Mapping changes in spatial patterns of racial diversity across the entire United States with application to a 1990–2000 period

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Abstract

Changes in racial configuration patterns are affected by uneven population growth of different racial/ethnic groups and by modification of social attitudes. A comprehensive assessment of these changes is important for effective policy-making. Conventional assessments, which rely on tabular census data, are restricted to a handful of major metropolitan areas and do not provide spatial information. Here we propose using high resolution categorical demographic grids to assess and map spatio-temporal changes in racial configuration patterns over the entire United States. Recently published demographic grids for the years 1990 and 2000 are classified into neighborhood types based on the local level of diversity and the dominant race. Codifying the 1990-2000 transitions of neighborhood types for all grid cells yields a transition grid, which provides raw information for all subsequent assessments. The change is evaluated from three different perspectives: overall statistics, mapping, and neighborhood topology. A change diagram visualizes diversity change from statistical perspective using transitions collected from the entire U.S. Change map reveals complex spatial transitions between different neighborhood types; examples of change maps for metropolitan areas of Chicago, San Francisco, and Houston are shown and described. Topologies of spatial change for various neighborhood types are also visualized showing the specific manner of transition from one type of neighborhood to another. Presented methodology opens the door to much more comprehensive and in-depth assessment of changes of racial and diversity patterns.

Keywords: mapping racial diversity, high-resolution population grid, demographic change, racial classification, dasymetric modeling

1. Introduction

Spatial segregation along racial and ethnic lines is a continuing reality of American social structure, but shifting social attitudes results in a gradual increase of residential racial diversity (Iceland et al., 2002). In addition, changes in the U.S. demographic makeup, in particular, significant increases of Hispanic and Asian populations (Iceland, 2004), transforms America's racial configuration from a binary paradigm (for example, a Black/White dichotomy) to a much more complex multi-racial pattern (Iceland, 2004). Thus, a thorough geospatial analysis of the U.S. racial configuration dynamics requires tracking temporal changes in a multi-class spatial pattern over the entire country at a high spatial resolution. No such analysis presently exists because the long-standing methodologies of measuring residential segregation and diversity are not designed to address the problem in as comprehensive a fashion as stated above.

Because of a significant interest in the issue of racial configuration there exists a significant body of literature on the topic. A common thread to all previous analyzes is a demographic data model based on the U.S. Census Bureau aggregation areal units, such as census tracts or blocks. Consequently, the scope of previous investigations, analytical tools developed for these investigations, and even the nomenclature used, are heavily influenced by the character of this "tabular" data model. We submit that tabular data model impedes analysis of racial segregation and diversity as summarized in the next three paragraphs.

Residential racial segregation – the physical separation of two or more groups into different neighborhoods (Massey and Denton, 1988) – has been the major focus of previous research, with segregation indices be-

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ing the analytical tool of choice. A large number of segregation indices, later shown (Massey and Denton, 1988) to measure five independent aspects (evenness, exposure, centralization, concentration, and clustering) of two-group segregation, were proposed. These indices characterize a region (most often a metropolitan statistical area or MSA) and are calculated using demographic data assigned to the region's sub-divisions (most often census tracts or blocks). Most proposed indices are aspatial (White, 1983, 1986; Massey and Denton, 1987, 1988) although some do incorporate spatial relations between sub-divisions (Jakubs, 1981; Morgan, 1982; Reardon and Sullivan, 2004; Dawkins, 2004; Wong, 2004; Brown and Chung, 2006). The shortcomings of segregation indices include dependence on the scale of sub-divisions (for example, tracts vs. blocks) (Parisi et al., 2011) and difficulties with change assessment due to census-to-census changes in delineations of sub-divisions (Reardon et al., 2009). Also, indices-based analysis does not address the issue of diversity at a neighborhood scale, as diversity is defined only at a regional scale. Given the character of segregation indices analysis, a typical result is in a form of a table that compares the values of indices between different MSAs or between different years for the same MSA.

