Spatializing Segregation Measures: An Approach To Better Depict Social Relationships

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Abstract

Segregation involves more than one population group, and segregation measures quantify how different population groups are distributed across space. One of the key conceptual and methodological foundations of segregation studies is to account for the potential of spatial interaction among two or more population groups across areal units. This foundation implies the need for a spatial approach to portray the spatial (and thus social) interaction among neighbors. In general, simple percentages (for example, percent Black) are not a measure of segregation. Because local spatial segregation measures did not emerge until recently, the objectives of this article are threefold: (1) to explain a spatial approach for measuring the level of segregation at the neighborhood (or local) level, (2) to demonstrate the deficiencies of using a percentage of racial/ethnic group as a measure of segregation, and (3) to clarify the appropriateness of two commonly used indexes of dissimilarity and diversity. Data from St. Louis, Missouri, and Chicago, Illinois, are used to discuss these three points.

Introduction

Residential segregation and the persistence thereof have long been topics of interest to a wide variety of academic disciplines (for example, sociology, demography, geography, political science, and public health) and to professionals or practitioners in multiple fields (for example, law enforcement, urban planning, and health service providers). Particularly in the United States, such phenomena have been viewed as a key factor of significant separation between White and Black residents.

Therefore, formulating potential solutions to reduce the levels of residential segregation have been considered as a major societal concern (for example, Anderson et al., 2003; Charles, 2003; Clark, 1986; Massey and Fischer, 2000; Taeuber, 1968; Williams, 1999; Williams and Collins, 2001). Note that all racial groups in this article refer to the non-Hispanic populations.

With a view to inform public policies and decisionmaking, however, the use of effective and meaningful segregation measures is fundamental and crucial to develop a reliable depiction and understanding of the social environment that different population groups experience in their place of residence (Johnston, Poulsen, and Forrest, 2014).[1] Since the publication of the review papers (for example, Massey and Denton, 1988; Massey, White, and Phua, 1996) that assessed several dozens of segregation measures, many more segregation measures have been introduced. Many of these newer measures are extensions or modifications of existing measures (for example, Feitosa et al., 2007; Reardon and O'Sullivan, 2004; Wong, 2008, 2002), but some are actually not measures of segregation (for example, Brown and Chung, 2006; Reibel and Regelson, 2007). The mushrooming in the number of segregation measures reflects that the concept of segregation is fluid, difficult to pin down, and multifaceted so that one or a few simple definitions are not capable of capturing its essence entirely. As a result, rather ineffective and insufficient ways of measuring segregation are evident in research and practice.

One major "malpractice" quite prevalent among studies focusing on neighborhood comparisons is using the percentage of racial and ethnic groups (for example, percent Black) as a measure of segregation to examine, for instance, the possible effects of residential segregation on academic performance (for example, Bennett, 2011; Card and Rothstein, 2007), home equity (for example, Deng, Ross, and Wachter, 2003; Kim, 2000), and health (for example, Inagami et al., 2006; Vinikoor et al., 2008). Census statistical units (tracts or block groups) have been used to denote the "neighborhoods" in most U.S. studies (including the six studies listed previously). Percentages, however, are not a measure of segregation (Johnston, Poulsen, and Forrest, 2007; Massey and Denton, 1988; Massey, White, and Phua, 1996; Reardon and O'Sullivan, 2004). A segregation measure needs to quantify how two or more population groups are distributed across space and to account for the potential of spatial interaction among population groups across areal units (Feitosa et al., 2007; Reardon and O'Sullivan, 2004; White, 1983; Wong, 2008, 2004, 2002, 1998, 1993).

Because the conceptual and methodological foundations of segregation studies have not been adequately translated into research and practice, the objectives of this article are threefold: (1) to explain a spatial approach for measuring the level of segregation at the neighborhood (or local) level, (2) to demonstrate the deficiencies of using a percentage of racial and ethnic group as a measure of segregation, and (3) to clarify the appropriateness of two commonly used indexes of dissimilarity and diversity. Data from two cities in the U.S. Midwest, St. Louis, Missouri, and Chicago, Illinois, are used to discuss such conceptual and methodological concerns.

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[1] We do realize that measuring segregation should not be constrained to residential space only, but segregation in the residential space, nevertheless, has received the most attention.

Methods

In this section, we first provide an overview about how measures that depict segregation levels at the local or neighborhood level are formulated. Both aspatial and spatial versions of these measures will be discussed. Then, we apply these measures to study the two cities.

Segregation Measures

The dissimilarity index (*D*) and the entropy-based diversity index (*H*) are two common segregation indexes used to measure the unequal or differential distributions of population groups (that is, the evenness dimension of segregation). *D* was introduced by Duncan and Duncan (1955), and its use was advocated by Massey and his colleagues (Massey and Denton, 1988; Massey, White, and Phua, 1996). On the other hand, *H* was introduced by Shannon (1948a, b) or Theil (1972), depending on the fields of study (also referred to as the Shannon index or Theil index, respectively), and its use in segregation studies was advocated by White (1986) and Reardon and Firebaugh (2002).

