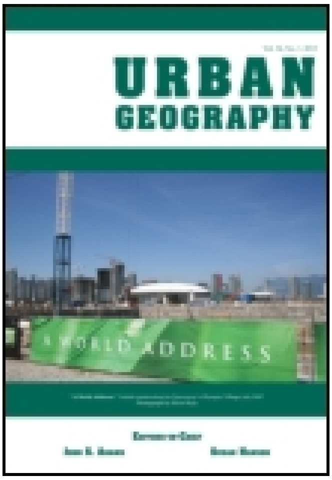

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GEOSTATISTICS AS MEASURES OF SPATIAL SEGREGATION

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Abstract: Traditional measures of segregation, such as the index of dissimilarity, have been criticized as aspatial in nature. Spatial measures of segregation have been proposed, but they are difficult to use. Based on the idea that segregation implies a spatial separation of ethnic groups, the degree of spatial correlation among groups can reflect the level of segregation. This paper suggests that several geostatistical measures, especially the standard deviational ellipse, are effective tools for capturing the spatial characteristics of a population group. By comparing the ellipses of different groups, measures of segregation can be derived. The paper demonstrates this approach to measuring segregation by way of both a simulation and a case study. [Key words: spatial segregation, geostatistics, deviational ellipses, spatial correspondence/correlation.]

Over the past five decades, the measurement of segregation has been influenced by the index of dissimilarity or segregation index *D* advocated by Duncan and Duncan (1955). Although other measures of segregation or diversity have been proposed and used, such as the diversity index (White, 1986), it is argued that *D* is still the best measure of segregation because it effectively captures the evenness dimension, the most important dimension of segregation (Massey and Denton, 1988). This argument supporting the use of *D* is valid from a sociological point of view. But from a geographical perspective, *D* is not effective at all in capturing the evenness dimension of segregation. In short, as long as each areal unit is dominated exclusively by one ethnic group, no matter how the locations of different ethnic groups are rearranged, the value of *D* will be equal to one, representing a perfectly segregated situation (Morrill, 1991; Wong, 1993). Therefore, *D* cannot be regarded as an effective and meaningful measure of spatial segregation.

Based on the idea that segregation implies the spatial separation of different ethnic groups (Newby, 1982), Morrill (1991) proposed a spatial version of *D* based on the concept of measuring spatial autocorrelation. Subsequently, Wong (1993) extended Morrill's idea and proposed a family of spatial segregation measures. All these measures are able to distinguish different spatial arrangements of ethnic groups with slightly different conceptualizations of spatial segregation. However, most of these measures have not been used extensively, partly because they are relatively difficult to implement and are conceptually more complicated than existing aspatial measures. Even with today's Geographic Information Systems (GIS) technology, these measures require extensive programming skill before they can be operationalized.

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While researchers are relying on concepts related to spatial autocorrelation and spatial statistics to model spatial segregation, they tended to overlook the power of some simple, but intuitively useful, geostatistics. Most of these techniques are relatively straightforward and easy to implement, especially in a GIS environment. The purpose of this paper is to demonstrate that several commonly used descriptive geostatistical tools, especially the standard deviational ellipse, are a promising tool for deriving measures of spatial segregation. Standard deviational ellipses can be used to describe the spatial distribution of population groups. An ellipse can be derived for each population group. Multiple ellipses can be compared against each other or together to reflect the extent of spatial correlation among these groups. The area of overlap among these ellipses indicates the degree of spatial correlation among these groups, while the areas where ellipses do not overlap represent spatial segregation.

In the next section, I provide a brief review of the study of spatial segregation and then discuss how the concept of spatial correlation can be applied to the study of spatial segregation. Afterward, I discuss several descriptive geostatistics that have the potential to measure spatial segregation. Using simulated population settings as well as a real world situation, I demonstrate how these geostatistics can be used in conjunction with GIS to facilitate the application of the proposed approach.