As the U.S. is a multi-racial rather than a bi-racial society, two-group measures of segregation were recognized as insufficient, and multigroup indices, the most prominent of these being the Theil information theory index (Theil, 1972), were developed (Reardon and Firebaugh, 2002) and applied to characterize diversity at regional scale (Iceland, 2004; Farrell, 2008). In comparison to the segregation indices the Theil index provides additional and often more relevant information on racial configuration within a region, but it still suffers from the same limitations as segregation indices due to the reliance on the tabular data model. As the Theil index and two-group segregation indices are region attributes, they are predominantly calculated for prominent regions, such as MSAs (Frey and Farley, 1996; Logan et al., 2004; Johnston et al., 2007; Farrell, 2008; Farrell and Lee, 2011) with only a few analyzes quantifying rural areas and small towns (Cromartie and Kandel, 2004; González Wahl and Gunkel, 2007; Lichter et al., 2007; Lichter, 2012).

Recent research (Holloway et al., 2012; Wright et al., 2014) breaks away from the reliance on indices as a tool to assess and quantify the U.S. racial configuration and moves toward a more cartographic approach to the problem. In such an approach, neighborhoods (census tracts) are classified into a number of types on the basis of a combination of segregation and diversity criteria. The results are presented in the form of thematic map that explicitly shows the geography of racial diversity and segregation. Temporal change can be assessed by comparing maps constructed from data gathered at two different times. This method is a major step forward but still inherits the limitations of the tabular data model: poor spatial resolution outside MSAs and the possible incompatibility of areal units as delineated at different years.

In this paper we propose studying racial configuration in the U.S. and its temporal change using a raster data model instead of a tabular model. This is feasible due to recent availability of high resolution demographic grids for the entire U.S. (Dmowska and Stepinski, 2014). Cells in these grids have categorical values corresponding to several diversity/dominant race types (DDRTs). This allows us to think about the underlying data in terms of "human cover" in an analogy to the concept of a "land cover" in the field of remote sensing. Thus, we can analyze human cover patterns and their temporal change using robust methods already developed for the analysis of land cover. This method of analysis, intrinsically different from previous approaches, yields an in-depth assessment of racial configuration dynamics in a lucid form that could be used to inform decision makers responsible for the efficient allocation of economic, health, administrative, and law enforcement resources to a population going through changes in its racial makeup. We focus on analyzing change during the 1990–2000 period as the grids are presently available only for these two years. However, the more recent 2000–2010 change could be analyzed using the same method once 2010 grid becomes available.

2. Data and Methods

2.1. Population and diversity/dominant race grids

The U.S.–wide high resolution demographic grids by Dmowska and Stepinski (2014) constitute an input to our analysis. We refer a reader to that paper regarding detailed information on the method used to construct those grids. In the rest of this sub-section we briefly recount the computational process leading to obtaining DDRT grids.

Dmowska and Stepinski (2014) start by applying dasymetric modeling (Wright, 1936) to coarse, 1 km grids previously developed by the Socioeconomic Data and Application Center (SEDAC) (Seirup et al., 2012). SEDAC grids are products of a simple areal weighting interpolation from census blocks. They are disaggregated from 1 km to 90m resolution using dasymetric model with the National Land Cover Dataset (NLCD) land cover 1992 and 2001 data as an auxiliary variable. Because 1992 and 2001 editions of NLCD have different legends, a dasymetric model does not use the main land cover categories of each NLCD edition. Instead, it uses the NLCD 1992/2001 retrofit product (Fry et al., 2009) which classifies land cover into a smaller number of more generalized classes which, however, are common to 1992 and 2001.

Dasymetric modeling works for disaggregating total population because of the correlation between the type of land cover and the total population density. However, there is no robust correlation between land cover type and the density of population belonging to a given race/ethnicity group. Thus, members of race/ethnicity groups located within a coarse 1km SEDAC grid cell are disaggregated using weights established for the entire population. This means that in each populated 90m cell the relative percentages of different race/ethnicity groups is the same as in the entire coarse 1km cell, but the disaggregation improves information on the spatial distribution of different groups inasmuch as it shifts people away from uninhabited or sparsely inhabited areas.

Using population and race grids all inhabited grid cells are classified into 11 diversity/dominant race types (DDRTs) taking into consideration the level of diversity and the dominant race. Demographic information in a cell is encapsulated by a normalized histogram whose bins represent the proportions of a cell's population belonging to different racial/ethnic groups. Five race/ethnicity groups: white, black, Hispanic, Asian, and other are considered. Following (Holloway et al., 2012) the racial diversity of a cell is classified on the basis of the standardized informational entropy E of its histogram with modifications made to ensure agreement between obtained classes and customary notions of group dominance (Farrell and Lee, 2011).