Both *D* and *H* share a limitation and a shortcoming, however. First, they are global measures that summarize the condition of the entire region (for example, a city or a metropolitan area); thus, they fail to recognize the variations at the neighborhood (or local) scale (Feitosa et al., 2007; Reardon and O'Sullivan, 2004; Wong, 2004, 1996). Second, they are aspatial measures that do not account for the spatial relationships between areal units; thus, swapping the entire populations between areal units will not change the index values (Morrill, 1991; White, 1983; Wong, 2004, 1998, 1993). To address these two issues, Wong (1998) implemented the concept of composite population count to capture spatial relationships for modifying the global aspatial segregation indexes into local spatial segregation indexes (2008, 2002).

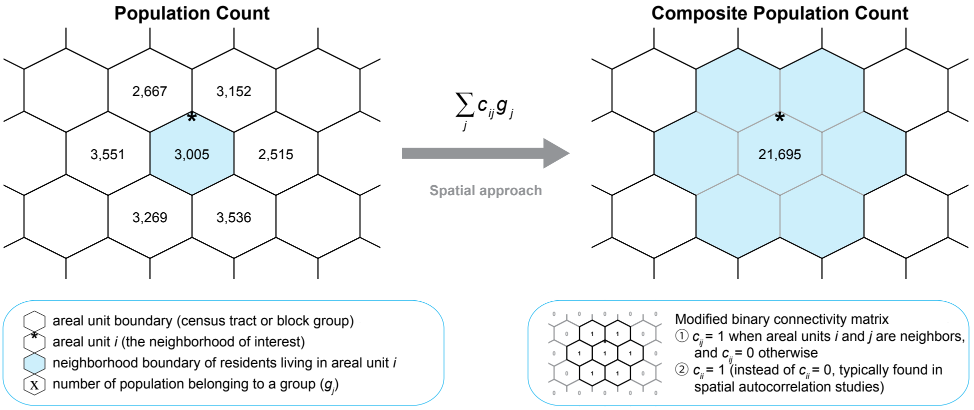
Borrowing the concept of modeling spatial autocorrelation, modifications of segregation indexes were achieved by adapting the function $c_{ij}(.)$ (Wong, 2008, 2002). Here, $c_{ij}(.)$ is the element of a (0, 1) matrix where $c_{ij} = 1$ indicates areal units *i* and *j* are neighbors, and $c_{ij} = 0$ otherwise; however, *i* can equal *j* and thus $c_{ii} = 1$. Therefore, the composite population count of group *G* in areal unit *i* (cg_i) is modeled as

$$cg_i = \sum_j c_{ij} g_j ,$$

where g_j is the population count of group *G* in areal unit *j*. In other words, a composite population count refers to the population count in areal unit *i* plus the population counts in its neighboring units *j*. This implicitly accounts for the spatial interaction of population groups across areal unit boundaries. Exhibit 1 illustrates how the function $c_{ij}(.)$ can be used to calculate the composite population count.

Exhibit 1

Illustration of the Concept of Composite Population Count



The concept and method of local spatial segregation measures did not emerge until recently (Wong, 2008, 2002). To explain the difference between aspatial and spatial segregation measures, specifications of the local aspatial dissimilarity index (D_i) and its spatial version (SD_i) along with the local aspatial diversity index (H_i) and its spatial version (SH_i) are given in the following discussion.

The local aspatial dissimilarity index (D_i) is defined as

$$D_i = \left| \frac{w_i}{W} - \frac{b_i}{B} \right|, \tag{1}$$

where w_i and b_i are the White and Black population counts in areal unit i, respectively, and W and B are the White and Black population counts for the entire study area, respectively. This index is the local aspatial version of the popular D. To derive the spatial version of this index, the local spatial dissimilarity index (SD_i), all population counts are replaced by their respective composite population counts—

$$SD_i = \left| \frac{cw_i}{CW} - \frac{cb_i}{CB} \right|, \tag{2}$$

where cw_i and cb_i are the composite White and Black population counts in areal unit i, respectively, and CW and CB are the composite White and Black population counts for the entire study area, respectively. This index is the local spatial version of the popular D.

The local aspatial diversity index (H_i) is defined as

$$H_i = -\sum_{k}^{n} \left(\frac{p_{ik}}{t_i}\right) \ln \left(\frac{p_{ik}}{t_i}\right), \tag{3}$$

where p_{ik} is the population count of mutually exclusive group *k* in areal unit *i* (for example, White, Black, Hispanic, … *n*), and t_i is the population count of total population in areal unit *i*. This index is the local aspatial version of the popular *H*. To derive the spatial version of this index, the local spatial diversity index (SH_i), all population counts are replaced by their respective composite population counts—

$$SH_i = -\sum_{k}^{n} \left(\frac{cp_{ik}}{ct_i}\right) \ln \left(\frac{cp_{ik}}{ct_i}\right), \tag{4}$$

where cp_{ik} is the composite population count of mutually exclusive group *k* in areal unit *i* (for example, White, Black, Hispanic, … *n*), and ct_i is the composite population count of total population in areal unit *i*. This index is the local spatial version of the popular *H*.