MEASURING SPATIAL SEGREGATION

Although this major shortcoming of *D* was first elaborated by Morrill (1991), the idea of developing segregation indices explicitly incorporating spatial information is not new. Jakubs (1979, 1981), for example, proposed a distance-based segregation index that was built on the distance-decay concept and designed to model spatial interaction among different ethnic groups. Based on Newby's (1982) argument that segregation implies spatial separation, Morrill (1991) proposed a framework to model segregation by incorporating the potential of interaction among different ethnic groups (e.g., lowering the level of segregation if these ethnic groups are neighbors to one another). Wong (1993) subsequently proposed various specifications for modeling neighborhood relationships among different ethnic groups by deriving a family of spatial segregation indices. More recently, adopting the same concept of spatial segregation, Wong (1998) proposed a spatial segregation index for multiethnic settings, which makes use of the same concept of spatial segregation.

The neighborhood interaction framework adopted by Morrill and Wong was intended to encapsulate Newby's concept of segregation involving spatial separation. However, the neighborhood interaction framework includes only partially the notion of spatial separation suggested by Newby. The framework assumes that if neighboring areal units have different concentrations of minority populations, and different ethnic groups can interact by crossing areal boundaries, then the level of segregation will be reduced. In other words, the neighborhood interaction approach accounts for the potential interaction among groups when measuring segregation. Nevertheless, this approach does not directly measure how different groups are spatially separated.

If different ethnic groups are spatially separated, there will be little spatial correlation between their locations and distributions. The magnitude of spatial correlation among different ethnic groups across different areas or regions can provide a basis for comparing their relative levels of segregation. There are many possible approaches because the spatial separation of any two groups can be viewed as differences that exist between the spatial characteristics exhibited by different ethnic groups. One intuitive approach involves measuring the correlation between two ethnic groups within a region using classical correlation statistics (Unwin, 1981). In this case, however, the spatial distributions of different groups are not accounted for explicitly. Another possible approach is to derive the distances between people of different groups to show how these groups are spatially separated. In any case, it is not the intent of this paper to enumerate and evaluate different approaches to address the concept of spatial separation. Instead, this paper will focus on the utility of using geostatistical techniques to measure spatial separation among ethnic groups and to derive more effective measures of spatial segregation.

USING GEOSTATISTICAL MEASURES TO EVALUATE SEGREGATION

Though one may argue that the level of segregation varies by location within a region, most measures of segregation are summary values for the entire study region. To evaluate the spatial separation of different ethnic groups for the entire region, one can compare their locations. Drawing an analogy from classical statistics, each variable exhibits a certain distributional property. In order to compare the distributional locations of different variables, one can compare their means, a measure of central tendency. In a spatial context, the population of different ethnic groups may have different spatial distribution patterns. A summary comparison of their locations would therefore involve comparing their spatial means. The spatial mean is defined as

$$(\bar{x}, \bar{y}) = \left(\frac{\Sigma x_i}{n}, \frac{\Sigma y_i}{n}\right) \quad (1)$$

where x_i and y_i are the x and y coordinate of observation i, and where there are n observations in the entire study area. The spatial mean can be regarded as the locational summary of all the observations or the center of all locations (Ebdon, 1988). In equation 1, each observation is weighted equally, and each location is treated as an observation. Quite often, a location is the spatial centroid representing an area within which multiple observations are found. In such case, each location has to be weighted by the number of observations represented by the centroid. The weighted spatial mean is defined as

$$(\bar{x}, \bar{y}) = \left(\frac{\Sigma f_i x_i}{\Sigma f_i}, \frac{\Sigma f_i y_i}{\Sigma f_i}\right) \quad (2)$$

where f_i is the weight for location i. When comparing the locational differences between different ethnic groups, a spatial mean can be calculated for each group, so that the distances among the spatial means of corresponding groups will reflect the extent of spatial separation among them.

