfers of minority and majority members between areas, not just those between areas of over- and underrepresentation (Allison 1978; Schwartz & Winship 1979). These properties are illustrated by Taeuber and Taeuber (1965) using simple data, and Duncan and Duncan (1955a) and James and Taeuber (1965) make similar points using the Lorenz curve. The formula for the Gini index is:

$$G = \sum_{i=1}^{n} \sum_{j=1}^{n} [t_i t_j |p_i - p_j| / 2T^2 P(1-P)] \tag{2}$$

A third measure of residential unevenness has recently attracted the interest of sociologists (James & Taeuber 1985; White 1986). Proposed originally by Theil (1972; Theil & Finizza 1971) as a measure of school segregation, the entropy index (also called the information index) measures departure from evenness by assessing each unit's departure from the racial or ethnic "entropy" of the whole city. A city's entropy is the extent of its racial or ethnic diversity, and with two groups reaches a maximum with a 50-50 division. It is defined by the following formulas. The city's entropy is given by:

$$E = (P)\log[1/P] + (1-P)\log[1/(1-P)] \tag{3}$$

and a unit's entropy is analogously:

$$E_i = (p_i)\log[1/p_i] + (1-p_i)\log[1/(1-p_i)] \tag{4}$$

The entropy index itself is the weighted average deviation of each unit's entropy from the city-wide entropy, expressed as a fraction of the city's total entropy:

$$H = \sum_{i=1}^{n} [t_i(E - E_i)/ET] \tag{5}$$

Like the Gini coefficient, the entropy index varies from 0 (when all areas have the same composition) to 1.0 (when all areas contain one group only), and it satisfies the transfers principle. However, unlike the other indices, it fails on the criterion of "compositional invariance" since its value is partly determined by P, the relative number of minority members (James & Taeuber 1985). White (1986), however, maintains that H approximates this criterion in practice. Both White and James and Taeuber give empirical examples of the index's performance, and Allison (1978) gives a hypothetical illustration of its properties.

Finally, one last index of residential evenness has only recently been applied to study segregation, although sociologists have been aware of its application to inequality for some time (Allison 1978; Schwartz & Winship 1979). The Atkinson (1970) index resembles the Gini coefficient in that it satisfies the transfers principle and is compositionally invariant. But unlike the Gini index, the Atkinson measure lets the researcher decide how heavily to weight areal units at different points on the Lorenz curve (over or under the city-wide minority proportion). To compute the Atkinson measure, the researcher must explicitly decide whether the segregation index should take greater account of differences among areas of over- or under-representation (James and Taeuber 1985). The formula for the Atkinson index is[1]:

$$A = 1 - [P/(1-P)] \left| \sum_{i=1}^{n} [(1-p_i)^{1-b} p_i^{b} t_i / PT] \right|^{1/(1-b)} \qquad (6)$$

where b is a shape parameter that determines how to weight the increments to segregation contributed by different portions of the Lorenz curve. For $0<b<.5$, areal units where $p_i<P$ contribute more to segregation; while for $.5<b<1.0$, units where $p_i>P$ give larger increments to segregation. When $b=.5$, units of minority over- and underrepresentation contribute equally in computing the segregation index. With values of b specified between 0 and 1.0, the Atkinson index also varies within this range. James and Taeuber (1985) provide a good illustration of the behavior of the Atkinson index using Lorenz curves, and White (1986) gives some empirical examples.

In their article, James and Taeuber evaluate all four of the above measures of unevenness against four criteria derived from an earlier study of inequality indices (Schwartz & Winship 1979). These criteria include the principles of transfers and compositional invariance mentioned before, plus two others: size invariance, which states that a segregation measure should be unchanged when the number of people in each group is multiplied by a constant; and organizational equivalence, which holds that an index should be unaffected by combining units with the same minority composition.

The only indices that simultaneously satisfy all four criteria are the Gini coefficient and the Atkinson index, with James and Taeuber preferring the latter for empirical reasons. In concrete applications, G and A will produce the same rank ordering of segregation only if the underlying Lorenz curves do not cross. When they do cross, the rank depends on the weight attached to the segments of the curve above and below the minority proportion. Since curve crossings are relatively frequent, at least in the authors' school district data, James and Taeuber prefer the Atkinson index because it forces the researcher to confront the problem directly, rather than defaulting to the fixed weighting scheme of the Gini index.

The problem with the Atkinson index is that it destroys comparability with a vast segregation literature based on the dissimilarity index; and even if the Atkinson index were used henceforth, the future comparability of results would suffer if different researchers selected different values of the shape parameter b. Moreover, curve crossings and differences in the sensitivity to transfers may indeed produce inconsistent segregation rankings between G, D, H, and A, but the absolute size of the differences between the indices may be relatively small, so that no matter which index were used, the same pattern of results would be found. If this were the case, a strong argument could be made for retaining D as the index of unevenness in most circumstances, in order to preserve historical continuity in the field and to facilitate future comparison across studies.

2. EXPOSURE

Residential exposure refers to the degree of potential contact, or the possibility of interaction, between minority and majority group members within geographic areas of a city. Indices of exposure measure the extent to which minority and majority members physically confront one another by virtue of sharing a common residential area. For any city, the degree of minority exposure to the majority may be conceptualized as the likelihood of their sharing the same neighborhood. Rather than measuring segregation as departure from some abstract ideal of "evenness," exposure indices attempt to measure the *experience* of segregation as felt by the average minority or majority member.

Although indices of exposure and evenness tend to be correlated empirically, they are conceptually distinct because the former depend on the relative size of the groups being compared, while the latter do not. Minority members can be evenly distributed among residential areas of a city, but at the same time experience little exposure to majority members if they are a relatively large proportion of the city, a point well-elaborated by Blau (1977). Conversely, if they are a very small proportion, minority members will tend to experience high levels of exposure to the majority no matter what the pattern of evenness. Exposure indices take explicit account of the relative size of minority and majority groups in determining the degree of residential segregation between them.

The importance of exposure as a dimension of segregation was noted early by Bell (1954), who introduced several indices to measure it. However, sociologists at the time were searching for a compositionally invariant segregation index, so that the degree of "segregation" could legitimately be contrasted between cities. With the establishment of the *Pax Duncana* in 1955, sentiment coalesced around the dissimilarity index and Bell's measures were largely forgotten until they were reintroduced to the field by Lieberson (1981) and subsequently employed in a series of recent investigations (Lieberson 1980; Lieberson & Carter 1982a, 1982b; Massey & Bitterman 1985; Massey & Mullan 1984). Blau (1977) has also given exposure a great deal of theoretical attention as a salient dimension of social life generally.

There are two basic measures of residential exposure. The first measures the extent to which members of minority group X are exposed to members of majority group Y, and it is usually called the interaction index. It is the minority-weighted average of each spatial unit's majority proportion, and has been denoted ${}_xP^*{}_y$ by Lieberson:

$${}_xP^*{}_y = \sum_{i=1}^{n} [x_i/X][y_i/t_i] \qquad (7)$$

where x_i, y_i, and t_i are the numbers of X members, Y members, and the total population of unit *i*, respectively, and X represents the number of X members city-wide. The converse of the interaction index is the isolation index, which measures the extent to which minority members are exposed only to one other, rather than to majority members, and it is computed as the minority-weighted average of each unit's minority proportion:

$${}_xP^*{}_x = \sum_{i=1}^{n} [x_i/X][x_i/t_i] \qquad (8)$$

Both of these indices vary between 0 and 1.0, and they may be interpreted as the probability that a randomly drawn X-member shares an area with a member of Y (in the case of ${}_xP^*{}_y$), or the probability that he or she shares a unit with another X member (in the case of ${}_xP^*{}_x$). In the two group case, ${}_xP^*{}_y + {}_xP^*{}_x = 1.0$, but if more than two groups are present (e.g. if there are minority groups X1, X2, and X3 with majority group Y) then only the sum of all intergroup probabilities plus the isolation index will equal 1.0 (e.g., ${}_{x1}P^{*x1} + {}_{x1}P^*{}_{x2} + {}_{x1}P^*{}_{x3} + {}_{x1}P^*{}_y = 1.0$). Hypothetical examples illustrating the computation of P* indices and their relationship to the dissimilarity index are given in Lieberson (1981), and empirical examples are presented in Lieberson and Carter (1982a).