To demonstrate the use of these four local segregation indexes, they were computed in R (R Core Team, 2014) based on the 2005–2009 American Community Survey (ACS) data. Population counts by race and ethnicity at the census tract level were obtained for St. Louis (that is, St. Charles County, St. Louis County, and St. Louis City) and Chicago (that is, Cook County). Census tract data were used because they (unlike other areal units) are designed to be relatively homogeneous with respect to population characteristics, economic status, and living conditions (U.S. Census Bureau, 2014). Note that the 5-year ACS estimates are based on a larger sample size and, therefore, are more reliable than the 1- and 3-year estimates. Because census tract boundaries extend into rivers and include large ponds and lakes, such water bodies were removed when the total land area (in square kilometers) was recalculated in ArcGIS 10. The population and selected geographic characteristics of these two Midwestern U.S. cities are summarized in exhibit 2.

Exhibit 2

Selected Summary Statistics of Two Midwestern U.S. Cities: St. Louis and Chicago

	St. Louis	Chicago
Distance between cities[a] (km)	≈ 480	
Total land area[a] (km^2)	2,918	2,433
Census tracts[b]	340	1,327
Total population[b]	1,692,563	5,257,001
Non-Hispanic White[b] (%)	70.0	45.2
Non-Hispanic Black[b] (%)	23.3	25.3
Hispanic[b] (%)	2.4	22.5
Asian[b] (%)	2.6	5.6
Other racial and ethnic groups[b] (%)	1.7	1.4

km = kilometers.

[a] *Derived from the Geographic Information System calculation by authors.*

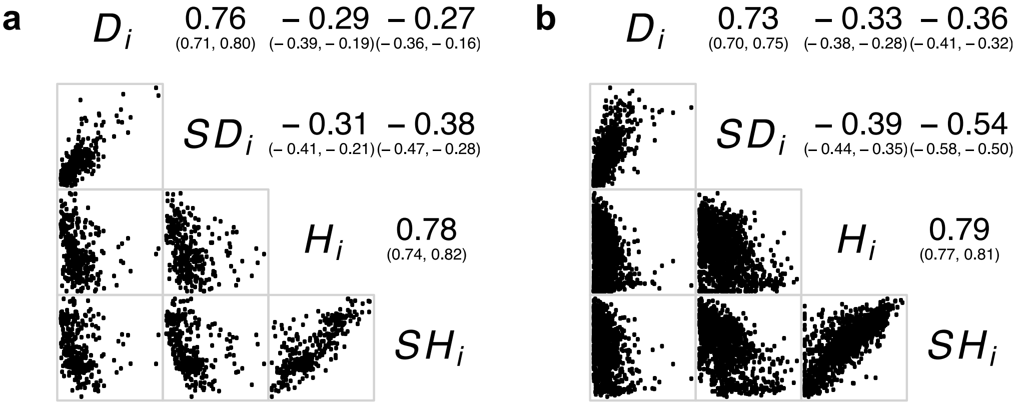
[b] *Derived from the 2005–2009 American Community Survey.*

Analysis

To examine the relationships of local aspatial and spatial segregation measures derived from the previous section (that is, D_i, H_i, SD_i, and SH_i), two separate correlation statistics (Friendly, 2002) were computed in R (Wright, 2012) for St. Louis (exhibit 3a) and Chicago (exhibit 3b). Correlations and scatterplot matrixes were used to display the relationships. The upper off-diagonal panels show the correlation coefficients with associated 95-percent confidence intervals (in parentheses), and the lower off-diagonal panels show the scatter plots.

Exhibit 3

Correlations of Local Aspatial and Spatial Segregation Measures in Two Midwestern U.S. Cities: (a) St. Louis and (b) Chicago