All inhabited cells are classified into three diversity types:

- ***Low diversity*** type if the histogram fulfills two conditions: (1) $E < 0.41$, and (2) the dominant race constitutes more than 80% of a cell's population.

- ***High diversity*** type if the histogram fulfills three conditions: (1) $E > 0.79$, (2) the dominant race constitutes less than 50% of a cell's population, and (3) the sum of the two most dominant races constitutes less than 80% of a cell's population.

- ***Moderate diversity*** type if the cell does not belong to either high or low diversity types.

Two of the three diversity types (low and moderate diversity) are further sub-divided with respect to five possible dominant races resulting in 11 DDRTs. Note that, by definition, the high diversity type does not have a dominant race and does not need further division. Using this classification scheme categorical grids of DDRTs for 1990 and 2000 are constructed. These grids form the basis for our analysis of spatio-temporal change in racial configuration during the 1990s. Each grid has 12 categories, 11 DDRTs and an "uninhabited area." They can be viewed using the SocScape (Social Explorer) – a GeoWeb application designed for fast and intuitive exploration of population and diversity patterns starting at the scale of the entire U.S. and progressing down to the scale of an individual street. SocScape is accessible at http://sil.uc.edu/.

2.2. Transition matrices

The first aspect of racial diversity dynamics is an overall change in the membership of individual DDRTs between 1990 and 2000. The term "DDRT membership" denotes the entire population living in a region consisting of grid cells having a given DDRT label. Previous research (Wright et al., 2014) quantified national change in diversity using a transition matrix which enumerated how many census tracts of a given DDRT in an earlier year transitioned to various DDRTs in a later year. We can construct an analogous matrix by enumerating cell instead of tracts transitions. As the cells are spatial units, such a transition matrix will account for changes in areal occupancy of different DDRTs, but, we are more interested in changes to membership of various DDRTs. Because we keep the full demographic information about each cell we can convert a cell-based transition matrix into a membership transition matrix. A membership transition matrix enumerates how many people living in a given DDRT in 1990 found themselves living in various DDRTs in 2000. The membership transition matrix has a size of 11×11 corresponding to 11 DDRTs in each of the two years. The matrix is visualized using a change diagram (Fig. 1).

2.3. Mapping change

The second aspect of racial diversity dynamics is a change is spatial coverage of DDRTs. Mapping the change in areal coverage of various DDRTs is necessary for understanding the local details of diversity spatial dynamics. The usual way to illustrate change in areal coverage, both in remote sensing and in diversity studies (Wright et al., 2011; Holloway et al., 2012; Dmowska and Stepinski, 2014; Wright et al., 2014), is to show two