The compositional dependence of the interaction index means that it is asymmetric, so that in general ${}_xP^*{}_y$ does not equal ${}_yP^*{}_x$. Only when two groups comprise the same proportion of the population will the indices equal one another. P^* indices can be adjusted, however, to control for the effect of population composition and so remove the asymmetry (Bell 1954; Coleman, Kelly & Moore 1975). When this task is undertaken for the isolation index, we obtain a measure that is precisely equivalent to the correlation ratio, or Eta^2 (White 1986):

$$V = Eta^2 = [({}_xP^*_x - P)/(1 - P)] \tag{9}$$

The correlation ratio has also been suggested as a potential measure of segregation in its own right. Stearns and Logan (1986) go so far as to suggest that it represents an independent dimension of segregation. James and Taeuber, however, consider it a measure of unevenness. Here, because of its straightforward relationship to the isolation index, and because of the fact that it has no geometric relationship to the Lorenz curve (Duncan & Duncan 1955a), we call it a measure of exposure and evaluate it empirically to see how it relates to the underlying dimensional structure of residential segregation. Stearns and Logan (1986) illustrate the computation and behavior of the correlation ratio with simulated data.

3. CONCENTRATION

Concentration refers to relative amount of physical space occupied by a minority group in the urban environment. Groups that occupy a small share of the total area in a city are said to be residentially concentrated. For example, suppose two cities have the same minority proportion and an equivalent degree of residential evenness, but in one city minority areas are few in number and small in area, while in the other they are numerous and large. Most observers would probably consider the former city to be more "segregated" than the latter. This observation stems from the fact that residential discrimination has traditionally restricted minorities to a small number of neighborhoods that together comprise a small share of the urban environment (Hirsch 1983; Kain & Quigley 1975; Massey & Mullan 1984; Spear 1967).

Relatively few indices of spatial concentration have been proposed in the research literature. The only measure we could identify was one proposed originally by Hoover (1941) and later adapted by Duncan, Cuzzort, and Duncan (1961), called delta:

$$DEL = 1/2 \sum_{i=1}^{n} |[x_i/X - a_i/A]| \tag{10}$$

where x_i and X are defined as before, and a_i equals the land area of unit i and A is the total land area in the city. Delta is a specific application of the more general index of dissimilarity. It computes the proportion of X members residing in areal units with above average density of X members. It is interpreted as the share of minority members that would have to shift units to achieve a uniform density of minority members over all units. Duncan, Cuzzort, and Duncan (1961) provide a good empirical example of the index's use to measure population concentration at several levels of aggregation.

Although delta is the only index of concentration we uncovered in the methodological literature, other measures may be defined to create additional variation along this dimension. A very simple measure of spatial concentration is derived by computing the total area inhabited by a group, and comparing this figure with the minimum and maximum possible areas that could be inhabited by that group in a given city, as shown by the following formula:

$$ACO = 1 - \{[\sum_{i=1}^{n} (x_i a_i / X) - \sum_{i=1}^{n_1} (t_i a_i / T_1)] / [\sum_{i=n_2}^{n} (t_i a_i / T_2) - \sum_{i=1}^{n_1} (t_i a_i / T_1)]\} \quad (11)$$

where the areal units are ordered by geographic size from smallest to largest, a_i is the land area of unit i, and the two numbers n_1 and n_2 refer to different points in the rank ordering of areal units from smallest to largest: n_1 is rank of the tract where the cumulative total population of areal units equals the total minority population of the city, summing from the smallest unit up; and n_2 is the rank of the tract where the cumulative total population of units equals the minority population totalling from the largest unit down. T_1 equals the total population of tracts from 1 to n_1, and T_2 equals the total population of tracts from n_2 to n. As before, t_i refers to the total population of area i and X is the number of group X members in the city.

The first quantity in the numerator is the average land area of geographic units inhabited by group X members, while the second quantity is the average land area they would inhabit under conditions of maximum spatial concentration (if all lived in the smallest areal units). In the denominator, the first quantity is the average land area that would be inhabited under conditions of minimum concentration (if all minority members lived in the largest areal units) and from this is subtracted the area inhabited under maximum concentration. The index thus varies from 0 to 1.0, where a score of 1.0 means that a group has achieved the maximum spatial concentration possible (all X members live in the smallest areal units), and a score of 0 indicates the maximum deconcentration possible (all X members live in the largest areal units).

This index measures the geographic concentration of minority group X in an absolute sense, regardless of how majority group Y is distributed. However, processes of segregation operate differentially on minority and majority groups, and it is often desirable to take account of this fact directly by calculating a relative concentration index:

$$RCO = \{[\sum_{i=1}^{n} (x_i a_i/X)]/[\sum_{i=1}^{n} y_i a_i/Y)] - 1\}/\{[\sum_{i=1}^{n_1} (t_i a_i/T_1)]/[\sum_{i=n_2}^{n} (t_i a_i/T_2)] - 1\} \quad (12)$$

where geographic units are again ordered from smallest to largest in areal size, and n_1, n_2, T_1, and T_2 are defined as before. This index takes the ratio of X members' to Y members' concentration and compares it with the maximum possible ratio that would be obtained if X were maximally concentrated and Y minimally concentrated, standardizing the quotient so that the index varies between -1.0 and 1.0. A score of 0 means that the two groups are equally concentrated in urban space. A score of -1.0 means that Y's concentration exceeds X's to the maximum extent possible, and a score of 1.0 means the converse. The relative concentration index measures the share of urban space occupied by group X compared to group Y.

4. CENTRALIZATION

A fourth dimension of segregation is related to concentration, but is conceptually distinct. Centralization is the degree to which a group is spatially located near the center of an urban area. Groups that settle near center city areas usually tend to be spatially concentrated as well, but this need not be so. A poor ethnic group may well inhabit a small share of the urban environment and yet be located in a suburban or peripheral area, as in many cities of the developing world (Ginsburg 1965; London & Flanagan 1976; Schnore 1965) as well as in some urban areas of the southwestern United States (Moore 1976). In the United States, however, centralization is usually a component of segregation because discrimination confines minorities to declining central city areas (Farley et al. 1978; U.S. National Advisory Commission on Civil Disorders 1969). In most industrialized countries, racial and ethnic minorities concentrate in center city areas, inhabiting the oldest and most substandard housing (Massey 1985), even though urban renewal and recent "gentrification" have mitigated this tendency somewhat (Lee, Spain & Umberson 1985; White 1980).

The degree of centralization has long been a concern of sociologists, and several indices have been proposed. Probably the simplest and most widely reported statistic is simply the number of people in a given group that live within the bounds of the central city, expressed as a proportion of the total number in the entire metropolitan area:

$$PCC = X_{cc}/X \tag{13}$$

where X_{cc} is the number of X members living within the boundaries of the central city.

While simple, this index has several drawbacks. The boundaries of a central city are political rather than natural creations. Central cities that were founded early have long been ringed by incorporated suburbs, while many newer cities continue to expand through incorporation. The relative size of the central city is therefore largely a function of the era in which the city developed, and does not indicate the extent of a group's centralization in any real sense. Moreover, it takes no account of the actual distribution of a group in space.