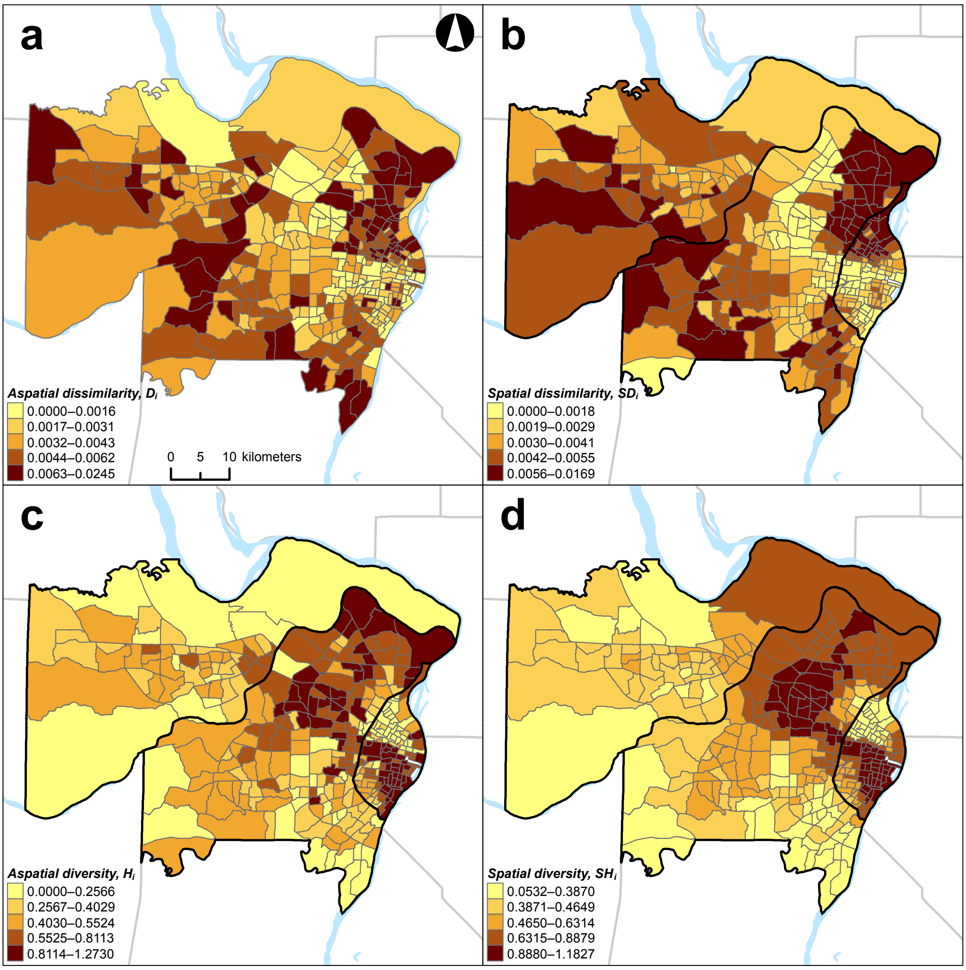


Note: Data represent 340 census tracts in St. Louis and 1,327 census tracts in Chicago.

As a way to understand the spatial patterns of racial and ethnic groups, the geographic distributions of local aspatial and spatial segregation measures are shown in maps for St. Louis (exhibit 4) and Chicago (exhibit 5). For demonstration purposes, the geographical distributions of percent White, Black, Hispanic, and Asian are also shown in maps for St. Louis (exhibit 6) and Chicago (exhibit 7). In these four maps, a quantile classification scheme was used to display the levels of segregation.

Exhibit 4

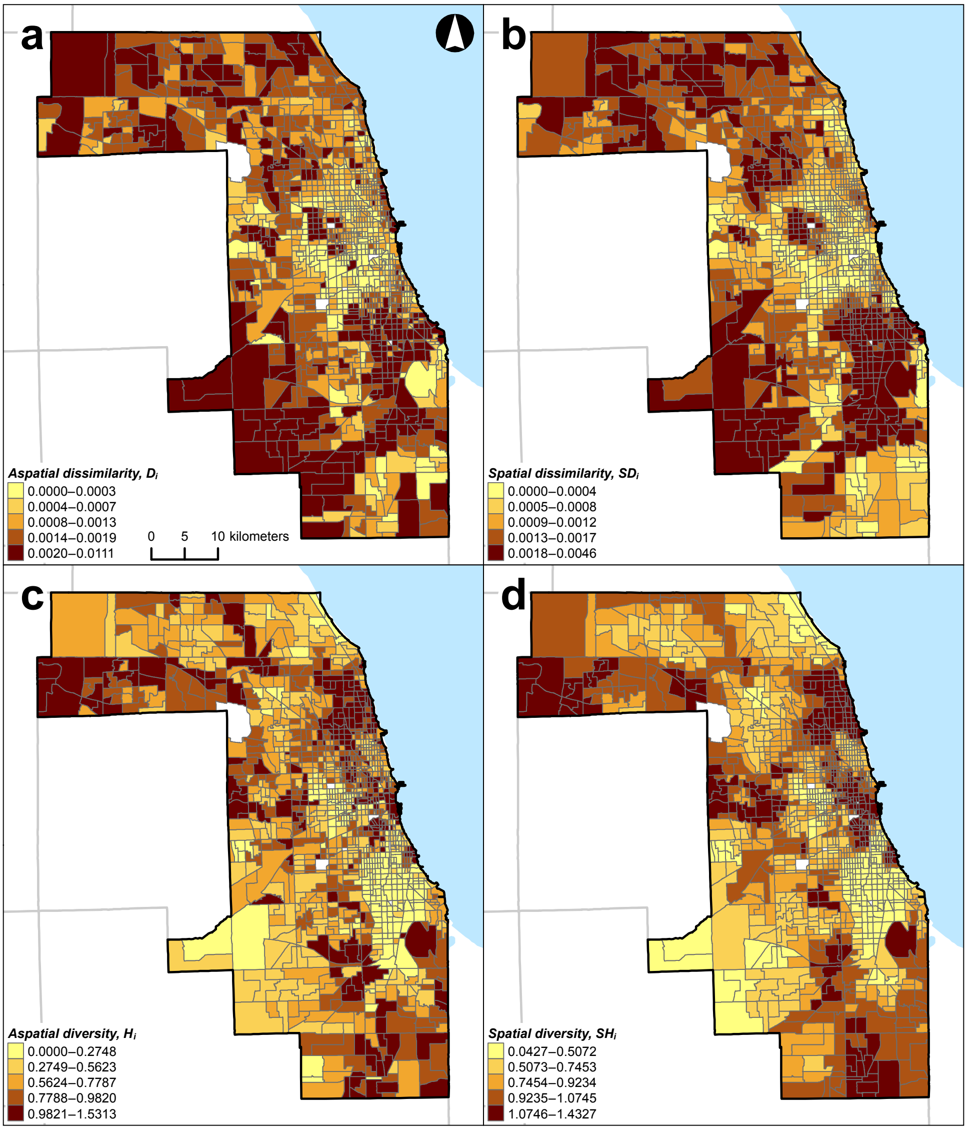
Geographic Distributions of Local Aspatial and Spatial Segregation Measures in St. Louis



