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Measuring segregation: an activity space approach

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Abstract

While the literature clearly acknowledges that individuals may experience different levels of segregation across their various socio-geographical spaces, most measures of segregation are intended to be used in the residential space. Using spatially aggregated data to evaluate segregation in the residential space has been the norm and thus individual's segregation experiences in other socio-geographical spaces are often de-emphasized or ignored. This paper attempts to provide a more comprehensive approach in evaluating segregation beyond the residential space. The entire activity spaces of individuals are taken into account with individuals serving as the building blocks of the analysis. The measurement principle is based upon the exposure dimension of segregation. The proposed measure reflects the exposure of individuals of a referenced group in a neighborhood to the populations of other groups that are found within the activity spaces of individuals in the referenced group. Using the travel diary data collected from the tri-county area in southeast Florida and the imputed racial-ethnic data, this paper demonstrates how the proposed segregation measurement approach goes beyond just measuring population distribution patterns in the residential space and can provide a more comprehensive evaluation of segregation by considering various socio-geographical spaces.

Keywords

Socio-geographical spaces; Activity space; Exposure; Travel diary

1 Introduction

Research in segregation has been focusing heavily on population distribution in the residential space. Using spatially aggregated census data to compute summary measures of segregation for a region or city has been a standard approach. Two general but related characteristics in segregation studies can be identified. First, while the importance of residential pattern in studying racial-ethnic relationships is well established in the literature, studies leaving out other socio-geographical spaces may offer only a partial or even biased assessment of the segregation situation. Second, census data aggregated to various census geography levels are the main sources of data for assessing residential segregation. Results from such ecological analysis should not be used to infer individual experiences. From a spatial perspective, most studies use global measures summarizing the segregation condition of the entire region or study area, failing to recognize the spatial variability of segregation across neighborhoods or individuals. So far, a few studies have shown how segregation level

varies by neighborhoods using local measures (e.g., Feitosa et al. 2007; Wong 2002) and have demonstrated how local segregation may have impacts on health outcomes (Grady 2006; Grady and McLafferty 2007). Because the computations of these local measures are based upon aggregated data which reflect the neighborhood situations, these local measures do not capture an individual's experience effectively.

The literature has shown clearly that racial–ethnic relations vary across socio-geographical spaces (e.g., Blumen and Zamir 2001; Ellis et al. 2004). Significant segregation in the residential space is well recognized, but relatively desegregated work or employment space is quite common (Estlund 2003). While quite a few studies have analyzed the differences in racial–ethnic relationship across socio-geographical spaces or spheres, measuring the level of segregation individuals may experience across relevant socio-geographical spaces has not been addressed explicitly. In this article, we propose an approach to evaluate the level of segregation that an individual may experience. The spatial domain of the concerned individual is delineated according to the concept of activity space. The proposed segregation measure is an extension of an exposure measure suggested by Lieberman (1981). An individual's segregation experience is a function of his or her exposure to other groups within his/her activity space. Activity spaces of individuals of the same group resided within a neighborhood are aggregated to represent the activity space of the entire group. Using the aggregated activity space, exposure of individuals in the group is evaluated to reflect the neighborhood condition.

2 Relevant literature

This article argues that segregation outside of the residential space should be taken into consideration in evaluating segregation level and suggests an exposure measure implemented through the concept of activity space. Therefore, the literature review will focus on only three aspects: (1) segregation studies across multiple socio-geographical spaces, (2) the exposure dimension and measures of segregation, and (3) the concept of activity space and its implementations.

2.1 Segregation in various socio-geographical spaces

Although segregation based upon population characteristics such as gender, occupation, and income have been discussed and analyzed (e.g., Abramson et al. 1995; Blair and Lichter 1991; Deutsch et al. 1994), segregation along the racial–ethnic line has clearly attracted the greatest attention in society and academic studies. On the other hand, racial–ethnic segregation seems to be the most profound and easily recognizable in the *residential space* (e.g., Dawkins 2004). Residential patterns have significant impacts on various socioeconomic and demographic aspects (Massey 1990). As a result, most studies of racial–ethnic segregation have focused on the residential space. High degree of residential segregation is often associated with issues in environmental justice (Bowen et al. 1995; Groves et al. 1996; Perlin et al. 2001; Sexton and Adgate 1999), access to facilities, opportunities and medical health services (e.g., Abramson et al. 1995; Galster and Killen 1995; Cromley and McLafferty 2002), and housing market discrimination (Yinger 1979.)