However, the spatial mean can measure only one aspect of the spatial distribution—the central location. It is possible that two ethnic groups have two very similar spatial means, but that the two groups are distributed very differently. For instance, one group can concentrate around the spatial mean while the other group may be relatively dispersed. To differentiate two groups with different degrees of dispersion, a measure of standard distance (Bachi, 1957) can be employed. Standard distance is

$$SD = \sqrt{\frac{\Sigma f_i (x_i - \bar{x})^2 + \Sigma f_i (y_i - \bar{y})^2}{\Sigma f_i}} \tag{3}$$

where all the notations are defined in the same manner as the previous equations. This version of standard distance assumes that each location is not an observation by itself, but instead represents a number of observations. Therefore, the weight is included in the calculation. Standard distance is the spatial equivalent of standard deviation and reflects the variation of the values around the mean. Therefore, standard distance can be used as the radius to create a circle—a standard distance circle—centered around the spatial mean (Taylor, 1977). Different standard distance circles can be created for the populations in different regions for cross-regional comparison or for different subsets of the population within the same region for inter-group comparisons. When the circles are calculated for different regions, the comparison has to take into account for variations in size between regions (Taylor, 1977).

Standard deviational circles have been applied in previous geographical research. A relatively recent example is Greene (1991), who compared the locational patterns of the underclass in several cities through time. For studies of segregation, a standard distance circle can be created for different ethnic groups to characterize *both* their locations (spatial mean) and their levels of spatial dispersion. If two groups overlap significantly, they are relatively "close" spatially, and thus are not highly segregated. In other words, the extent of overlap among standard distance circles associated with different groups can be used as a measure of segregation.

A standard distance circle, however, may not be able to capture another important aspect of a population's spatial distribution. For instance, it is possible that two population groups have similar central locations and have a similar degree of dispersion around the spatial mean, but in different directions. In this case, the orientations relating to the spatial extent of the two groups do not coincide. In other words, the spatial distributions of ethnic groups may have directional trends that a standard distance circle cannot reflect. To characterize the orientation of these distributions, a descriptive geostatistic, known as the standard deviational ellipse, has been developed. Furfey (1927) first proposed this technique, and Ebdon (1988) provided the computational procedure for fitting a set of points to a standard deviational ellipse. In addition to the spatial mean of the set of point locations, an ellipse has three components: the angle of rotation (θ), deviation of points along the x-axis (δ_x), and deviation of points along the y-axis (δ_y). These three components are derived, respectively, in the following manner:

$$\tan\theta = \frac{(\Sigma x'^2_i - \Sigma y'^2_i) + \sqrt{[(\Sigma x'^2_i - \Sigma y'^2_i)^2 + 4(\Sigma x'_i \Sigma y'_i)^2]}}{2\Sigma x'_i \Sigma y'_i} \tag{4}$$

$$\delta_x = \sqrt{\frac{\Sigma(x'_i \cos\theta - y'_i \sin\theta)^2}{n}} \quad (5)$$

$$\delta_y = \sqrt{\frac{\Sigma(x'_i \sin\theta - y'_i \cos\theta)^2}{n}} \quad (6)$$

In the previous three equations, x' and y' are the transformed x and y coordinates when all the points are centered at the spatial mean (equation 1), and n is the number of observations.

Standard deviational ellipses have not been used extensively. Abler et al. (1971) demonstrated how an ellipse can depict the orientation of daily activity patterns of households. Levine et al. (1995) used ellipses to uncover the spatial characteristics of different types of automotive accidents in Hawaii. Evidence shows that the standard deviational ellipse is a simple and powerful tool for discovering spatial patterns, and that the ellipse encompasses all of the spatial attributes of the previous two geostatistical measures. The ellipse is centered at the spatial mean, which is a summary of the point locations. The lengths of the two axes indicate the deviations of point locations along the major orientation and along the axis perpendicular to the major axis. Theoretically, if the set of point locations has no computable orientation or angle of rotation, the ellipse is reduced to a circle with a radius of 1/1.414 the radius of the standard distance circle. In addition to the spatial characteristics of location and dispersion, the ellipse also reflects the directional characteristics of the set of points.