Notes: A quantile classification scheme was used to display the levels of residential segregation. Data represent 340 census tracts.

Exhibit 5

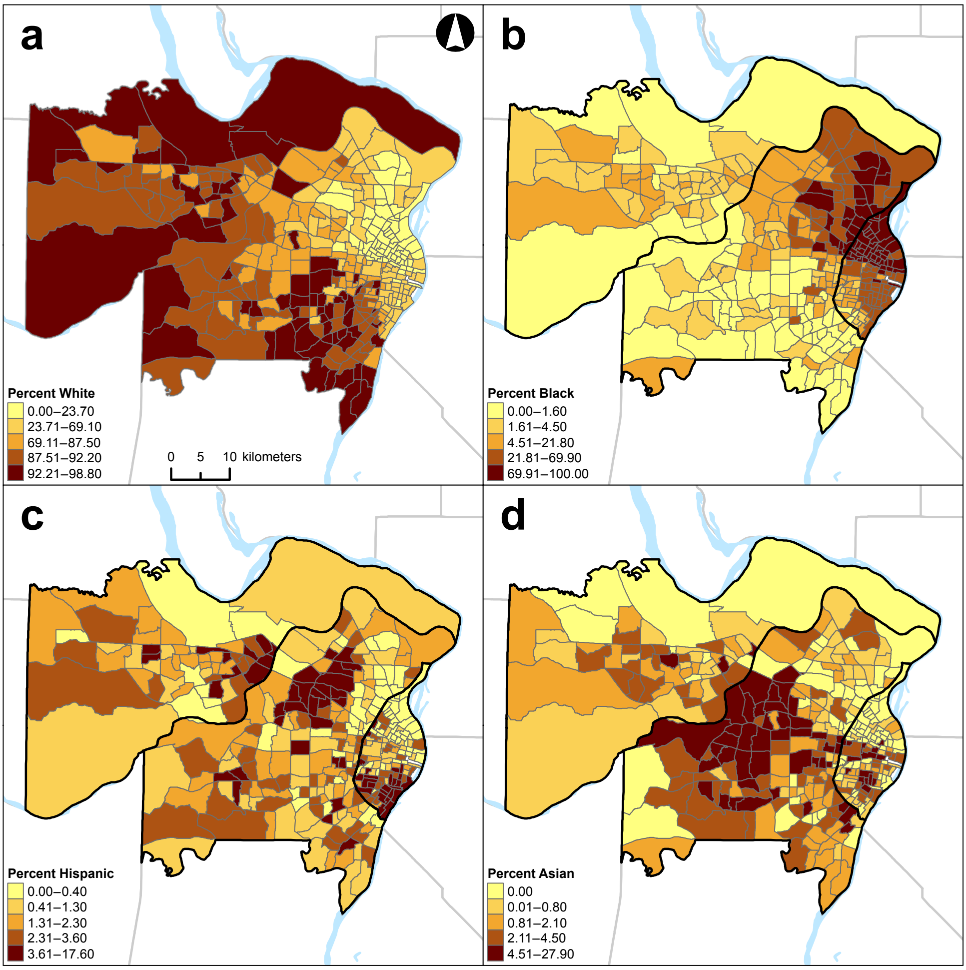
Geographic Distributions of Local Aspatial and Spatial Segregation Measures in Chicago



Notes: A quantile classification scheme was used to display the levels of residential segregation. Data represent 1,327 census tracts.