Because of its ease of computation and minimal data requirements, *PCC* is frequently computed and presented (Grebler, Moore & Guzman 1970; Massey 1979). However, recognizing its limitations, social scientists have developed other measures of centralization that make fuller use of spatial data. For example, Duncan and Duncan (1955b) have proposed a relative centralization index defined by the following formula:

$$RCE = \left(\sum_{i=1}^{n} X_{i-1}Y_i\right) - \left(\sum_{i=1}^{n} X_iY_{i-1}\right) \tag{14}$$

where the n areal units are ordered by increasing distance from the central business district, and X_i and Y_i are the respective cumulative proportions of X's and Y's population in tract i. This index varies between -1.0 and $+1.0$, with positive values indicating that X members are located closer to the city center than are members of group Y, and negative values indicating that group X members are distributed farther from the city center. When the index is 0, the two groups have the same spatial distribution around the central business district. The index may be interpreted as the relative share of group X members that would have to change their area of residence to match the degree of centralization of Y members. Duncan (1957), Duncan and Duncan (1955a), and Glaster (1984) give empirical examples illustrating the measure's properties.

RCE measures the extent of group X's centralization relative to group Y's. An analogous measure giving a group's absolute distribution in urban space can also be specified. Such an absolute centralization index measures a group's spatial distribution compared to the distribution of land area around the city center:

$$ACE = \left(\sum_{i=1}^{n} X_{i-1}A_i\right) - \left(\sum_{i=1}^{n} X_i A_{i-1}\right) \tag{15}$$

where the areal units are ordered as before and A_i refers to the cumulative proportion of land area through unit i. This index also varies between plus and minus one. Positive values likewise indicate a tendency for group X members to reside close to the city center, while negative values indicate a tendency to live in outlying areas. A score of 0 means that a group has a uniform distribution throughout the metropolitan area. The index therefore gives the proportion of X members required to change residence to achieve a uniform distribution of population around the central business district. Researchers have not yet made use of this variant of Duncan's centralization index, but conceptually it is quite like the concentration index employed by Duncan, Cuzzort, and Duncan (1961).

5. CLUSTERING

The last dimension of residential segregation is the degree of spatial clustering exhibited by a minority group—that is, the extent to which areal units inhabited by minority members adjoin one another, or cluster, in space. White (1983) has termed this the "checkerboard problem," as opposed to the "grid problem," which has traditionally occupied sociologists. While prior dimensions have dealt with the distribution of minority and majority members among areal units, or with the distribution of minority areas relative to some fixed central point, clustering concerns the distribution of minority areas with respect to each other. A high degree of clustering implies a residential structure where minority areas are contiguous and closely packed, creating a single large ethnic or racial enclave. A low level of clustering means that minority areal units are widely scattered around the urban environment, like black squares on a checkerboard.

While residential clustering is often associated empirically with spatial concentration and centralization, at a conceptual level it is distinct. For example, suppose we have two urban areas with the same number of minority members, who comprise the same proportion of the total population. In each place, no minority member shares a common residential area with a majority member, all minority areas are located the same average distance from the central business district, and all areas are of the same geographic size. In this case, both urban areas would display identical measures of evenness, exposure, concentration, and centralization. However, if all minority areas in one of the urban areas were contiguous to one another, but in the other area they were separated from one another, then we would probably consider the former urban area to be more segregated, since all minority members live within one single homogeneous ghetto, compared to the latter area, where they reside in minority neighborhoods that are scattered throughout the urban area.

Geographers have long been concerned with the "checkerboard problem" under the rubric of the "contiguity problem" and have devised a variety of indicators to measure it (Dacey 1968; Geary 1954). Drawing on their work, we can derive the following measure of residential clustering, which is an index of absolute clustering in urban space:

$$ACL = \{[\sum_{i=1}^{n} (x_i/X) \sum_{j=1}^{n} (c_{ij}x_j)] - [X/n^2 \sum_{i=1}^{n} \sum_{j=1}^{n} c_{ij}]\} / \{[\sum_{i=1}^{n} (x_i/X) \sum_{j=1}^{n} c_{ij}t_j] - [X/n^2 \sum_{i=1}^{n} \sum_{j=1}^{n} c_{ij}]\} \quad (16)$$

In the geographic literature, the quantity c_{ij} refers to an element in a "contiguity matrix" that equals 1 when units i and j are contiguous, and 0 otherwise. In studying residential segregation, however, the measurement of contiguity is problematic. Most researchers have to determine contiguity by visual inspection of maps, or by laborious analysis of machine readable geographic coordinates for tract boundaries, and then enter the information into a large ($n \times n$) matrix. For any representative set of urban areas, these operations require the separate identification of contiguities for millions of matrix cells. The New York SMSA alone would generate a contiguity matrix of some 6.5 million cells.

These practical problems are overcome by realizing that contiguity is simply a dichotomous measure of distance. Since it is easy to obtain centroid coordinates for areal units in urban areas, c_{ij} may be taken to represent a distance function between areas. In this paper, we define c_{ij} as the negative exponential of the distance between units i and j: $c_{ij} = \exp(-d_{ij})$, where d_{ij} is the distance between areal unit centroids, and where d_{ii} is estimated as $(.6a_i)^{.5}$ (following White 1983). This functional form closely approximates contiguity by recognizing that the influence of surrounding areas drops off rapidly with distance from the target unit (Morgan 1983b; White 1983). Given this definition of c_{ij}, the index expresses the average number of X members in nearby tracts as a proportion of the total population in nearby tracts. It varies from a minimum of zero to a maximum that approaches but never equals one. Geary (1954) illustrates the calculation of the contiguity index with sample data from Britain, and Duncan, Cuzzort, and Duncan (1961) provide a more extensive empirical evaluation using U.S. data.

White (1986) has also proposed an index to measure the clustering of groups in space, which he calls the index of spatial proximity. To calculate this measure, one begins by estimating the average proximity between members of the same group, and between members of different groups. The average proximity between group X members can be approximated by:

$$P_{xx} = \sum_{i=1}^{n} \sum_{j=1}^{n} x_i x_j c_{ij} / X^2 \qquad (17)$$

while the average proximity between members of X and Y is estimated as:

$$P_{xy} = \sum_{i=1}^{n} \sum_{j=1}^{n} x_i y_j c_{ij} / XY \qquad (18)$$

whereas before $c_{ij} = \exp(-d_{ij})$. The average proximities between Y members (P_{yy}) and among all members of the population (P_{tt}) are calculated by analogy with Equation (17). These average proximities have also been recommended by Blau (1977) as key theoretical indicators of intergroup association.

White's index of spatial proximity is simply the average of intragroup proximities, P_{xx}/P_{tt} and P_{yy}/P_{tt}, weighted by the fraction of each group in the population:

$$SP = (XP_{xx} + YP_{yy})/TP_{tt} \qquad (19)$$

This index equals 1.0 if there is no differential clustering between X and Y, and is greater than 1.0 when members of each group live nearer one another than each other. The ratio would be less than 1.0 in the unusual event that members of X and Y resided closer to each other than to members of their own group. White (1983) illustrates the behavior of the index with data from 17 SMSAs.

The various proximities can also be combined to form another measure of clustering not mentioned by White:

$$RCL = P_{xx}/P_{yy} - 1 \qquad (20)$$

This index is a measure of relative clustering, since it compares the average distance between X members (the minority) with the average distance between Y members (the majority). It equals 0 when minority members display the same amount of clustering as the majority, and is positive whenever minority members display greater clustering than is typical of the majority. If minority members were less clustered than the majority, then the index would be negative. While simple to compute and interpret, this index has the disadvantage of having no theoretical maximum or minimum.