In studying segregation, an ellipse can be derived for each ethnic group to reflect its location, dispersion, and orientation. If different ethnic groups have similar spatial distributions, which imply that they are not spatially separated and low segregation prevails, then ellipses from different groups should overlap significantly. In other words, the amount of overlap among ellipses can indicate the extent of spatial separation of the corresponding ethnic groups. Traditionally, the level of segregation is expressed as an index ranging from 0 to 1, reflecting no segregation and perfect segregation, respectively. In using ellipses to measure the degree of spatial separation, the overlap or intersection of ellipses can be regarded as the magnitude of spatial correlation, while the portions of ellipses outside the overlap can be regarded as the extent of spatial separation. In addition, the ratio formed by the intersection and the union of all ellipses reflects the proportion of spatial correlation. If we assume n population groups and that E_i is the ellipse of group i, then a spatial segregation index S based on the extent of spatial separation can be formulated as

$$S = 1 - \frac{E_1 \cap E_2 \cap E_3 \cap \ldots E_n}{E_1 \cup E_2 \cup E_3 \cup \ldots E_n} \quad (7)$$

As with the interpretation of many indices of segregation, the larger value in S indicates a higher level of segregation and vice versa. If all groups have identical spatial distribution characteristics, then their ellipses should coincide perfectly, and S will be zero. If different groups have very different distribution patterns, their ellipses will not overlap at all, and S will be one.

Normally, the calculation of ellipses and the set of ellipse operations are relatively straightforward. But when the set of point locations does not exhibit an orientation (i.e., when the points are distributed in the same manner in all directions), then the ellipse cannot be computed. Although in real-world applications, this kind of spatial configuration is highly unlikely, the use of ellipses still has to accommodate this situation. As mentioned before, if the set of point locations does not exhibit an orientation, theoretically the major and minor axes of the ellipse should have the same length and therefore the ellipse is the same as the standard distance circle with a shorter radius (Furfey, 1927). To make the "circular" ellipse (equations 4 through 6) comparable to the corresponding standard distance circle, the lengths of both axes have to be multiplied by $\sqrt{2}$. In the following simulation experiment and empirical examples, all ellipses are scaled to be comparable to their corresponding standard distance circles.

A SIMULATION EXPERIMENT

The purpose of this simulation is to demonstrate the applicability of standard deviational ellipses as a device for measuring segregation or integration. The setting of the experiment is presented in Figure 1, where nine hypothetical configurations (a through i) are created for illustrative purposes. In each configuration, there are two population groups, and the entire area is partitioned into a regular grid. People are assigned to the centroid of each cell and, therefore, all configurations are essentially regular lattices. Different configurations are created to show how ellipses can be used to characterize different population distribution patterns for the two groups. For each group in each configuration, an ellipse is calculated with the length of both axes multiplied by $\sqrt{2}$ so that its area is comparable to the standard distance circle as if point locations do not exhibit a specific orientation. For those groups showing no specific orientation, standard deviational circles are calculated instead. The ellipses or circles for both groups are plotted. If they overlap, the area of intersection is calculated. The union area of the two circles or ellipses is also calculated. Then the S index defined in equation 7 is calculated for each configuration to indicate the level of segregation. Statistics related to the S index are also included in Figure 1.

Configuration (a) resembles a checkerboard pattern. Each group exclusively occupies alternate cells—which probably represent the least segregated situation since each location is dominated by only one group. However, the two ellipses do not overlap completely, because group 1 occupies the extreme northwest and southeast corners and group 2 occupies the extreme northeast and southwest corners. Thus, although the two groups display the same degree of dispersion, they have rather different orientations. In this case, the level of segregation reflected by the S index is rather low (0.0618). This result is intuitively obvious since the people belonging to the two groups are juxtaposed to each other and create an environment for greater potential interaction. This result is also consistent with results previous spatial segregation studies (Wong, 1993; Wong, 1998) that suggested that the checkerboard patterns usually yield low levels of segregation, while using