Exhibit 6

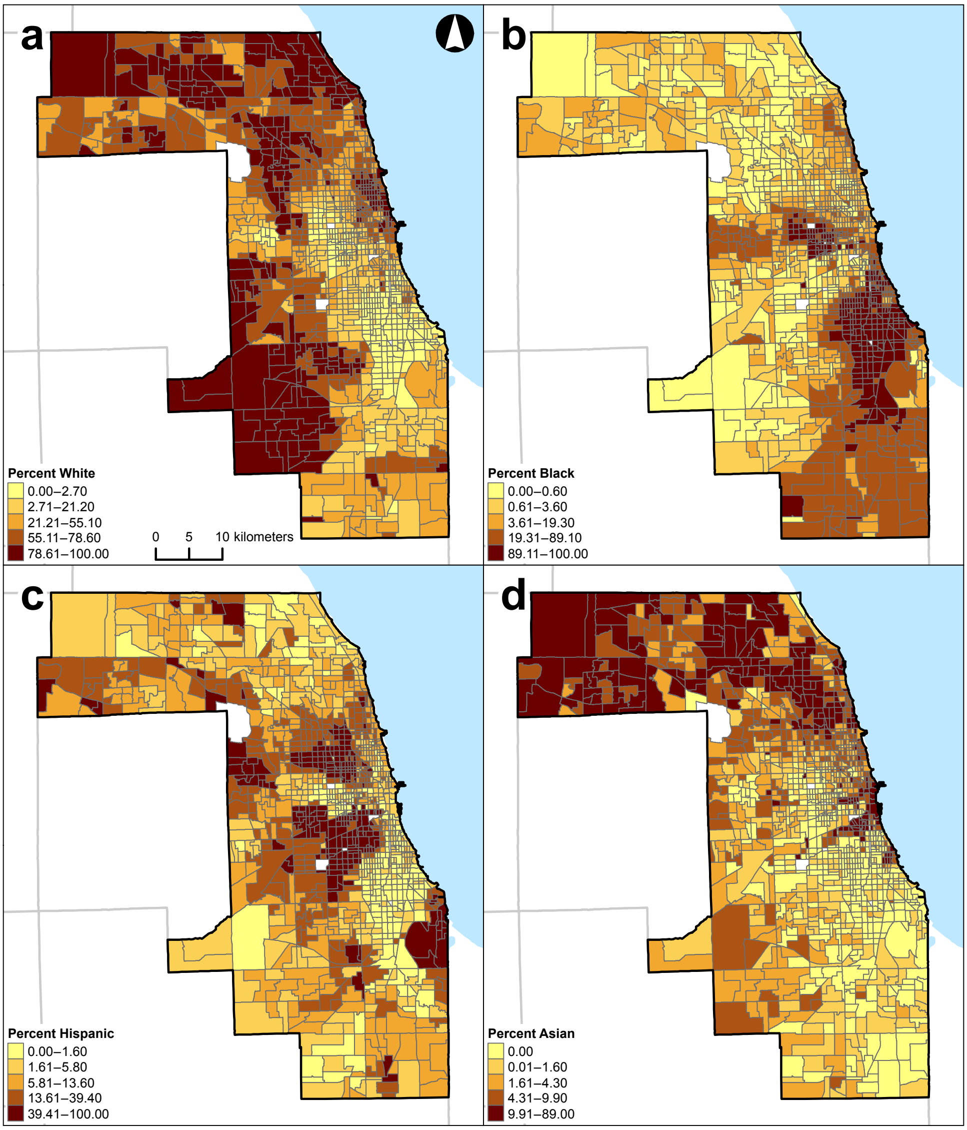
Geographic Distributions of Racial and Ethnic Groups Expressed as Percentages in St. Louis



Notes: A quantile classification scheme was used to display the levels of residential segregation. Data represent 340 census tracts.

Exhibit 7

Geographic Distributions of Racial and Ethnic Groups Expressed as Percentages in Chicago



Notes: A quantile classification scheme was used to display the levels of residential segregation. Data represent 1,327 census tracts.

Results

As illustrated in exhibit 1, the basic principle of the composite population count uses the function $c_{ij}(.)$ to remove the enumeration boundaries as the absolute barriers for intergroup interaction by aggregating population counts across adjacent (or contiguous) neighborhoods. Such operation provides a more realistic portrayal of the spatial (and thus social) interaction among neighbors in their place of residence than that of such interaction to occur only within the confined unit boundary (that is, colored cells on the right versus left).

The two Midwestern U.S. cities were examined because they are in the same geographic region with similar total areas, but they have different population characteristics (exhibit 2). In St. Louis, about 70.0 percent of the population was White and 23.3 percent was Black. In Chicago, however, the population was composed of fewer White residents relatively (45.2 percent), about the same proportion of Black residents (25.3 percent), and a larger proportion of Hispanic residents (22.5 percent). The proportion of the Asian population was slightly larger in Chicago (5.6 percent) than it was in St. Louis (2.6 percent).