Rather than trying to measure spatial clustering per se, several researchers have adopted a different strategy of attempting to adjust measures of evenness or exposure to take account of the effect of clustering. Jakubs (1981) and Morgan (1983a) have both proposed the calculation of a distance-based index of dissimilarity. This measure is analogous to the normal index of dissimilarity, except that it introduces distance explicitly into measurement and interpretation. It represents the ratio of the minimum distance (in person-miles) that minority members would have to move to achieve evenness, over the minimum distance that would be required under conditions of maximum segregation.

Unfortunately, both measures require the solution of max–min functions using linear programming methods. After some initial experimentation with Morgan's computer program, we discovered that computing costs and machine requirements quickly became prohibitive for large urban areas. The computation of distance-based dissimilarity indices for the 60 largest SMSAs was simply not practical, and therefore the idea was abandoned.

Morgan (1983b), however, has proposed a distance-adjusted P^* that is considerably more tractable. Normally, ${}_xP^*{}_y$ is interpreted as the probability of interaction with Y experienced by the average X, based on the internal composition of geographic units within which X members reside. Yet minority members come into contact with many majority members outside of their own spatial unit, and as one considers greater diameters away from the home unit, the more potential contacts there are. At the same time, however, as one moves away from the home area, the actual likelihood of minority interaction with majority members decays rapidly. The distance-decay P^* index proposed by Morgan reflects these two countervailing forces. The probability of meeting a member of another group decreases as a function of distance, while the number of potential contacts increases:

$$DP_{xy}{}^* = \sum_{i=1}^{n} x_i/X \sum_{j=1}^{n} K_{ij}y_j/t_j \tag{21}$$

where

$$K_{ij} = \exp(-d_{ij})t_j / \sum_{i=1}^{n} \exp(-d_{ij})t_j$$

The distance-decay P^* may be interpreted as the probability that the next person a group X member meets anywhere in the city is from group Y. For each area i, the probability of meeting Y is the likelihood of interacting with a resident of area *j*, summed over *j* and weighted by the proportion of *Y*'s living in the area. The separate *Y* interaction probabilities for each unit *i* are then summed and weighted by the proportion of *X*'s in each unit to compute the total *X*-*Y* interaction probability. The corresponding distance-decay isolation index for intragroup exposure is defined analogously as:

$$DP_{xx}^{*} = \sum_{i=1}^{n} x_i/X \sum_{j=1}^{n} K_{ij}x_j/t_j \qquad (22)$$

In his original paper, Morgan did not give an empirical example of the indices or their behavior.

We have thus surveyed the methodological literature to identify 20 measures of segregation that have interested ecological researchers over the years. We have shown how each of these indices corresponds to one of five basic dimensions of residential segregation, and have conceptually distinguished the dimensions from one another. The 20 measures and five dimensions are summarized in Table 1. Given this plethora of indices and dimensions, it is no wonder that the field of residential segregation presently lacks coherence. In the following section, we attempt to rend this congeries of measures down to a more manageable set that researchers can employ consistently, with confidence about what they are measuring.

Data

The data for this article were assembled as part of a larger study of Hispanic, black, and Asian segregation in the 50 largest SMSAs of the United States, plus 10 others with sizeable concentrations of Hispanics. These metropolitan areas provide a balanced cross-section of the country's regions, with 14 in the Northeast, 11 in North Central region, 19 in the South, and 16 in the West. It also provides a wide range of "minority" experiences, from areas where minority members comprise less than one percent of the population (e.g., Asians in Indianapolis) to places where they are actually in the majority (e.g., Hispanics in El Paso). Data were obtained from the 1980 STF4 data tapes provided by the U.S. Bureau of the Census (1980), which give counts of Hispanics, blacks, Asians, and non-Hispanic whites in census tracts of SMSAs. To these data we added the areal size of each tract, and the coordinates of its geographic centroid.

An unavoidable problem in any study of segregation is the choice of areal units for the calculation of indices. This study is based on census tracts, which are defined to range in size from 3,000 to 6,000 people, with an average of roughly 4,000 (U.S. Bureau of the Census 1982). Tracts are

Table 1. THE DIMENSIONS OF RESIDENTIAL SEGREGATION AND THEIR MEASURES

Dimension and Index	Name of Measure
Unevenness	
D	Index of Dissimilarity
G	Gini Index
H	Entropy Index or Information Index
A1	Atkinson Index with b=.10
A5	Atkinson Index with b=.50
A9	Atkinson Index with b=.90
Exposure	
xPy*	Interaction Index
xPx*	Isolation Index
V	Correlation Ratio or Eta Squared
Concentration	
DEL	Duncan's Delta Index
ACO	Absolute Concentration Index
RCO	Relative Concentration Index
Centralization	
PCC	Proportion in Central City
ACE	Absolute Centralization Index
RCE	Relative Centralization Index
Clustering	
ACL	Absolute Clustering Index
SP	Spacial Proximity Index
RCL	Relative Clustering Index
DPxy*	Distance Decay Interaction Index
DPxx*	Distance Decay Isolation Index

established by local committees following Census Bureau guidelines and are designed to be of uniform size and as internally homogenous as possible, with due regard paid to natural boundaries (Taeuber & Taueber 1965). In general, tract boundaries are not changed from census to census, although some tracts may be subdivided if they become too populous. Rarely are census tract grids completely redefined between censuses.

We chose census tracts for the simple reason that more racial and ethnic data are available for them than for other geographic units. As a result, they are the most widely used spatial unit in segregation studies. In spite of these practical strengths, however, census tracts have several problems. First, they are often not homogeneous. In general, the greater homogeneity the higher the level of apparent segregation. The ideal of homogenity conflicts with the ideal of constant boundaries, however, so as neighborhoods change through population succession, the use of constant boundaries leads to growing heterogeneity within tracts. Since tracts are initially defined to be homogenous, urban areas with a predominance of newer tracts tend to have higher segregation indices than places where older tracts predominate, which affects interurban and city-suburban comparisons. Second, city and suburban tracts tend to differ in population size and composition, so interpretive problems also arise when urban areas have different proportions of their populations in cities and suburbs. Third, indices that use land area in their calculation, notably the concentration indices, are affected by variations in the areal size of census tracts. In order to maintain an average population size of 4,000 people, tracts from densely settled urban areas such as New York must be systematically smaller than those in sparsely settled areas like Los Angeles, and minority groups in the former may appear to be more "concentrated" than the latter solely because of differences in the areal size of the tracts. Finally, some indices (e.g., the concentration and centralization indices) are sensitive to variations in the number and population of tracts.

These problems are inherent to studies of segregation, since all computations must ultimately be based on arbitrary areal units. At one time, a controversy raged about whether tracts or blocks were more appropriate for studies of residential segregation (Cowgill & Cowgill 1951; Jahn 1950). But switching down to blocks or up to tract groups will not eliminate any of the problems we have mentioned. Although smaller areal units generally yield higher indices of segregation because they are more homogenous, it is always theoretically possible to define a smaller unit. Moreover, the effect of areal size tends to be constant and linear, generating a strong correlation between block-based and tract-based measures (Duncan & Duncan 1955b; Taeuber & Taeuber 1965). Nonetheless, the choice of an areal unit does affect the size and variability of segregation indices.