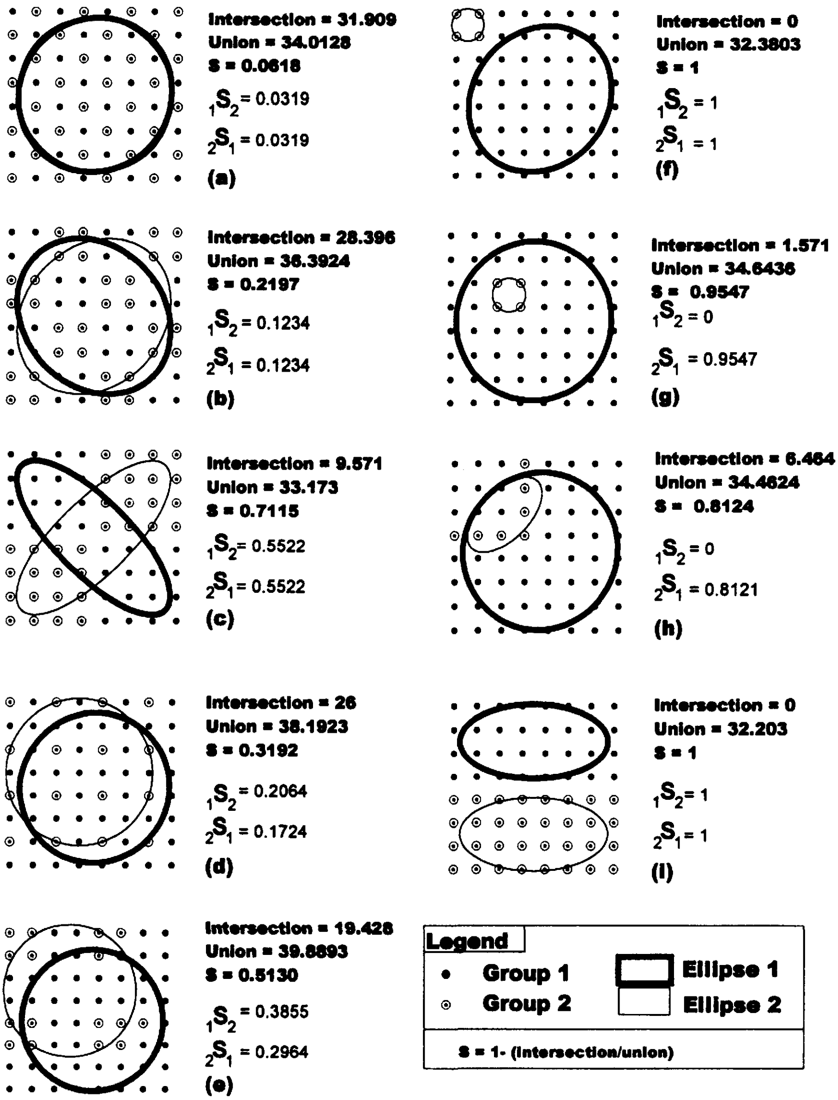

Fig. 1. The *S* indices and the conditioned *S* indices for simulated population configurations.

traditional aspatial segregation measures such as *D*, the results are always perfectly segregated as long as each areal unit is dominated by one group exclusively.

Configurations (b) and (c) are extensions of (a). Groups cluster more from (a) to (c) although the spatial dispersion of the two groups is basically the same in each configuration. However, the differences in orientation become more apparent. The level of segregation increases to 0.7115 in configuration (c) when the overlap of the two ellipses is limited to the central portion. Also, the two groups in configuration (c) have the same spatial mean. Ellipses are comprehensive and represent the spatial distribution characteristics of the two groups successfully.

Configurations (d) and (e) belong to the same "family." In (d), each group 2 cell, except those along the boundary, is completely surrounded by group 1 cells. The pattern becomes more clustered in configuration (e), which displays a slightly deviant pattern of group 1 cells that clustered in the southeast. The clustering of population in (e) reduces the degree of spatial dispersion and draws the locations of the two groups farther apart from each other as compared to (d). Therefore, the level of segregation is higher in (e) than in (d).

Configurations (f) and (g) reflect aspects of segregation concerned with both location and dispersion. The clusters of group 2 cells in both configurations have the same degree of spatial dispersion, but one is at the edge in (f) and one is completely surrounded by group 1 in (g). Because group 2 is compact and does not exhibit a direction, a standard distance circle is used to describe the group in both configurations. However, in configuration (f), group 2 is at the edge, the circle does not intersect the ellipse of group 1 at all. Thus, according to the specific size definition of the ellipse adopted, the configuration has perfect segregation because of the lack of locational correlation. In configuration (g), the locations of two groups are relatively close, but they each have a very different spatial extent. Group 2 is only a small subset of group 1. The level of segregation in this case is still relatively high.