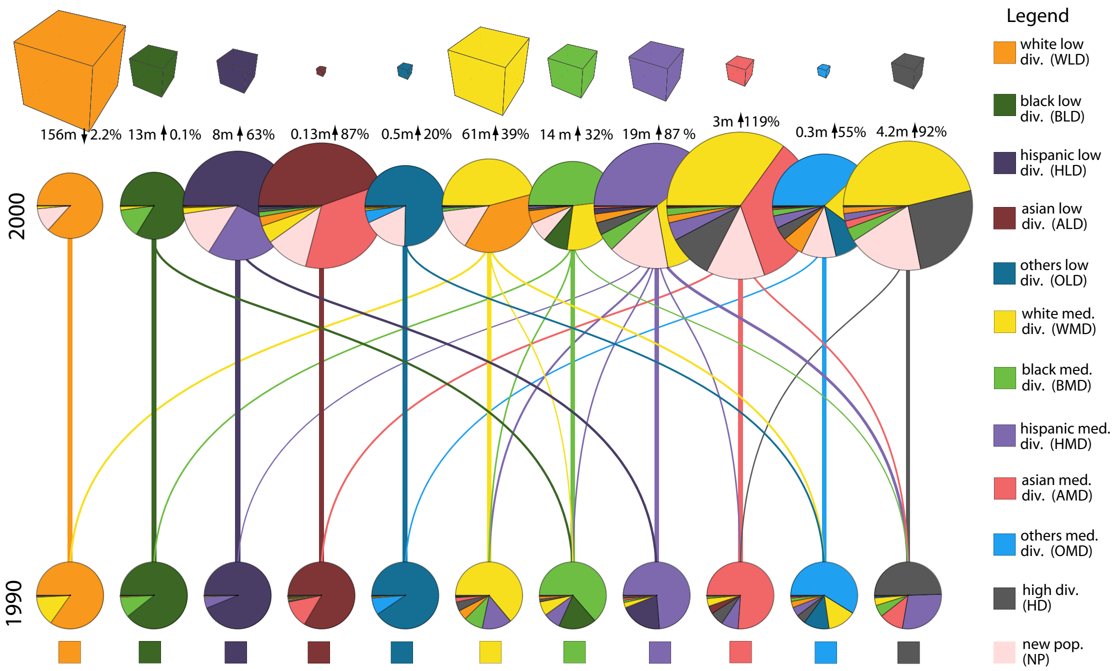

Figure 1: Change diagram summarizing 1990-2000 transitions of population between different diversity/dominant race neighborhood types. Diagram pertains to the population of the entire conterminous U.S. See the main text for a detailed description of the diagram.

maps (corresponding to two different years) for a side-by-side comparison. We have found this method to be adequate for an overall impression of the change but insufficient for an in-depth description. To best convey the complex dynamics of areal change we have developed a visualization method that explicitly shows all transitions in a single map. The raster map with all 12×12 = 144 possible transitions between cell labels is converted to a vector (shapefile) format and generalized to eliminate very small regions. Unchanged areas are shown in the original colors as assigned to the DDRTs, while the areas which experienced transitions are shown in stripes – with the color of the broader strip indicating the DDRT in 2000 and the color of the narrower stripe indicating the DDRT in 1990.

2.4. *Landscape metrics*

The third aspect of racial diversity dynamics is the change in the extent and topology of an area occupied by each DDRT. Although it is possible to characterize such change on the scale of the entire U.S. it is more telling to characterize it for a collection of MSAs. We perform our spatial analysis on a collection of 37 MSAs distributed across all geographical regions of the U.S. Like any other categorical (thematic) map, the map of DDRTs constitutes a spatial pattern or, in ecological terms, a “landscape.” Landscape metrics (Haines-Young and Chopping, 1996), originally developed for application in ecology, are algorithms that quantify the specific spatial characteristics of a landscape pattern. For the purpose of characterizing the extent and topology of an area occupied by a given DDRT we use two metrics, PLAND (percentage of landscape) which gives the percentage of an MSA area occupied by a DDRT, and the aggregation index (AI).

An aggregation index (He et al., 2000) is a class (DDRT)–specific landscape metric designed to work with raster data and independent of PLAND. Let e_i represent the total number of edges that an i-th DDRT shares with itself (as opposed to edges shared with other DDRTs in the region under consideration). The value of AI is the value of e_i divided by the maximum possible number of like adjacencies involving the given DDRT multiplied by 100 (to convert to a percentage). Thus, the theoretical range of values for both PLAND and AI is between 0 and 100. The maximum aggregation level (AI=100) is reached when raster cells making up a given DDRT areal clump into one compact patch. The minimum aggregation level (AI=0) is reached when the entire DDRT area consists of individual disjointed cells. The actual ranges of PLAND and AI, as calculated for our selection of MSAs, are narrower and vary from one DDRT to another.

To analyze tendencies in the spatial evolution of areas occupied by a given DDRT we construct a PLAND-AI diagram on which each MSA is represented by an arrow starting at the point $(\text{PLAND}, \text{AI})_{1990}$ and ending at the point $(\text{PLAND}, \text{AI})_{2000}$.