Separate segregation measures were computed for Hispanics, blacks, and Asians in each of the 60 SMSAs, giving 180 independent observations for each index. Non-Hispanic whites (henceforth called Anglos) were always considered to be the majority population. In order to eliminate extraneous variation stemming from intermetropolitan differences in ethnic and racial diversity, we artificially restricted attention to the two-group case. Indices were calculated as if Anglos and the minority in question were the only two groups present. For example, in measuring the degree of segregation between Hispanics and Anglos, the total population was assumed to equal the sum of these two groups.

In pooling data for the three minority groups to get 180 observations on 20 measures, we sought to obtain a wide range of variation over a

Table 2. MEASURES OF DISPERSION AND CENTRAL TENDENCY FOR 20 INDICES OF SEGREGATION BY DIMENSION: 60 U.S. SMSAS AND 3 MINORITY GROUPS*

Dimensions and Indices	Median	Unweighted Mean	Weighted Mean	Unweighted Standard Deviation	Weighted Standard Deviation	Minimum	Maximum
Evenness							
D	.465	.510	.597	.169	.048	.215	.906
G	.620	.654	.736	.171	.048	.318	.974
H	.198	.267	.381	.196	.058	.042	.780
A1	.148	.170	.181	,114	.040	.024	.553
A5	.358	.427	.517	.214	.067	.097	.922
A9	.551	.599	.713	.237	.066	.171	.994
Exposure							
xPy*	.805	.713	.470	.261	.066	.147	.989
xPx*	.195	.287	.530	.261	.066	.011	.853
V	.126	.232	.399	.230	.063	.006	.811
Concentration							
DEL	.781	.774	.792	.097	.028	.416	.937
ACO	.936	.901	.840	.098	.045	.468	.990
RCO	.469	.458	.512	.291	.099	-.483	.945
Centralization							
PCC	.526	.536	.621	.237	.071	.000	1.000
ACE	.778	.744	.759	.154	.047	.128	.969
RCE	.265	.291	.365	.202	.060	-.142	.742
Clustering							
ACL	.060	.137	.263	.168	.053	.006	.668
SP	1.053	1.133	1.263	.182	.061	1.000	1.844
RCL	.518	1.198	1.124	1.742	.545	-.729	10.086
DPxx*	.886	.790	.567	.214	.061	.261	.993
DPxy*	.114	.210	.433	.214	.061	.007	.739

*Weighted figures are weighted by the minority proportion.

large number of cases. The summary measures shown in Table 2 suggest that this operation was a success. Each index varies over a wide range and the distribution is typically centered near the middle of continuum. A good example is the index of dissimilarity, which varies from .215, representing a very low degree of segregation, to .906, which is very high, with a median of .465.

However, many of the SMSAs contain very small numbers of one or more of the minority groups. When the minority proportion gets small, random factors play a large role in determining the settlement pattern of group members, leading to greater variability in the indices (Cortese, Falk & Cohen 1976; Massey 1978). Therefore, two separate calculations of means and standard deviations were made: one weighted by the minority proportion and the other not. Using minority proportions as weights reduces the influence of unstable indices based on small numbers, and typically lowers standard deviations by a factor of three or more compared to unweighted figures. At the same time, using weights increases the mean, since minorities tend to be more segregated in cities where they are relatively numerous. In order to reduce random noise in the following results, the factor analyses discussed below were conducted on weighted data. However, both weighted and unweighted results were inspected, and the conclusions would not differ if the unweighted data had been used.

Empirical Analysis of Segregation Indices

Table 3 presents the correlation matrix for the 20 indices of segregation. Coefficients below the diagonal are based on weighted data, while those above the diagonal are not. For ease of interpretation, intercorrelations between measures within each of the five dimensions are underlined and separated by a blank line, forming squares which cluster along the diagonal. The top left square contains intercorrelations between the six measures of evenness: the dissimilarity index (*D*), the Gini index (*G*), the entropy index (*H*), and three versions of the Atkinson index (*A1*, *A5*, and *A9*, where the shape parameter equals .1, .5, and .9, respectively). The high degree of intercorrelation between these six indices suggests that they all measure essentially the same property of segregation, and that no matter which one is used, basically the same conclusions are drawn. The weighted correlations range from a low of .81 to a high of .99, while the unweighted ones vary between .75 and .99. *A1* generally displays the lowest correlations with other measures of evenness, although they are still quite high.

The second square along the diagonal contains the three measures of exposure: the interaction index (${}_xP_y{}^*$), the isolation index (${}_xP_x{}^*$), and the correlation ratio (V). In the two group case, ${}_xP_y{}^* + {}_xP_x{}^* = 1.0$, so the interaction and isolation indices display a perfect negative relation. The correlation ratio has a weighted correlation of .87 and an unweighted correlation of .97 with these measures, so that the three measures clearly measure the same thing. The exposure indices are also strongly correlated with the various measures of evenness, however, which suggests a substantial empirical overlap between these two dimensions of segregation, as other researchers have noted (Lieberson, 1981; Stearns and Logan, 1986). The associations between the correlation ratio and the evenness measures are especially strong.

On the dimension of spatial concentration, the relative concentration index (RCO) and Duncan's delta (DEL) are highly correlated with one another (.63 weighted and .71 unweighted) and display similar patterns of intercorrelation with indices on the other dimensions. The absolute concentration index (ACO) is less correlated with the other two measures (with correlations ranging from .43 to .68). All three measures display low to moderate correlations with other indices, which suggests that we are

Table 3. CORRELATION MATRIX FOR 20 INDICES OF RESIDENTIAL SEGREGATION*

	D	G	H	A1	A5	A9	P*XY	P*XX	V	DEL	ACO	RCO
D		.99	.97	.80	.99	.97	-.86	.86	.92	.62	.21	.66
G	.99		.95	.80	.98	.98	-.82	.82	.89	.62	.22	.66
H	.98	.97		.75	.96	.94	-.92	.92	.98	.61	.17	.64
A1	.89	.86	.90		.86	.75	-.52	.52	.65	.51	.31	.51
A5	.99	.99	.99	.92		.97	-.81	.81	.90	.62	24	65
A9	.96	.98	.95	.81	.97		-.83	.83	.89	.60	.17	.62
P*XY	-.77	-.75	-.78	-.56	-.71	-.74		-1.00	-.97	-.50	.11	-.51
P*XX	.77	.75	.78	.56	.71	.74	-1.00		.97	.50	-.11	.51
V	.96	.94	.98	.83	.95	.93	-.87	.87		.57	.06	.59
DEL	.64	.63	.64	.66	.66	.60	-.34	.34	.58		.43	.71
ACO	.38	.38	.38	.50	.43	.34	.18	-.18	.26	.55		.56
RCO	.63	.63	.62	.60	.63	.57	-.37	.37	.56	.63	.68	
PCC	.43	.42	.41	.36	.41	.44	-.47	.47	.41	.40	-.06	.28
ACE	.32	.30	.33	.34	.33	.32	-.15	.15	.29	.63	.21	.24
RCE	.73	.74	.73	.66	.74	.74	-.54	.54	.71	.52	.36	.64
ACL	.74	.72	.77	.62	.71	.69	-.89	.89	.83	.33	-.04	.41
SP	.80	.76	.82	.75	.77	.71	-.77	.77	.85	.52	.21	.52
RCL	.57	.57	.57	.67	.60	.52	-.22	.22	.48	.49	.51	.48
DPXY	-.57	-.54	-.58	-.34	-.49	-.53	.94	-.94	-.70	-.16	.39	-.21
DPXX	.57	.54	.58	.34	.49	.53	-.94	.94	.70	.16	-.39	.21

*Upper half contains unweighted correlations, lower half contains correlations weighted by minority proportion.

tapping a relatively independent axis of segregation, in contrast to evenness and exposure, which are more highly correlated with one another, and to indicators on other dimensions.