Although segregation in the residential space has been the center of most studies, segregation in other socio-geographical spaces has attracted some attention. To school-age children, segregation in the *school space* could have significant impacts (DuBois 1934; U.S. Commission on Civil Rights 1967), and therefore measuring school segregation is of interest to some researchers (e.g., Reardon et al. 2000; Zoloth 1976). On the other hand, most adults spend a significant proportion of their time in their *work space* and segregation at work and in labor markets is also a concern (Blair and Lichter 1991; Deutsch et al. 1994).

Besides these three social spaces, residential, school, and work, other socio-geographical spaces are of lesser concerns in terms of segregation. Most studies focus on only one of these spaces, ignoring the fact that an individual or household may experience segregation in varying degrees across these socio-geographical spaces. Some studies examine how the interaction between different socio-geographical spaces may affect segregation. Using Israel's census data, Blumen and Zamir (2001) argued that workers in Tel Aviv had different segregation experiences across the residential space and employment space. They computed the index of dissimilarity, D , by employment and residential units to indicate the social and spatial distances between population groups. D is generally defined as the sum of the absolute differences between the two ratios reflecting how the two population groups are distributed across all units in the study area (Massey and Denton 1988). Arguing that census units are not merely for residential purposes, but also for employment, Ellis et al. (2004) computed the index of dissimilarity for the Los Angeles area to illustrate that segregation levels in the employment space are lower than that in the residential space. This conclusion confirms one of the main themes in Estlund (2003) that segregation in the employment space is less severe than that in the residential space. Results of these studies imply that an individual may experience different levels of segregation in different socio-geographical spaces, and therefore segregation level in the residential space reflects only one facet of the multispace experiences of an individual.

2.2 Exposure measure for segregation

Although some of the studies discussed above analyzed the differences in segregation across selected socio-geographical spaces and provided conceptual explanations of the differences, they do not offer specific methods or approaches to evaluate the level of segregation that an individual may experience across relevant socio-geographical spaces. In these studies, subjects of analysis are census units, which are treated as both residential and employment units. The index of dissimilarity, D , is often used to indicate the segregation level for the entire study area, and therefore cannot reflect the experiences an individual may have across different socio-geographical spaces. While Massey and Denton (1988) endorse the use of the D index as an evenness measure, recent literature has been quite critical about the use of the index, partly on the utility of the evenness dimension in measuring segregation (Reardon and O'Sullivan 2004; Brown and Chung 2006), and partly on the fact that the index and other traditional segregation measures cannot distinguish population distribution patterns effectively (e.g., Morrill 1991; Wong 1993).

Schnell and Yoav (2001) proposed a set of sociospatial isolation indices reflecting the segregation level of an individual based upon the spaces in which an individual conducts his or her daily activities. The two indices can accommodate two population groups, and they complement each other with one index reflecting isolation, and another reflecting the level of exposure to the other group. These indices are weighted by the time an individual spent in various spaces. Both indices are ratios of population counts. The isolation index is the proportion of population in the unit that belongs to the group of concern. The exposure index is the ratio between the population size of the concerned group and the total population size of other groups in the unit.

In this article, we propose an alternative index summarizing the level of segregation that an individual may experience across various socio-geographical spaces where the individual has conducted activities. Different from the formulation by Schnell and Yoav (2001) that clearly divides activities into various spaces or zones, our proposed approach adopts the activity space concept as the foundation to formulate the proposed index. The proposed approach is intended to be more comprehensive than current approaches by considering all relevant socio-geographical spaces in evaluating segregation with a focus on individuals.

The proposed index is based upon the concept of exposure, and its formulation is quite similar to the original set of exposure measures suggested by Lieberman (1981).