Exhibit 3 displays the relationships between the local aspatial and spatial segregation measures in St. Louis (exhibit 3a) and Chicago (exhibit 3b). Overall, similar trends can be seen in the two cities. Comparing local aspatial segregation measures with their spatial counterparts, D_i and H_i are moderately and positively correlated with SD_i ($r = 0.76$ in St. Louis and $r = 0.73$ in Chicago) and SH_i ($r = 0.78$ in St. Louis and $r = 0.79$ in Chicago), respectively; scatterplot matrixes also suggest modest linear associations but relatively high degrees of variation between the two types of measures in the two cities. As explained previously, such differences are attributable to the incorporation of the function $c_{ij}(.)$ or the lack thereof (exhibit 1). Moreover, in comparison with dissimilarity and diversity measures, both D_i and SD_i are weakly, but negatively correlated (or not correlated) with H_i and SH_i ($-0.27 \leq r \leq -0.38$ in St. Louis and $-0.33 \leq r \leq -0.39$ in Chicago); the only exception here is that SD_i is moderately, but negatively, correlated with SH_i ($r = -0.54$) in Chicago.

Exhibit 4 (for St. Louis) and exhibit 5 (for Chicago) show that results of correlation analysis in exhibits 3a and 3b, respectively, are manifested spatially in the two cities. By comparing the geographical distributions of D_i with SD_i (4a versus 4b and 5a versus 5b), as well as H_i with SH_i (4c versus 4d and 5c versus 5d), it is clear that local aspatial segregation measures and their spatial counterparts do not exactly resemble similar spatial patterns; noticeably, SD_i (4b and 5b) and SH_i (4d and 5d) show much “smoother” spatial patterns and lower segregation levels than D_i (4a and 5a) and H_i (4c and 5c), respectively. In addition, neither the geographical distributions of D_i (4a and 5a) nor SD_i (4b and 5b) are the opposite of H_i (4c and 5c) and SH_i (4d and 5d). Put differently, areas with the highest (or lowest) values of D_i and SD_i do not always correspond to the lowest (or highest) values of H_i and SH_i in the two cities.

As emphasized earlier, percentages of racial and ethnic groups should not be used as a measure of segregation, because the geographical distributions of percent White, Black, Hispanic, and Asian cannot quantify how different population groups are distributed across areal units. For example, in St. Louis, areas with higher percentages of White (exhibit 6a), Black (exhibit 6b), Hispanic (exhibit 6c), and Asian (exhibit 6d) residents coincide in the central, northwestern, and lower eastern parts of

St. Louis. Similarly in Chicago, areas with higher percentages of White (exhibit 7a), Black (exhibit 7b), Hispanic (exhibit 7c), and Asian (exhibit 7d) residents coincide along the shore of Lake Michigan and in the northern, central, and southern parts of Chicago. Taken together, a higher percentage of a racial/ethnic group could refer to both a racially/ethnically dominated and diverse (or integrated) neighborhood in the two cities. More importantly, simple percentages can capture the within-unit relationships, but they cannot capture the between-unit relationships as modeled in spatial segregation measures. Despite their simplicity, both exhibits 6 and 7 demonstrate that the percentage of racial/ethnic groups is not an appropriate measure of segregation (Johnston, Poulsen, and Forrest, 2007; Massey and Denton, 1988; Massey, White, and Phua, 1996; Reardon and O'Sullivan, 2004).

Discussion

A series of correlation and visual analysis of St. Louis and Chicago (exhibits 3 through 7) leads to two main conclusions: (1) local spatial segregation measures (SD_i and SH_i) produce a "smoother" spatial pattern and lower segregation levels than their aspatial counterparts (D_i and H_i, respectively), and (2) the two-group-based dissimilarity measures (D_i and SD_i) do not capture the local variation of segregation as the multiple-group-based diversity measures (H_i and SH_i) do (aspatial and spatial alike). These results, in turn, highlight two important remarks about the measurement of segregation.

For the first remark, the difference between aspatial and spatial approaches to measure segregation reflects the recent methodological achievements. Most segregation indexes introduced in the early era of developing segregation measures are aspatial in nature (for example, Morrill, 1991; White, 1983; Wong, 1993). A typical example used to demonstrate the aspatial nature is a checkerboard pattern in which each cell is dominated by only one group and cells are arranged in a spatially alternate manner. Calculating D for such a pattern produces a value of 1, indicating perfect segregation. Clustering together all cells that belong to one group, creating a perceivably more segregated pattern, will also produce a D value of 1. The bottom line is that D does not consider the spatial relationship of population distribution and, thus, exaggerates segregation levels. A similar demonstration can be conducted for H. To overcome this limitation, existing measures were modified to incorporate spatial information into the formulations so that these spatial versions of the indexes consider the spatial distributions of different population groups.

A common approach is to include populations in the neighboring units when evaluating the population characteristics of a unit (Feitosa et al., 2007; Reardon and O'Sullivan, 2004; Wong, 2008, 2002). Doing so implicitly allows for the mixing of neighboring populations, removing the artificial boundaries between units in separating the populations. Both Reardon and O'Sullivan (2004) and Feitosa et al. (2007) adopted the fancy concept of a spatial kernel to derive the weights to count populations in the neighboring units toward the reference unit. The kernel implements the distance decay concept so that population at and near the reference unit will be counted more and populations in farther away units will be counted less. Nevertheless, the basic principle of using the simplistic composite population count (Wong, 2008, 2002) or the elegant spatial kernels is the same. Because local spatial segregation measures (compared with their aspatial counterparts) provide a more realistic portrayal of the spatial (and thus social) interaction among neighbors, future studies should consider using local spatial segregation indexes.