Correlations among the three centralization indices—proportion in the central city (PCC), the absolute centralization index (ACE), and the relative centralization index (RCE)—are relatively weak, ranging from .26 to .46 in the weighted case, and from .39 to .52 in the unweighted instance. Among all the dimensions, the indices of centralization least appear to measure the same thing. The relative centralization index is also quite highly correlated with measures of unevenness and exposure, and to a lesser extent so is PCC. Only the absolute centralization index seems to vary relatively independently of other indices in the table.

Finally, on the clustering dimension, the five measures are quite highly intercorrelated, with the exception of the relative clustering index, RCL. As with the unadjusted P^* measures, the distance-decay ${}_xP_x^*$ displays a perfect negative relation with distance-decay ${}_xP_y^*$, which follows tautologically from their definition in the two group case. Moreover, both of the distance-based P^*'s are very highly correlated with their unadjusted counterparts (.97 unweighted and .94 weighted), which suggests that despite the adjustment for distance, the values of DP_{xx}^* and DP_{xy}^* are determined primarily by the compositions of areal units themselves, rather

Table 3. (continued)

PCC	ACE	RCE	ACL	SP	RCL	DPXY	DPXX
.52	.36	.75	.81	.81	.60	-.76	.76
.51	.35	.74	.77	.76	.60	-.72	.72
.52	.36	.74	.88	.87	.56	-.83	.83
.36	.24	.53	.57	.64	.60	-.41	.41
.50	.35	.73	.78	.79	.62	-.70	.70
.52	.35	.74	.75	.74	.58	-.72	.72
-.49	-.29	-.65	-.93	-.87	-.37	.97	-.97
.49	.29	.65	.93	.87	.37	-.97	.97
.51	.33	.71	.92	.89	.47	-.90	.90
.53	.71	.51	.45	.50	.41	-.42	.42
.09	.24	.20	-.08	.06	.34	.23	-.23
.45	.46	.68	.49	.55	.46	-.42	.42
	.39	.52	.45	.44	.31	-.44	.44
.26		.50	.26	.32	.28	-.25	.25
.42	.46		.63	.65	.54	-.57	.57
.40	.13	.57		.95	.43	-.94	.94
.35	.29	.63	.90		.57	-.85	.85
.18	.25	.51	.40	.62		-.23	.23
-.41	-.08	-.40	-.85	-.68	-.01		-1.00
.41	.08	.40	.86	.68	.01	-1.00	

than the composition of the surrounding units. The absolute clustering index (ACL) and the index of spatial proximity (SP) are highly correlated, and they are also quite highly related to indices of other segregation dimensions.

The correlation matrix thus provides prima facie evidence on the dimensions of residential segregation. For all dimensions except centralization, indices are highly intercorrelated within dimensions, suggesting common underlying factors of variation. But most indices are also strongly intercorrelated between dimensions, indicating that while the dimensions may be distinct at a conceptual level, they overlap empirically to a considerable degree.

By inspection alone, it is difficult to sort out the 190 simultaneous interrelationships in the correlation matrix and construct from them a clear picture of the dimensional structure of segregation. In order to explicate the structure underlying the matrix of Table 3, the weighted correlations were factor analyzed by principal axis factoring. Initial communalities were estimated by using the maximum squared correlation between each variable and other variables in the matrix. Five factors were extracted, and the initial pattern matrix was rotated orthogonally using varimax rotation to give the factor loadings shown in Table 4. Large loadings have been underlined to facilitate interpretation.[2]

Table 4. ORTHOGONALLY ROTATED VARIMAX PATTERN MATRIX FOR FACTOR ANALYSIS OF 20 INDICES OF RESIDENTIAL SEGREGATION

Hypothesized Dimensions and Indices	Factors 1	2	3	4	5	Communality
Evenness						
D	0.81	0.43	0.27	0.22	0.18	0.99
G	0.83	0.40	0.27	0.20	0.13	0.99
H	0.80	0.44	0.26	0.22	0.22	0.99
A1	0.76	0.20	0.26	0.24	0.38	0.88
A5	0.85	0.34	0.27	0.23	0.20	1.00
A9	0.84	0.39	0.20	0.24	0.06	0.96
Exposure						
xPy*	-0.43	-0.89	-0.05	-0.10	-0.04	1.00
xPx*	0.43	0.89	0.05	0.10	0.04	1.00
V	0.73	0.57	0.21	0.18	0.19	0.97
Concentration						
DEL	0.43	0.06	0.39	0.60	0.16	0.72
ACO	0.40	-0.44	0.62	0.12	0.22	0.80
RCO	0.38	0.14	0.74	0.19	0.13	0.76
Centralization						
PCC	0.21	0.38	0.08	0.40	-0.07	0.36
ACE	0.14	0.00	0.06	0.78	0.11	0.64
RCE	0.47	0.32	0.40	0.40	0.16	0.67
Clustering						
ACL	0.36	0.80	0.13	0.05	0.37	0.93
SP	0.42	0.60	0.22	0.19	0.57	0.94
RCL	0.46	-0.04	0.28	0.17	0.59	0.67
DPxy*	-0.17	-0.98	0.03	-0.06	0.00	1.00
DPxx*	0.17	0.98	-0.03	0.06	0.00	1.00
Eigenvalue	6.23	6.15	1.84	1.77	1.27	17.25
Prop. variance	0.36	0.36	0.11	0.10	0.07	

Given the obviously high intercorrelation we have seen between indices on the various dimensions, especially between evenness and exposure measures, it is not surprising that the first two factors account for most of the common variance, 72 percent. The first factor is clearly interpretable as an evenness factor. All of the unevenness measures load very highly on it (.76 or greater) and, with one exception discussed below, their loadings are at least 30 points greater than those for other indices. The second factor represents an exposure dimension, displaying very high loadings for the unadjusted and distance-based P^* measures (.89 and .98, respectively). This interpretation is clouded somewhat by the fact that two clustering indices (ACL and SP) also load highly on it (with loadings of .80 and .60, respectively), but this fact does not affect the distinction between the first two dimensions.

The pattern of loadings on factors one and two thus suggests that evenness and exposure are two equally important, independent dimensions of residential segregation, each explaining about 36 percent of the variance. Indicators of evenness or exposure tend to load highly on one factor or the other but not on both, providing good factor separation. The one exception is V, the correlation ratio, which James and Taueber (1985) classify as an evenness measure, and which we describe as an exposure measure. In reality, it appears to be both, for it loads highly on both factors. Empirically, the correlation ratio seems to straddle evenness and exposure. Being a standardization of $_xP_x^*$ for population composition, it loads on the same factor as the other P^* measures, but standardization makes it behave like a measure of evenness, even though it is unlike other evenness measures in not being derived from the Lorenz curve.

The remaining three factors exlain 7 to 11 percent of the common variation and are clearly interpretable as independent axes corresponding to the hypothesized dimensional structure of segregation. The third factor represents the concentration dimension, with the three concentration indices generally having the highest loadings on it. The ACO and RCO indices have particularly high loadings, while that for Duncan's delta is much lower, about the same size as the absolute centralization index, which it resembles computationally. The fourth factor represents centralization and the fifth clustering. In the former case, the relative and absolute centralization indices display markedly higher loadings than other measures, and in the latter case loadings for the spatial proximity index and the relative clustering index stand out clearly from the others. Duncan's delta, theoretically a concentration measure, loads highly on the centralization factor—even more so than on the concentration axis—indicating a potential problem with this measure.