Configuration (h) is similar to (g) with a moderate orientation and a high degree of dispersion. As a result, the level of segregation is lower than that in (g), even though the ellipse for group 2 is completely surrounded by group 1. In contrast, in configuration (i) ellipses for groups 1 and 2 do not overlap at all. According to the current formulation of the S index, the two groups are perfectly segregated.

In general, using ellipses or standard distance circles in specific cases can help to distinguish different spatial distribution patterns very successfully. By comparing the ellipses (or circles) spatially to derive the S index, the index effectively describes the extent of spatial separation among the population groups. But configurations (g) and (h) highlight an important issue in measuring spatial segregation—that is, that the segregation between groups is not a symmetrical relationship. Group 2 is completely surrounded by group 1 in both configurations (g) and (h). Conceptually, group 2 is not spatially separated from group 1, but large proportions of group 1 are spatially separated from group 2. Therefore, the levels of spatial separation displayed by the two groups with respect to the other group are different. By adopting the same concept that the amount of spatial overlap of the ellipses reflects the degree of spatial correlation, and that the nonoverlapping area reflects the degree of segregation, a variation of the S index, which is a conditioned S index, can be formulated. Borrowing the notation from the exposure index (Massey and Denton, 1988), let ${}_iS_j$ be the conditioned S index, the degree of spatial separation of group i from group j. Then

$$ {}_iS_j = 1 - \frac{E_i \cap E_j}{E_i} \qquad (8) $$

where all the notations are the same as in previous equations. The conditioned index indicates the proportion in group i not spatially correlated with group j. Thus, for any two-group comparison, a conditioned S index can be derived for each group. The same concept can be extended to compare the separation of one group from multiple groups. In such a case, the numerator will be the intersection of ellipses for all groups involved, and the denominator will be the union of ellipses for groups from which that group is separated. The values for the conditioned index are also reported in Figure 1. Three configurations (a, b, and c) exhibit a symmetrical relationship when the two groups are compared. Configurations (d) and (e) are slightly asymmetrical between the two groups. Exceptions are in configurations (g) and (h) where group 1 displays a moderate degree of separation from group 2, but group 2 is not separated from group 1. In the next section, the use of ellipses and the derivation of the S index is illustrated by data from Fairfax County and surrounding areas in Northern Virginia and Washington, DC.

A CASE STUDY

This case study employed data extracted from the 1990 Census of Population and Housing at the block level. The centroid of each block is used to represent the location of the block, and population counts of the four racial groups (White, Black, Indian-Eskimo-Aleut, Asian) are assigned to the centroid of each block. The areas selected for this analysis are Northern Virginia and Washington, DC. Fairfax County is the largest county in terms of population in Northern Virginia. In order to form a coherent Northern Virginia region, this study also includes Arlington (a neighboring county), and three other independent cities (Fairfax, Falls Church, and Alexandria) that are located in the vicinity. Washington, DC, is across the Potomac River east of Arlington and Fairfax counties. An ellipse is derived for each ethnic group in Northern Virginia and in Washington, DC, using ArcView, a desktop GIS package. The block centroid locations are extracted from ArcView data, and an Avenue script—the programming language for ArcView—based on equations 2, 4, 5, and 6 is used to derive the ellipses. These resulting ellipses are plotted in Figure 2. The S index and associated statistics for each area are also reported.

First, the distribution of Blacks in Northern Virginia does not exhibit a clear spatial orientation. Their geographical center is closer to Washington, DC, than that of other groups. The spatial centers of the other three groups are west of the center representing Blacks, and these groups also exhibit a slight east-west orientation, partly because of the shape of the region. Apparently, the geographical distributions of the four groups in Northern Virginia have relatively similar spatial patterns. Therefore, the area of overlap among the four ellipses is quite significant, and thus the S index calculated for Northern Virginia is 0.5.

For Washington, DC, population groups have different spatial distribution patterns. Blacks exhibit a northwest-southeast orientation. Indians, Eskimos, and Aleuts have similar orientation, but are more concentrated. Spatial means for both Whites and Asians are farther west or northwest of the other groups, and they do not exhibit any clear orientations. A visual inspection of the four ellipses indicates that the four groups have a high degree of spatial separation. The statistics related to the overlapping of ellipses indicate that the intersection of the four ellipses is relatively small as compared to the union of the ellipses. Consequently, the S index, 0.75, is relatively high as compared to Northern Virginia.