Regarding the second remark, the difference between dissimilarity and diversity measures (aspatial and their spatial versions alike) warns that a careful consideration is needed before choosing the segregation index in future studies. Both *D* and *H* measure the evenness dimension of segregation. From a conceptual standpoint, these two measures are the inverse of each other (Massey and Denton, 1988; Massey, White, and Phua, 1996). Such an expectation does not generally hold, however (exhibits 3 through 5). *D* has become one of the most popular measures of segregation.[2] The popularity of *D* is, in part, induced by its easy calculation and interpretation. Also, the use of *D* was popularized by the strong endorsements from Massey and his colleagues (Massey and Denton, 1988; Massey, White, and Phua, 1996).[3]

Despite many desirable properties, the use of *D* in segregation studies has long been criticized for its inconsistencies with the notions of segregation (for example, Reiner, 1972; Winship, 1978; Zelder, 1972). In fact, Cortese, Falk, and Cohen (1976) demonstrated some of the systematic biases in *D* nearly four decades ago. More recently, a major concern of *D* raised by White (1983) is that the measure is insensitive to the spatial arrangement of population distribution. Simply put, by swapping the populations in any two subareas (for example, neighborhoods) within a larger region (for example, a city or a metropolitan area), the value of *D* will not change; *D* is influenced only by the population mix within each areal unit and does not consider who are "next" to each other. On the other hand, *H* has been determined to be a superior measure. It conceptually and mathematically satisfies the desirable decomposition properties for handling multiple population groups in segregation studies (Reardon and Firebaugh, 2002; White, 1986). Because *H* is global and aspatial in nature, future studies should consider using its local spatial version (that is, SH_i).

In summary, local spatial segregation measures produce "smoother" spatial patterns at lower segregation levels than their aspatial counterparts, and the dissimilarity measures cannot handle multiple-group comparisons as effectively as the diversity measures. For these reasons, the use of SH_i (instead of SD_i) is recommended to measure the unequal or differential distributions of racial and ethnic groups (that is, the evenness dimension of segregation) in future studies.

Limitations

Two challenges should be considered when using SH_i in future studies. First, SH_i captures only the evenness dimension of segregation that Massey and Denton (1988) claimed to be the most important dimension of segregation. It fails to evaluate another important and distinct dimension of segregation, however—isolation (that is, the potential interaction of population groups; Johnston, Poulsen, and Forrest, 2007; Reardon and O'Sullivan, 2004). The isolation index (P^*) (Lieberson, 1981) has been regarded as the standard index to measure isolation. Wong (2008, 2002) introduced the local spatial version of P^*, denoted as the local spatial isolation index (S_i). Although the detailed explanation of S_i is beyond the scope of this article, SH_i and S_i should be used to reflect the evenness and isolation dimensions of segregation, respectively.

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[2] A search on http://www.scholar.google.com (on September 16, 2014) showed that the paper by Duncan and Duncan (1955) has been cited 1,898 times.

[3] A search on http://www.scholar.google.com (on September 16, 2014) showed that these seminal review papers together have been cited 1,911 times (1,731 and 180 times, respectively).

Second, SH_i (as well as all spatial segregation indexes) is influenced by the boundary or edge effect. Such effect introduces bias into the identification of spatial distribution and the parameter estimates of spatial processes (Griffith, 1983). Several solutions have been proposed, but none can fully solve the problem (Griffith, 1987, 1980). One rather simple practical solution, which was not implemented in this study, is to include a buffer zone around the study area. Because the function $c_{ij}(.)$ adopted to implement the concept of composite population involves only the immediate neighboring units (Wong, 1998), a buffer zone including the first order adjacent units along the study area will be sufficient for using SH_i to measure the level of segregation.[4]

Conclusion

The use of effective and meaningful segregation measures holds the key to examining the possible (that is, adverse, protective, or null) effects of residential segregation on its residents (Johnston, Poulsen, and Forrest, 2014). Otherwise, only limited (if not biased) knowledge can be gained to formulate potential solutions to reduce the levels of segregation, and then to inform public policies and decisionmaking. A gap between the conceptual and methodological achievements in segregation studies and their implementations in different fields is quite prevalent, however, especially among those focusing on neighborhood comparisons.

From a critical point of view, the continued uses (or misuses) of ineffective and insufficient segregation measures will substantially undermine the purposes of research and their potential contributions to inform public policies and decisionmaking. Hence, future research needs to build on the conceptual and methodological foundations of segregation studies established by demographers, geographers, and sociologists.

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[4] Because the $c_{ij}(.)$ function can be implemented differently (for instance, including higher order neighbors), the buffer size should be adjusted accordingly to contain the edge effect.

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