The apparent empirical insignificance of the last three factors is troublesome, but is largely an artifact of the assumption of factorial independence required by the factor extraction method. Although conceptually the dimensions might be distinct, in the real world they tend to be empirically correlated with the major axes of evenness and exposure. Groups that are segregated on one dimension tend to be segregated on other dimensions as well. In order to overcome the limitations imposed by independence, we rotated the factor axes obliquely using promax rotation, relaxing the assumption of independence and letting the dimensions become correlated with one another. The results of this exercise are shown in Table 5.

The factors are interpretable as before: the first factor is evenness, the second exposure, the third concentration, the fourth centralization, and the fifth clustering. However, by allowing the factors to become corre-

Table 5. OBLIQUELY ROTATED PROMAX PATTERN MATRIX FOR FACTOR ANALYSIS OF 20 INDICES OF RESIDENTIAL SEGREGATION

Hypothesized Dimensions and Indices	Factors 1	2	3	4	5
Evenness					
D	0.84	0.17	0.06	0.00	0.04
G	0.91	0.12	0.06	-0.02	-0.03
H	0.81	0.18	0.03	0.00	0.09
A1	0.78	-0.07	-0.03	0.05	0.30
A5	0.93	0.05	0.02	0.01	0.06
A9	0.99	0.08	-0.04	0.03	-0.10
Exposure					
xPy*	-0.30	-0.82	0.01	0.02	0.05
xPx*	0.30	0.82	-0.01	-0.02	-0.05
V	0.71	0.36	0.02	-0.02	0.06
Concentration					
DEL	0.26	-0.04	0.27	0.48	0.05
ACO	0.30	-0.52	0.62	-0.07	0.11
RCO	0.03	0.19	0.86	-0.03	-0.04
Centralization					
PCC	0.10	0.35	0.04	0.37	-0.16
ACE	0.00	-0.06	-0.11	0.83	0.08
RCE	0.25	0.25	0.32	0.26	0.03
Clustering					
ACL	0.08	0.78	0.03	-0.07	0.34
SP	0.10	0.55	0.04	0.05	0.57
RCL	0.34	-0.20	0.04	0.04	0.60
DPxy*	0.06	-1.04	0.00	0.00	0.05
DPxx*	-0.06	1.04	0.00	0.00	-0.05
Prop. variance	0.64	0.49	0.32	0.22	0.27
Interfactor Correlations					
1	1.00	0.54	0.63	0.46	0.53
2		1.00	0.08	0.18	0.20
3			1.00	0.47	0.54
4				1.00	0.29
5					1.00

lated, the promax rotation has simultaneously produced a cleaner solution, and increased the empirical significance of the later factors relative to the first two. (Since the factors are no longer independent of one another, the proportions of variance explained by the five factors now sum to more than one.)

The relative importance of the first factor, evenness, has been increased and now accounts for 64 percent of the common variance, and the pattern of loadings is more consistent with the hypothesized dimensional structure. Loadings for each of the evenness indices have increased, while those for indices hypothesized to represent other dimensions have decreased, although the correlation ratio still loads highly on this factor. The second factor, exposure, is positively correlated with the evenness factor, but its share of common variance explained has increased to 49 percent. As before, this dimension primarily reflects variation in exposure as reflected in the P^* indices, but contrary to our hypothesized dimensional structure, the loading for the correlation ratio has decreased. Moreover, two clustering indices, ACL and SP, still load highly on the exposure factor, contrary to expectations.

The pattern of factor loadings for the remaining three dimensions, which was clear in the orthogonal analysis, has been sharpened by the oblique rotation. But the most important effect has been to increase the empirical importance of these factors. The third factor, concentration, is now correlated with evenness, but its share of variance explained has risen to 32 percent. Similarly, the fourth factor, centralization, is moderately correlated with the first and third factors, but now accounts for 22 percent of the common variance. Finally, the last factor, which is clearly clustering, is correlated with the first and third factors, but its proportion of variance explained has increased to 27 percent.

In short, no matter whether we consider orthogonal or oblique factor solutions, we obtain a pattern matrix that is interpretable in terms of the hypothesized dimensional structure of segregation. But when we allow the factor solution to reflect more realistically conditions in the social world—that is, to permit correlated factors—we obtain a solution indicating that each dimension is also empirically important in explaining spatial variation in cities. Evenness is generally the most important dimension, followed closely by exposure, and then concentration, centralization, and clustering in decreasing order.[3]

Choosing Indices for the Five Dimensions

Factor analyses of 20 different segregation indices have provided support for the dimensional structure of segregation postulated at the outset of this article. It is clear that the various measures proposed under each of the five dimensions vary together empirically and are conceptually related to one another. For reasons of parsimony and to eliminate needless redundancy, it is useful to reduce the list of 20 candidates down to a list of five measures, each corresponding to a separate dimension of segregation.

The choice of an evenness measure is simple. The correlation and factor pattern matrices indicate that little information is contained in any of the other candidates not already in the dissimilarity index. It has been the mainstay of segregation research for thirty years, and its further use would preserve continuity in the research literature. It also has the advantages of being easy to interpret and to compute. There are thus many compelling reasons to retain *D* as the basic index of the evenness.

Choosing an exposure index is similarly straightforward. The correlation ratio can be ruled out because of its factorial complexity, straddling the dimensions of evenness and exposure. The P^* indices, on the other hand, load highly only on one factor each and have simple, straightforward interpretations. Moreover, they have already been used in several studies emanating from the 1970 Census. Their continued use in 1980 and after would build an early comparability into the research literature. The P^* indices are, therefore, the preferred measures of exposure. It is not important, however, to distinguish between the isolation and interaction indices. In the two-group case they are redundant, and in real world applications, both should be reported.

On the concentration dimension, the selection of RCO over ACO and DEL is justified on several grounds. First, both the orthogonal and oblique factor solutions show it to have the highest loading on the concentration factor, and to display the smallest loadings on the other dimensions. Second, RCO seems to be more desirably distributed, being centered nearer the midpoint of the 0 to 1 range, and having greater variability than either ACO or DEL. Finally, although simpler to calculate and more firmly established in the literature, DEL was rejected because it loads highly on both the concentration and centralization axes.

In selecting a measure of centralization, there is little doubt that the absolute centralization index, ACE, is the better measure. It displays the highest loading on the centralization dimension and loads highly on one and only one factor. In contrast, RCE loads weakly onto the centralization factor and is as strongly related to the concentration factor. Both measures are equally interpretable and are reasonably well distributed.

Finally, selecting a clustering index is somewhat more problematic. The factor pattern matrices show that the relative clustering index RCL has the highest loading on the clustering factor, and very small loadings on other factors, which would dictate its choice as the clustering index. But RCL is poorly distributed compared to the other candidates. It varies way outside the 0 to 1 range and is highly skewed (compare its mean and median). It also has no prior application in the research literature. Among the other candidates, the distance-decay P^* measures proposed by Morgan do not seem to be desirable. Their value reflects primarily the degree of exposure and they load highly on that factor rather than the clustering dimension. Rather than adjusting the exposure index to take account of clustering, a better plan is to measure clustering directly as a separate dimension.

The choice is thus between the absolute clustering index, ACL, and White's index of spatial proximity, SP. Both have factorial complexities greater than one, with strong loadings on the exposure as well as the clustering factor. Both indices are skewed to the right, and both vary roughly in the range from 0 to 1 (if one adjusts SP by subtracting 1 from it). SP has the stronger loading on the clustering factor, however, and has at least appeared in the research literature. It is also easier to calculate and to interpret than ACL. On balance, therefore, SP seems to be the preferred measure of residential clustering.