The conditioned S index is also derived for each ethnic pair in Northern Virginia and Washington, DC (Table 1). With respect to the notation in equation 8, the rows are i and

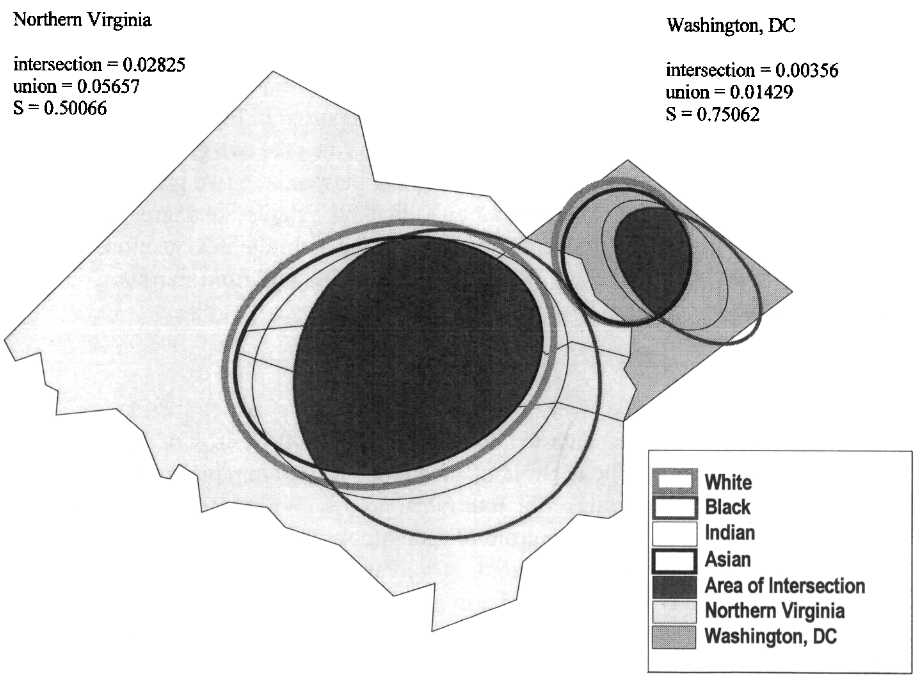

Fig. 2. The *S* indices and ellipses for Northern Virginia and Washington, DC.

the columns are *j*. It is obvious that many pairwise comparisons do not exhibit a symmetrical relationship. For instance, the separation of Indians from Blacks was relatively low (0.352), but the separation of Blacks from Indians was higher (0.620) in Washington, DC. This result is caused by the fact that Indians were relatively concentrated as compared to Blacks, and therefore a large portion of the Black population does not coincide with Indians spatially. In Northern Virginia, the separation of Asians from Whites was 0.0 because the ellipse for Asians was completely encompassed by Whites. On the other hand, the separation of Whites from Asians was 0.170, reflecting that a small portion of Whites was separated from Asians in Northern Virginia.

SUMMARY AND DISCUSSION

Based on Newby's conceptualization that segregation implies spatial separation among ethnic groups, this paper proposed the use of a standard deviational ellipse to characterize the spatial attributes (location, dispersion, and orientation) of each ethnic group. Ellipses derived from different groups can be compared spatially to derive an *S* index, which is a function of the intersection and union of all ellipses, thereby reflecting the degree of spatial separation of the ethnic groups within the study area. The *S* index provides an overall, or summary, measure for the entire study region for all groups by focusing on the overlapping area of the ellipses. However, the portions of ellipses not overlapping with others reflect the levels of spatial segregation specific to the correspond-

TABLE 1.—CONDITIONED S INDICES FOR NORTHERN VIRGINIA AND WASHINGTON, DC

$i\backslash j$	Whites	Blacks	Indians	Asians
Northern Virginia				
Whites	–	0.241	0.141	0.170
Blacks	0.305	–	0.239	0.388
Indians	0.094	0.124	–	0.184
Asians	0.000	0.197	0.068	–
Washington, DC				
Whites	–	0.620	0.504	0.125
Blacks	0.571	–	0.270	0.565
Indians	0.352	0.158	–	0.345
Asians	0.014	0.566	0.435	–

ing groups. Therefore, the conditioned S index, which reflects the spatial separation of one group from the other, was introduced.