The set of segregation measures proposed by Lieberman (1981) is regarded as measures of exposure, one of the five dimensions of segregation summarized by Massey and Denton (1988). The five dimensions are evenness, exposure/isolation, concentration, centralization and clustering. Subsequent studies argued that the meaningful dimensions of segregation are less than five. Reardon and O'Sullivan (2004) came to the conclusion that the five dimensions can be reduced to two composite dimensions of evenness-clustering and isolation-exposure, and "centralization and concentration dimensions can be seen as specific subcategories of spatial unevenness" (p. 127). Brown and Chung (2006) reduced the five dimensions to two: evenness-concentration and clustering-exposure. They argued that evenness is similar to concentration and clustering represents low exposure. They also claimed that "in today's increasingly polycentric, multimodal and sprawled city, centrality has little meaning" (p. 126). Therefore, the original centralization dimension was left out in their framework.

Despite these efforts in consolidating the original five segregation dimensions, exposure is a relatively distinctive dimension. It is applicable to describe the situation of both a population group and an individual. In studying the segregation level of an individual across relevant socio-geographical spaces, the exposure dimension is probably the most appropriate. All other dimensions concern some aspects of population distribution patterns and fail to evaluate individual experiences. In the original formulation of the exposure indices, the exposure of group a to group b (i.e., $a \times b$) is

$$P_{a \times b} = \sum_{i=1}^n (a_i/A)(b_i/t_i) \quad (1)$$

where a_i , b_i , and t_i are the population counts of the two group and total population in unit i , respectively, A is the total population of group a in the entire region, and n is the total number of areal units in the entire region. Therefore, the first ratio in Eq. 1 is the proportion of population group a residing in unit i and the second ratio is the probability that someone selected in unit i belongs to group b . Thus, the product of the two ratios indicates the exposure of an individual in group a to group b within unit i . However, exposure is not symmetrical between groups. Therefore, by swapping terms between the two population groups in Eq. 1, $P_{b \times a}$, exposure of b to a , can be derived. The exposure measures use population data aggregated to census units in the computation, and the resultant measures reflect the exposure level of an average person in one group to the other group within the same local unit. The original formulation also assumes that individuals in i cannot interact with or are not exposed to another group outside of unit i , even if the other group is adjacent to unit i .

A modified version of the exposure measure was introduced by taking into account of neighboring population characteristics, and the exposure levels are disaggregated to reflect the average exposure of an individual in one group within an areal unit to another group within the neighborhood (Wong 2002). In this case, the geographical scope of exposure to another group is constrained by the neighborhood, which is often delineated according to census unit boundaries. However, an individual's activities are not constrained to a neighborhood like a census tract and an individual may have interactions with other groups outside of the neighborhood. Different interaction channels with other groups should be considered in evaluating exposure level.

2.3 Activity space as a spatial construct to evaluate segregation

To capture all relevant interaction spaces and to constrain the spatial domain meaningfully in evaluating the segregation experience of an individual, we adopt the concept of activity space. The activity space concept has a long history in the geographical literature. The concept has been used to describe the spatial behavior of individuals (Abler et al. 1971; Brown and Moore 1970; Wolpert 1965). Many definitions of activity space have been proposed and one of them states that an activity space is “the subset of all locations within which an individual has direct contact as a result of his or her day-to-day activities” (Golledge and Stimson 1997, p. 279). This definition is identical to one of the earliest definitions by Horton and Reynolds (1971, p. 37) that only “the subset of all urban locations with which the individual has direct contact as the result of day-to-day activities” will be considered.

Because an activity space does not have an explicit temporal dimension, studies in time geography do not rely on this concept heavily, although the concept can be used to define the geographical scope of the space–time prism (Hägerstrand 1970; Miller 1991). However, data used in time geography studies can be used to construct activity spaces. Some of the early studies of space–time structures of travelling pattern used simulated data (Taylor and Parkes 1975) and travel diary data (Goodchild and Janelle 1984). Locations of individuals over time and space have been used to measure accessibility to physical space and virtual space (e.g., Kwan 1998, 2002, 2004; Yu 2006; Yu and Shaw 2008; Shaw and Yu 2009). Data supporting space–time analysis, such as the travel diary survey data that we use for illustration in this article, have been gathered in the past several decades (e.g., U.S. National Household Travel Survey, <http://nhts.ornl.gov/>; Puget Sound Panel Survey, <http://www.psrc.org/>; Shaw and Wang 2000), but their quality and detail levels vary. Due to the recent advancements in information, communication, and location-aware technologies, data of individual-level activities are being gathered (Janelle and Hodges 2000; Nobis and Lenz 2009). Such data may help evaluate segregation level more comprehensively and accurately at the disaggregated and aggregated levels.