Thus, empirical analysis combined with a variety of a priori considerations suggest the following indices are the best measures of the five dimensions of residential segregation: *D* for evenness, ${}_xP_y^*$ for exposure, *RCO* for concentration, *SP* for clustering, and *ACE* for centralization. In order to confirm the legitimacy of this selection, we performed a principal components analysis on these five indices alone, and rotated to both orthogonal and oblique solutions, which are presented in Table 6.

Both solutions produce interpretable pattern matrices that are consistent with the hypothesized dimensional structure.[4] The cleanest and most realistic solution is the oblique rotation. Each measure loads highly on one and only one factor, and although the five factors are correlated, they do not overlap completely. Each measure therefore contributes something different to the understanding of residential segregation. In the five-variable oblique solution, evenness is the most important factor, followed by clustering, exposure, concentration, and centralization. In different contexts, the relative importance of the different factors might vary.

Summary

This article has proposed conceptualizing residential segregation in terms of five conceptually distinct dimensions of variation. Urban spatial structure is inherently multidimensional (Timms 1971), and residential segregation, in particular, does not stem from a single process, but from a complex interplay of many different social and economic processes that generate various constellations of outcomes interpreted as "segregation." These spatial outcomes are created through the combination of five basic distributional characteristics. Evenness is the degree to which groups are distributed proportionately across areal units in a city. Exposure is the

Table 6. ROTATED ORTHOGONAL (VARIMAX) AND OBLIQUE (PROMAX) PATTERN MATRICES FOR PRINCIPAL COMPONENTS ANALYSIS OF 5 SEGREGATION INDICES

Rotations and Indices	Factors 1	2	3	4	5
Orthogonal Rotation					
D	-0.51	0.38	0.17	0.35	0.66
xPy*	0.92	-0.15	-0.04	-0.30	-0.19
RCO	-0.15	0.95	0.11	0.18	0.16
ACE	-0.05	0.10	0.99	0.09	0.07
SP	-0.48	0.26	0.15	0.79	0.22
Prop. variance	0.27	0.23	0.21	0.18	0.11
Oblique Rotation					
D	-0.17	0.07	0.01	0.08	0.79
xPy*	0.95	0.00	0.00	-0.05	-0.02
RCO	0.00	0.99	0.00	0.01	0.01
ACE	0.00	0.00	0.99	0.00	0.00
SP	-0.14	0.02	0.00	0.87	0.03
Prop. variance	0.45	0.36	0.25	0.47	0.48
Interfactor Correlations					
1	1.00	-0.33	-0.13	-0.66	-0.65
2		1.00	0.23	0.47	0.58
3			1.00	0.29	0.32
4				1.00	0.67
5					1.00

extent to which members of different groups share common residential areas within a city. Concentration refers to the degree of a group's agglomeration in urban space. Centralization is the extent to which group members reside toward the center of an urban area; and clustering measures the degree to which minority areas are located adjacent to one another.

After surveying 20 different indices, and conceptually linking each one with one of the five dimensions, we undertook a series of factor analyses to confirm the postulated dimensional structure. An orthogonal factor solution confirmed the five-dimensional structure of segregation, but the last three factors were relatively unimportant in empirical terms. An oblique rotation increased the empirical importance of the later factors and sharpened the pattern of factor loadings, giving a solution even more consistent with the hypothesized dimensional structure. In the oblique solution, the interfactor correlations were sizeable, but they hardly indicated a complete redundancy. In the real world of cities, the dimensions of segregation may overlap, but each is conceptually distinct and contributes a unique component to the understanding of spatial segregation.

Using empirical and conceptual criteria, five indicators were chosen to represent each of the separate dimensions of segregation. These five measures were then subjected to a principal components analysis to confirm their appropriateness as indicators of the five dimensions. An oblique promax rotation produced an exceptionally clean pattern matrix, confirming the five measures as appropriate indicators for the five dimensions of segregation. To practitioners in the field of residential segregation, therefore, we recommend that segregation be conceptualized as a multidimensional phenomenon coalescing around five basic axes of variation measured by the following indices: *D* for evenness, P^* for exposure, *RCO* for concentration, *ACE* for centralization, and *SP* for clustering.

These conclusions are reassuring because they reaffirm the traditional reliance of segregation researchers on *D*, which is readily interpretable and simple to compute. Our findings suggest that its mathematical flaws do not matter much in practice, since it is highly correlated with other evenness measures that satisfy more stringent mathematical criteria (James & Taueber 1985; White 1986). There is one application where *D* might not be the best choice, however, and that is in computing a single measure of segregation across a variety of groups. *D* does not extend readily to the multi-group case. For example, if one wants to compare occupational segregation in different cities, separate values of *D* would have to be computed between all pairs of occupations and averaged to get a single measure. The entropy index, on the other hand, generalizes readily to the multi-group case, and can be decomposed into portions corresponding to different groups (Pielou 1972; White 1986).

Our findings also suggest that adjusting *D* or P^* for the spatial distribution of groups, as suggested by Jakubs (1981) and Morgan (1983a, 1983b), is not particularly fruitful. At least in the case of P^*, such an approach yields a measure whose value reflects primarily the value of the index being adjusted. A better approach is to recognize aspects of spatial distribution as separate dimensions, and to measure them directly with their own indices. Interpretation can then focus on the dimension itself, rather than on a measure confounding two or three dimensions.

Perhaps this article's most important contribution is the empirical verification of the five dimensions of segregation. Recently, much controversy has centered on defining what segregation is, or should be. Some observers have emphasized evenness, others exposure, and still others clustering, with each person advocating a particular index as the appropriate measure of "segregation." We argue that segregation is a multidimensional phenomenon that should be measured by a battery of indices rather than one single index. Viewing segregation as a multidimensional construct will, we hope, encourage research into the many ways that segregation can affect people's lives. Its effects are easier to imagine in terms of concrete spatial outcomes such as evenness, exposure, concentration, centralization, and clustering, than in terms of the ambiguous idea "segregation."

Notes

1. This formula corrects a mistake in the formula given by James and Taeuber, where the product on the right hand stood by itself instead of being subtracted from one, a mistake that James and Taeuber have acknowledged by oral communication with the authors.
2. We were initially concerned about the effect of singularities in the correlation matrix on the stability of the factor solution, particularly those stemming from the perfect correlations between ${}_xP_x{}^*$ and ${}_xP_y{}^*$, and between $DP_{xx}{}^*$ and $DP_{xy}{}^*$. Removing ${}_xP_x{}^*$ and $DP_{xx}{}^*$ from the correlation matrix made practically no difference in the factor solutions, so they were left in the analysis to make explicit the logical link between exposure and isolation.
3. In order to check the robustness of the factor solutions reported in this paper, we divided up the dataset into different partitions and performed factor analyses separately for each one. The data were divided by minority group (Blacks, Hispanics, or Asians), region (Northeast, North Central, South, and West), size (splitting the SMSAs into small and large halves by population), and random allocation (dividing the SMSAs randomly into two groups). Among the minority groups, blacks and Hispanics each displayed clear five-factor solutions, but for Asians exposure and clustering tended to load together. Five factors also clearly emerged among SMSAs in the South and West, and promax rotation produced a clear five-factor solution in the Northeast, but in the North Central region, evenness and exposure loaded together. Both the larger and smaller halves of the SMSAs yielded clear five-factor solutions; and when the 60 SMSAs were randomly divided into two groups, one half yielded a very clear solution (although the order of the five factors was somewhat different—exposure came before evenness), and the other half produced a solution that was less clean, but still interpretable in terms of the five basic dimensions. In general, the similarity of the various factor solutions was impressive, which lends credibility to our conclusions regarding the dimensional structure of segregation. (Pattern matrices for the various factor analyses are available on request).
4. We replicated these factor solutions using 1970 data on the same groups and SMSAs (pattern matrices available on request).

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