In effect, the S index can be regarded as a spatial version of D. In the simplest sense,

$$D = 0.5 \times \sum_i \left| \frac{b_i}{B} - \frac{w_i}{W} \right| \tag{9}$$

where b_i and w_i are the Black and White population counts in areal unit i, and B and W are the total Black and White population counts in the entire study region. There are many interpretations of D. The two ratios inside $|.|$ indicate how the two groups are spread among areal subunits. If two groups have very similar distribution patterns among areal subunits, then D will approach 0, indicating no segregation. Therefore, D can be thought of as the total discrepancies in the distribution of the two groups over all subunits. As mentioned before, a major deficiency of D is that spatially rearranging subunits does not change the results. By fitting each population group with an ellipse, the spatial distribution of the population is captured. Then, by comparing the ellipses of different groups, we are essentially comparing their spatial spreads, but with the location information of the population already embedded in the ellipses. If the ellipses are similar (i.e., have considerable intersection), then the level of segregation is relatively low, and vice versa.

Mathematically, the S index ranges from 0 to 1. Ideally, 0 refers to no segregation and 1 refers to perfect segregation. However, the interpretations of the minimum and maximum have to be placed in context and have their limitations. When $S = 0$, all ellipses coincide perfectly, indicating all ethnic groups have the same distributional characteristics. However, an S index = 1 may not mean perfect segregation. In Figure 1, configuration (i) has two regions, each of which is occupied by one group exclusively. Depending on one's perception and definition of segregation, configuration (i) may not be regarded as perfect segregation. As Morrill (1991) and Wong (1993) argued, people along the boundary of the two regions are not segregated when an interaction approach to segregation is adopted, even the two groups occupy the two subregions exclusively. This idea brings us to consider to what extent spatial separation can be regarded as perfect segregation.

Recall that the ellipses in the simulation and case study are scaled by a factor of $\sqrt{2}$, so that the ellipses are comparable to their corresponding standard-distance circles. The ellipses can be expanded further (Furfey, 1927), such that the two ellipses in configuration (i) in Figure 1 can overlap one another. Consequently, the highest degree of segregation among these configurations (i.e., configuration [i]) is less than 1, but the relative levels or rankings of segregation among these configurations are not altered because of the expansion of the ellipses. In other words, one's notion of perfect spatial segregation determines the scaling factor for the ellipses, and the interpretations of the index based on the overlapping of ellipses has to be related to one's notion of segregation and the scaling factor. Despite the flexibility in determining perfect segregation, the *S* index can reflect relative segregation levels very effectively. Comparative studies should be consistent in adopting a particular scaling factor when deriving ellipses.

Using ellipses to capture spatial distribution characteristics and then derive the *S* index to reflect level of spatial segregation is conceptually simple. The *S* index is spatial in nature because rearranging population locations will yield different results (Goodchild, 1992). The concept of spatial separation captured by the *S* index is much simpler than the spatial version of *D* (Wong, 1993 and 1998). Though the *S* index is more complicated and difficult to compute than the calculation of *D*, the index of dissimilarity, it is still comprehensible when appropriate tools are used. GIS are probably the most appropriate tools to implement the *S* index. All spatial techniques or indices require spatial information in the form of locational, distance, or adjacency attributes. To derive ellipses, GIS can provide the locational information in geographic coordinates. Given all ellipse parameters, ellipses can be created and overlay operations can be used to derive the areas of intersection and union of the ellipses. All these processes can be implemented in most GIS environments. This paper focuses only on the spatial separation of ethnic groups. Nevertheless, the indices derived and illustrated here have the potential to be applied elsewhere to analyze broader spatial segregation issues in the urban environment, or any geographical issues related to incidences or population settlements.

Finally, similar to most measures of segregation, the *S* index is a summary measure of the entire study region. Within the region, level of segregation varies by location, and the *S* index, like other summary measures, cannot reflect effectively local variations in the degree of segregation.

NOTE

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