On the other hand, the concept of activity space has been utilized extensively in the transportation literature. Many methods have been proposed to measure or represent activity spaces. Schönfelder and Axhausen (2003) summarized these methods into three categories: two dimensional ellipse, kernel densities, and shortest paths network (p. 276). Buliung and Kanaroglou (2006) provided a detailed list of studies using various concepts and implementations, including a list of studies using ellipses to represent the activity spaces of individuals (p. 37). Using a standard deviational ellipse, a centrophraphic measure, to summarize the spatial distribution of point patterns is a several decades–old idea (Kellerman 1981). Newsome et al. (1998) offered a detailed illustration of how ellipses are constructed to represent activity spaces. Morency et al. (2010) and Páez et al. (2010) used the total distance traveled as a proxy of an activity space. Apparently, there is no generally agreeable method to operationalize activity spaces in the literature. Different implementations of activity spaces are partly dependent upon different conceptualizations and partly determined by the specific analytical tools or methods adopted in the analysis.

Ellipses have been used to study social exclusion (Schönfelder and Axhausen 2003) and segregation (Wong 1999). Relationship between ellipse-based segregation measure and the index of dissimilarity, D , has also been demonstrated (O’Sullivan and Wong 2007). As for any analytical techniques, using ellipses to represent and model activity spaces has some technical issues, some of which have been addressed in the literature (Buliung and Kanaroglou 2006; Buliung and Remmel 2008; Beckmann et al. 1983a, b). Still, peculiar but realistic spatial distributions of visited locations could make the derivation of ellipses difficult (e.g., three visited locations forming a line). Too few visited locations may also fail

to meet the geometric requirements in defining an ellipse computationally (Newsome et al. 1998). Another well-known conceptual issue of using ellipses in depicting activity spaces is the inclusion of locations not being part of the actual activity space, as an ellipse includes extensive areas other than the visited locations. In addition, ellipses are not very effective to implement the concept of exposure. In this article, we will adopt a more conservative approach to implement the activity space concept in order to evaluate segregation at the individual and group levels.

3 Activity space–bounded exposure measures

An alternative method to implement the activity space concept is to connect all locations visited by an individual by straight lines to form polygons representing the activity space. This is similar to the minimum convex hull or polygon approach adopted by Buliung and Kanaroglou (2006) and Buliung and Remmel (2008). Then, areas touched by or within the boundaries of the polygon will be included as part of the activity space of that individual. The idea is that when individuals travel between locations, they may also interact or be exposed to other groups (Newsome et al. 1998). An obvious issue with this implementation is that we do not travel in straight lines between stops. Moreover, a prominent problem is that the activity space polygon defined by the convex hull includes areas that are inside the polygon boundary but are not intersected by the straight lines connecting visited locations.

The operational methods we adopted here are more conservative than the convex hull and ellipse methods. Only visited units or neighborhoods will be counted as part of the activity space if the population is assumed not to interact with others between stops. This method to implement the activity space concept is labeled as the point-based method and is very close to the definition of activity space suggested by Horton and Reynolds (1971). However, the “point-based” label could be somewhat misleading because neighborhoods (or census units) of visited locations are also considered as part of the activity space. A less restrictive implementation is to consider the visited locations and locations in between. This method belongs to the shortest path network approach identified by Schönfelder and Axhausen (2003). It assumes that interactions take place between stops, and therefore, neighborhoods between stops are included as part of the activity space (i.e., line-based method). Surely, road networks instead of straight lines between visited locations can be used for the line-based method to identify intersected neighborhoods. In the illustrative example below, the two implementation methods yield slightly different results.

Equation 1 describes the original formulation of Lieberman’s exposure index, which is a global index, as it summarizes the situation of the entire region across all neighborhoods. The exposure concept will be used here to evaluate segregation levels constrained by activity spaces. Assuming that in a given area or a neighborhood, a number of individuals are sampled and the locations that each individual visited within a given time are known. Then the activity space of each of these sampled individuals in the neighborhood can be derived. If sampled individuals are divided into population groups, activity spaces by population groups in that neighborhood can also be identified. Using the exposure concept, we can evaluate the magnitude of exposure of one group in a given neighborhood to other groups within the activity spaces of sampled individuals.