3. Results

3.1. Statistics of change

Fig. 1 visualizes all the information from the 1990–2000 DDRT membership transition matrix. DDRTs are color-coded as shown in the legend. The names of DDRTs in the legend indicate the dominant race and the level of diversity. Hereafter we refer to different DDRTs by abbreviations of their names as indicated in the legend. The lower row of pie-diagrams pertains to DDRTs membership in 1990. Sizes of the 1990 pie-diagrams are normalized to the same size. Sectors of a 1990 pie-diagram correspond to percentages of a given DDRT's 1990 membership transitioning to 2000 DDRTs. Thus, for example, 85% (orange sector) of the 1990 WLD membership transitioned to the 2000 WLD while 14% (yellow sector) transitioned to the 2000 WMD. Note that the term "transitioned" does not refer to direct spatial movement of people but rather to a reclassification of their neighborhood as a result of multiple factors including, but not limited to, spatial movement. The upper row of pie-diagrams pertains to DDRTs membership in 2000. Sizes of the 2000 pie-diagrams are in proportion to 1990–2000 membership increases/decrease of corresponding DDRTs. Sectors of a 2000 pie-diagram correspond to percentages of a given DDRT's 2000 membership coming from 1990 DDRTs. Again, the term "coming from" refers to reclassification of neighborhood rather then physical movement. 2000 pie-diagrams have also an additional sector accounting for population growth between 1990 and 2000. Thus, for example, 45% (maroon sector) of the 2000 ALD membership came from the 1990 ALD, 35% (red sector) came from the 1990 AMD, while 11% (pink sector) is due to population growth. Transfers larger than 5% of membership are illustrated by lines connecting the 1990 DDRTs with the 2000 DDRTs; the widths of the lines are proportional to the percentage of the transfer. The row of cubes illustrates the absolute size of DDRTs membership in 2000; actual numbers (in millions), as well as the percentage of change from 1990, are also given.

The Fig. 1 diagram contains rich information about dynamics of various DDRTs. In general, only the WLD lost membership (mostly to the WMD) but remained by far the largest DDRT in the U.S. The membership of the BLD remained stable while undergoing some back and forth exchange with the BMD. The memberships of AMD, HD, ALD, HMD, and HLD experienced large relative gains. The 92% growth of the HD membership came mostly from converting the WMD neighborhoods to higher diversity neighborhoods. The growth of AMD and HMD memberships also came from converting the WMD neighborhoods. However, the WMD membership experienced 32% gains itself at the expense of the WLD neighborhoods and remained the second largest DDRT. The growth of ALD and HLD memberships came mostly from the incorporation of AMD and HMD neighborhoods, respectively. The neighborhoods dominated by Asians (ALD and AMD) were the fastest growing but remained small in absolute terms. The neighborhoods dominated by Hispanic population (HLD and HMD) were also fast growing and much larger in absolute terms than those dominated by the Asian population.

3.2. Spatio-temporal change

U.S.-wide statistics succinctly reveal the changes in racial configuration during the 1990s at the scale of the entire country but do not reveal any information about the spatial aspects of those changes. To analyze changes in areal cover of various DDRTs we constructed a U.S.-wide change map as described in section 2.3. Fig. 2 shows a fragment of this map covering the Chicago, Illinois region. The two smaller maps in Fig. 2 show the spatial extents of various DDRTs in 1990 and 2000, respectively. A comparison of the two maps reveals the expansion of areas dominated by the Hispanic population and contraction of areas dominated by the white population. However, a more detailed analysis of the spatial dynamics is difficult-to-impossible using a side-by-side comparison of the two maps. The main map in Fig. 2 shows spatial change in a way that permits a detailed analysis. There are 24 different DDRT transitions within the mapped region but most of them involve small areas.

The major racial configuration dynamic in the Chicago region involves the transition of white-dominated neighborhoods into Hispanic-dominated neighborhoods. There are two main locations where such transitions occur. The first location is along I-55 and the second is along the northern stretch of I-90,94. In the first location the Hispanic-dominated areas expanded to the west and to the south from the centrally-