In the current study, the level of individual exposure to other groups is our basis of formulation. Different individuals in areal unit i have different activity spaces. The exposure of an individual to other groups, in general, is constrained by his/her activity space, not by the residing neighborhood boundary. Therefore, Eq. 1 can be modified to reflect the exposure of an individual to another group, constrained by the individual’s activity space. Let us use Ω_{ij} to denote the set of locations representing the activity space of individual j in

unit i , and S_{ijk} represents the k th location in that individual's activity space, where $k = 1, 2, 3, \dots, n_{ij}$. In other words, S_{ijk} refers to each of the site visited by individual j in a given period, and $S_{ijk} \in \Omega_{ij}$. These sites can be discrete location points or areal units, which collectively define the activity space of individual j in unit i . Depending on the actual method adopted to implement the activity space, these sites may include the visited locations only, or all locations between visited points. In each S_{ijk} of Ω_{ij} , individual j of group a has the potential to encounter people in group b . Therefore, the total population in group b that individual j may be exposed to is the total population of group b in the activity space Ω_{ij} , or

$$B_{ij} = \sum_{k=1}^{n_{ij}} b_{S_{ijk}}, \quad (2)$$

where $b_{S_{ijk}}$ is the population count of group b who are at site S_{ijk} . Assuming that there are only two groups a and b , the total population that an individual j in unit i is exposed to within his or her activity space Ω_{ij} is

$$T_{ij} = \sum_{k=1}^{n_{ij}} (a_{S_{ijk}} + b_{S_{ijk}})$$

Then, the exposure of an individual j in group a in unit i to group b within the activity space of individual j will be

$$E_{ij,a \times b} = \frac{1}{A_{ij}} \times \frac{B_{ij}}{T_{ij}}, \quad (3)$$

where A_{ij} is total population of group a in the entire activity space of individual j in unit i . This is the individual version of Lieberman's exposure measure in Eq. 1, but with the exposure of an individual constrained by his/her activity space. For the exposure of all individuals in group a in unit i to group b , we need to aggregate the activity spaces of all individuals in group a in unit i , and to derive the population sizes of corresponding terms in Eq. 3. Assumed that the activity spaces of all individuals in group a in unit i are aggregated together, then $A_{i\Omega}$, $B_{i\Omega}$, and $T_{i\Omega}$ are the total population counts of group a , group b , and both groups in the aggregated activity space, respectively. The exposure of group a to group b constrained by the aggregated activity space will be:

$$E_{i,a \times b} = \frac{a_i}{A_{i\Omega}} \times \frac{B_{i\Omega}}{T_{i\Omega}}. \quad (4)$$

Similarly, we can define the exposure of population group b in the same unit i to group a by switching the related terms to derive the asymmetric dual of the activity space-constrained exposure index, $E_{i,b \times a}$. The general idea is that instead of defining interaction among individuals according to neighborhoods or areal units where they reside, activity spaces of individuals are used to define the geographical coverage of interaction. Exposure of individuals to other groups is no longer limited to the neighborhoods where they reside, or within a certain distance. Nor is it unbounded in the entire study region as in the global exposure measure (Eq. 1). Segregation level is now referenced to the activity spaces of individuals.

The structure in Eq. 4 is consistent with Lieberman's original formulation. However, this version is different from the original one in two aspects: (1) the population counts of $A_{i\Omega}$, $B_{i\Omega}$, and $T_{i\Omega}$ are functions of individual activity spaces in unit i , but not the population counts of the entire study area or individual areal units; and (2) the measure is now for an areal unit or neighborhood i , not for the entire study area. The formulation of this measure is consistent with recent developments in modeling space–time accessibility and exposure analysis in environmental health, switching the focus from place-based measures to people-based measures (Kwan 2009). Exposure at the individual level serves as the basis to represent segregation levels by areal units.

The index depicted in Eq. 4 and its asymmetric dual treat each visited location in the activity space equally. Apparently, if a visited location is a workplace, the exposure to another group at the workplace should be longer than the exposure to another group in, for instance, a grocery store. Therefore, if we know the relative length of time that the individual spent at each visited location, we can derive a weight for each visited location as a function of time spent there. These weights may be incorporated into Eq. 2 to account for the relative differences in exposure to the other group across locations within the activity space. The literature is not clear what the best implementation of the activity space concept is. Therefore, other reasonable methods to implement the activity space concept may be used for Eq. 3.

4 A demonstration example: tri-county area in southeast Florida

In the United States, many state departments of transportation (DOTs) and local metropolitan planning organizations (MPOs) have collected travel data at the individual level. Sampled individuals are asked to report where and when they have visited in the survey days. These data are often called the travel diary data (e.g., Charlotte, North Carolina data used by Newsome et al. 1998; Mobidrive for German cities used by Schönfelder and Axhausen 2003; Oregon data used by Buliung and Kanaroglou 2006). Depending on the data gathering agencies, quality, format, and content of this type of datasets vary. They all include some socioeconomic and demographic data about the surveyed households and individuals. Unfortunately, race and/or ethnicity, a primary population classification variable, is not a mandatory variable in some surveys. Although travel diary data are becoming more popular, access to them has not become easier. Such data may include some personal and sensitive information; therefore, access to such data is often restricted.

The dataset used in this illustrative example is for the tri-county area in southeast Florida, which includes Miami-Dade County, Broward County, and Palm Beach County (Corradino 2000a). A household travel characteristics survey was conducted in 1999 to collect data on the demographics of households and the travel patterns of individual household members. Households agreeing to participate in this survey received a survey package that included a travel diary survey for each person in the household on the selected survey date (Corradino 2000b). This survey collected data of the household as well as the individual respondents for variables such as age, annual income, residency status, and various work characteristics.

Each participating household was asked to report all travel-related activities for every member of the household (including infants) for an entire 24-h survey day. Travel information was collected for tours. A tour is defined as “a series of trips that began at home, visited other locations, and ended at home.” (Corradino 2000b, p. 2) Data collected from a travel diary include address of each origin/intermediate stop/destination, departure and arrival times for each origin/intermediate stop/destination, activity, purpose, and other characteristics. A race–ethnicity variable, however, was not included in this survey, and therefore this dataset is not ideal for racial–ethnic segregation study. Nevertheless, the tri-

county data are used for our purposes due to the following reasons. First of all, the purpose of this article is to demonstrate how the conceptual framework can be implemented with data of similar characteristics, but not to perform an actual segregation study of southeast Florida. Values for the race–ethnic variable can be simulated or imputed to meet our purposes. Analysis results from our study are not intended to be used to support policy formulation related to segregation in the study region. Secondly, access to travel diary data is quite restrictive and expensive. One of the authors has already gained access to and processed the data for use in a GIS. Finally, the geographical coverage of the data is at a regional scale, which is appropriate for our purposes and is manageable.

Household samples were drawn from geographical subareas to ensure a complete geographical coverage. All household and trip end data were geocoded such that they can be used in a GIS environment. A total of 5,168 households completed the household travel characteristics survey. Among them, 5,067 households had valid addresses. Close to 34% of the surveys were collected from Broward County, and 33% each were from Miami-Dade County and Palm Beach County. Population distribution pattern in this tri-county area is heavily concentrated along the coastal area, with large inland areas preserved as part of the conservation areas or the Everglades National Park.

The dataset was evaluated, examined, reformatted, and imported into a GIS. Because the data do not include a race and/or ethnicity variable, a race–ethnic category, non-Hispanic white, non-Hispanic black, and Hispanic, is assigned to the sampled individuals probabilistically based upon the proportions of the three groups in the census tract where the individual resided according to the 2000 Census. Therefore, results of this example reflect hypothetical, not the actual, racial–ethnic experiences of the population in the tri-county area, although the imputed data should reflect the actual racial–ethnic mixes quite realistically. Some national and regional travel diary surveys did gather race–ethnic information from the respondents, but we do not have convenient access to them. The purpose of this example is to illustrate how the proposed framework can be supported by other travel diary or similar types of individual-level data.

According to Eq. 4, the exposure segregation measures are computed at the local or neighborhood level to reflect how the residents of each race–ethnic group in a neighborhood were exposed to the two other groups together based upon their activity spaces. Locations and corresponding census tracts visited by each sampled individual in the travel diary are first identified. This set of census tracts defines the activity space of that specific individual. Exposure of that individual to the two other groups in the activity space is then evaluated according to Eq. 2. Exposure levels of individuals of the same group within the neighborhood (census tract) to the two other groups together within their aggregated activity spaces are evaluated (Eq. 4). This demonstration example uses census tracts as the local neighborhoods, but other areal units may be used.

Essentially, Eq. 4 is computed for each census tract and for each of the three groups, non-Hispanic white, non-Hispanic black, and Hispanic. The activity space concept is implemented using the line- and point-based methods discussed above. First, the activity space concept is implemented by including all census tracts intersected by lines connecting all visited locations (line-based method). Population counts from the 2000 Census in these census tracts were used to compute the exposure levels depicted in Eq. 4. Then, the activity space concept is implemented again by only including those census tracts containing the visited locations, but not the census tracts between stops (point-based method).

Figure 1 shows the proportions of the three groups in each census tract in the study region and Table 1 reports the population counts and proportions for different groups for the entire

tri-county area. While white is the majority group in the region, population size of Hispanic was substantial (34%), and black is relatively small, concentrating along a strip inland parallel to the Florida coast (Fig. 1). Whites tend to concentrate along the coast and north of the region and Hispanics tend to locate in the south around the city of Miami and Dade County. Note that the neighborhood population data were the actual census data, not the synthetic racial-ethnic data estimated for the travel diary respondents.

Figure 2 shows the exposure of whites to others (blacks and Hispanics) based upon the two activity space implementation methods (line-based and point-based). The two maps are very similar in overall patterns with minor differences. Quantile classification is used in mapping the exposure values. The major difference between the two maps is that the absolute values using the point-based method are consistently higher than that using the line-based method. However, very similar patterns between the two maps indicate that the relative exposure levels among neighborhoods are maintained in each map regardless of which method to implement the activity space concept is adopted. In general, high levels of exposure of whites to other groups are found in the northwest corner of Palm Beach County and parts of the Miami-Dade County. These two areas have relatively high concentrations of blacks and Hispanics, respectively (Fig. 1). However, the high exposure levels of whites to these two groups in the two subregions are not determined purely by the high concentration levels of these two groups in the two subregions, but are moderated or constrained by the activity spaces of whites in those subregions. In other words, according to our partially imputed data, whites in the northwest corner and near the Miami-Dade County area have their activity spaces covering areas with high concentrations of the other two groups.

Figures 3 and 4 show the results using the two activity space implementation methods to compute the exposures of blacks and Hispanics to the other groups, respectively. Similar to Fig. 2, the differences from the two activity space implementation methods in these figures are discernable, but overall patterns are very similar. Exposures of blacks to others are relatively high along the strip with high black concentration and the southern tip of the region. The relatively large number of census tracts with missing data is due to the small sample size for blacks and the absence of blacks in many census tracts. Hispanics exposure (Fig. 4) to other groups is relatively high at the southern end of the Miami-Dade County, and in the north, but away from the coastal region, with a few exceptions. Exposure and segregation levels are inversely related; therefore, high exposure levels imply less segregation. Thus, those group-specific high exposure areas may be considered having low levels of segregation.

As pointed out before, the exposure levels of one group to the other groups derived from the proposed approach are not purely determined by the concentration levels of the other groups in the local neighborhoods, but are moderated or constrained by the activity spaces of individuals in the first group. The roles of activity spaces in determining exposure patterns may be demonstrated by comparing the activity-based exposure levels described in Figs. 2, 3, 4 with the exposure levels of populations within their own neighborhoods derived from Eq. 1. Equation 1 is the global exposure index, but the exposure level for each areal unit i can be used to create a local exposure map. Large discrepancies between the activity-based and the neighborhood-based exposure levels are indications that the population groups conduct activities outside of their residential neighborhoods, and they visit neighborhoods with racial-ethnic compositions quite different from their residential neighborhoods. While the local neighborhood-based exposure maps can be created for this study, they are not comparable to the results shown in Figs. 2, 3, 4 because the individual race-ethnic classifications in this study are imputed, but the local neighborhood-based exposure maps are based on racial-ethnic counts in the actual census. Nevertheless, such comparison is warranted in future studies with appropriate data.

5 Summary and discussions

This article reiterates the fact that segregation is not limited to residential space and therefore a more comprehensive evaluation of an individual's experience should include the exposure of that individual to other population groups in all relevant socio-geographical spaces. These spaces constitute one's activity space, which offers the basis of the proposed individual-based exposure segregation measure. Such measure, which is conditioned on one's activity space, captures an individual's experience more comprehensively than traditional measures designed to assess segregation primarily in the residential space. Activity spaces of individuals of the same group within a neighborhood can be aggregated. The exposure level of that population group to others within the aggregated activity space can then be evaluated. Travel diary data of the tri-county area in southeast Florida with imputed race-ethnic data are used to demonstrate the proposed approach. The empirical results, therefore, do not reflect the actual situation and should not be used for policy formulation. More sophisticated methods to synthesize individual-level travel data may be used if ideal travel diary data are not available (Guo and Bhat 2007).

Unlike other segregation measures using aggregated data to infer an individual's experience, this proposed approach uses individual-level data as the basis and then aggregates the results of individuals to the areal units of interest. This approach is in line with Kwan's call for the departure from place-based measures to people-based measures (Kwan 2009). Although aggregated census data instead of individual-level data are used to evaluate the exposure levels in the visited neighborhoods, the proposed approach represents an improvement over the traditional methods to evaluate segregation levels based on aggregated population data. While census population data are unlikely to reflect accurately the population composition at the workplace, nevertheless they should describe the population compositions in the workplace neighborhoods. Individuals at work are likely to interact not just with coworkers at their workplaces, but also with residents in the workplace neighborhoods. Therefore, using aggregated census data to estimate exposure level is a compromised, but reasonable approach. The demonstration example uses census tracts as proxies of neighborhoods. While this method of delineating neighborhoods has been widely adopted, we know that the method is not ideal. However, the proposed approach in measuring segregation is independent of the definition of neighborhoods. Any reasonable definitions of neighborhood, census-based or noncensus-based, can be used for the proposed measure.

Adopting the proposed approach to measure segregation has several concerns. One of them is data quality issues, such as whether the sample individuals adequately represent the population in terms of demographic characteristics and activity patterns. Data quality issues may be addressed by careful survey design and improved data collection efforts. Another concern is about the implementation methods of the activity space concept. Besides the two methods suggested in the demonstration, other methods to implement the activity space concept are also viable. Different implementations may yield different results as shown in this article. Additional research is needed to evaluate the appropriateness of each implementation method.

The proposed approach in evaluating segregation levels can lead to important implications in practice and policy formulation. For example, most current approaches in evaluating segregation level focus exclusively on the residential space. Focusing on just one socio-geographical space exclusively very much ignores the potential moderating effects brought by the exposure to other population groups in other relevant spaces. In other words, current evaluation of segregation focusing on the residential space may have overestimated the levels of segregation one may have experienced.

Existing policies tend to focus on changing the racial–ethnic mix at the neighborhood scale to increase the population diversity or the exposure to different groups through various means, such as subsidized housing programs. If other socio-geographical spaces are relevant in determining an individual's segregation level, the racial–ethnic mix of the entire activity space of a person should be taken into account. Therefore, improving people's access to neighborhoods dominated by other groups may be an additional policy to lower segregation levels. Facilitating interactions across racially or ethnically disparate neighborhoods through, for instance, better public transportation may enhance exposure levels between population groups. Such policies could have ramifications in areas such as urban planning and public transportation, beyond the context of segregation studies. Nevertheless, the proposed approach provides an additional avenue to assess segregation level based upon individual's exposure level, and relevant sociogeographical spaces are taken into consideration.

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Fig. 1.
a Proportions of non-Hispanic whites, **b** proportions of non-Hispanic blacks, and **c** proportion of Hispanics in each census tract

Fig. 2.
Exposure of whites to blacks and Hispanics at the census tract level using line-based and point-based methods to define activity spaces

Fig. 3.
Exposure of blacks to whites and Hispanics at the census tract level using line-based and point-based methods to define activity spaces

Fig. 4. Exposure of Hispanics to whites and blacks at the census tract level using line-based and point-based methods to define activity spaces

Table 1

Population counts and proportions of population groups in the tri-county area, Florida (2000 Census of Population and Housing)

	Population counts	Proportions
Total population	5,007,564	–
Non-Hispanic whites	2,205,930	0.44
Non-Hispanic blacks	904,878	0.18
Hispanics	1,704,064	0.34
Others	192,692	0.04