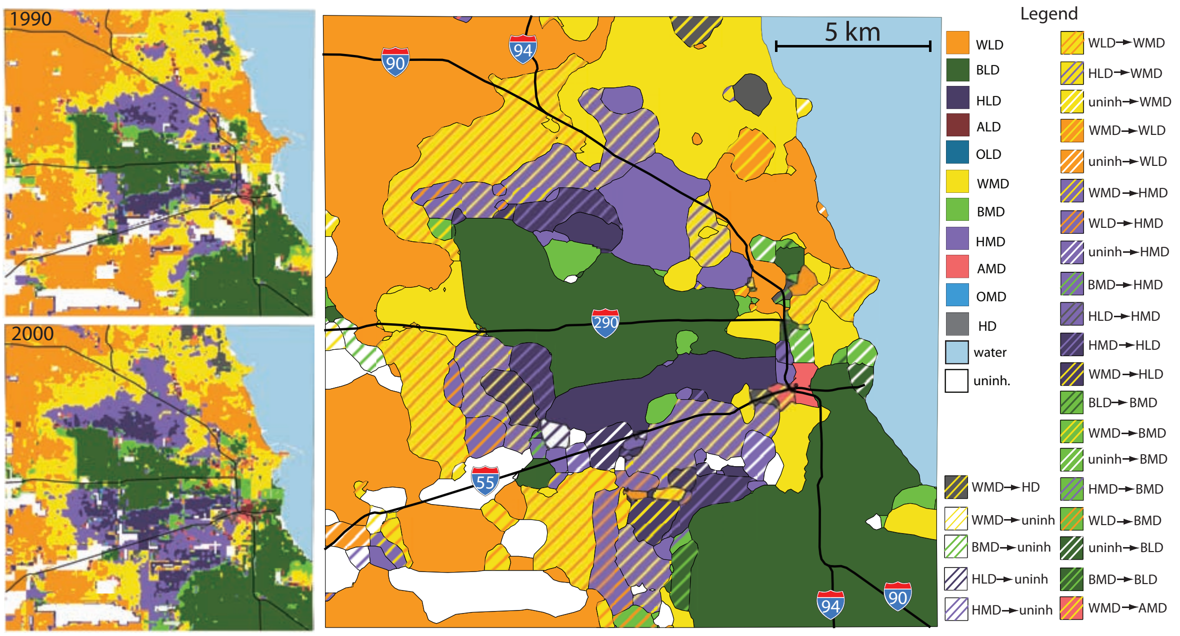

Figure 2: Map of areal change of different diversity/dominant race neighborhood types in Chicago, Illinois during the period of 1990-2000 (main panel). Major highways are mapped for spatial reference. The panels on the left show the maps of neighborhood types in 1990 and 2000, respectively.

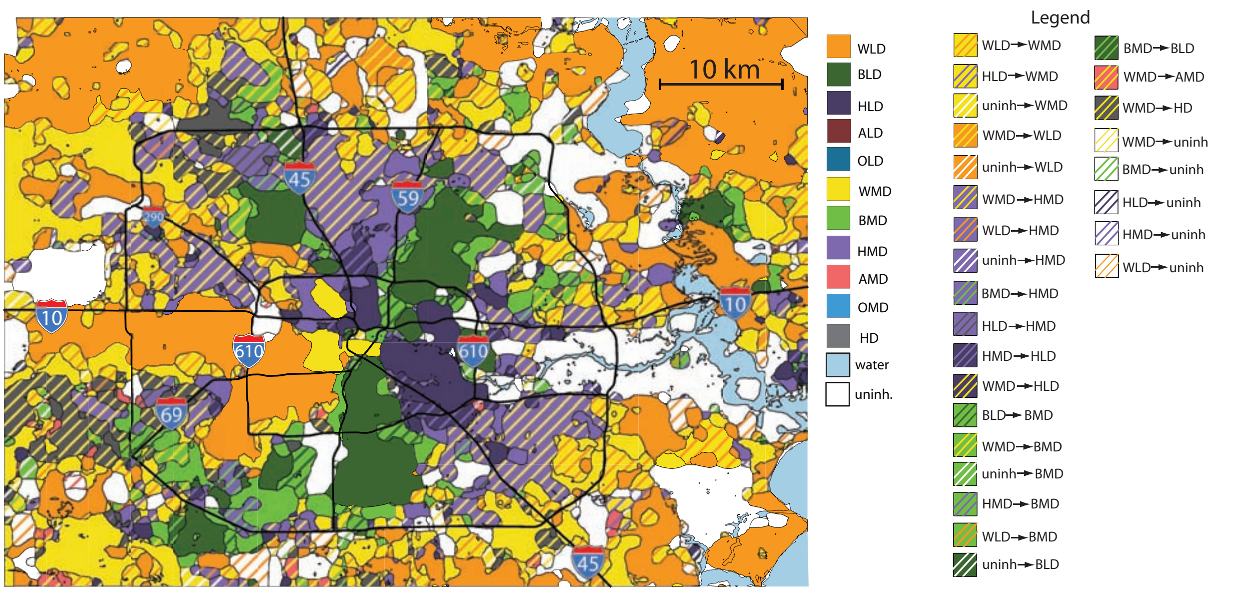

Figure 3: Map of areal change of different diversity/dominant race neighborhood types in Houston, Texas during the period of 1990-2000. Major highways are mapped for spatial reference.

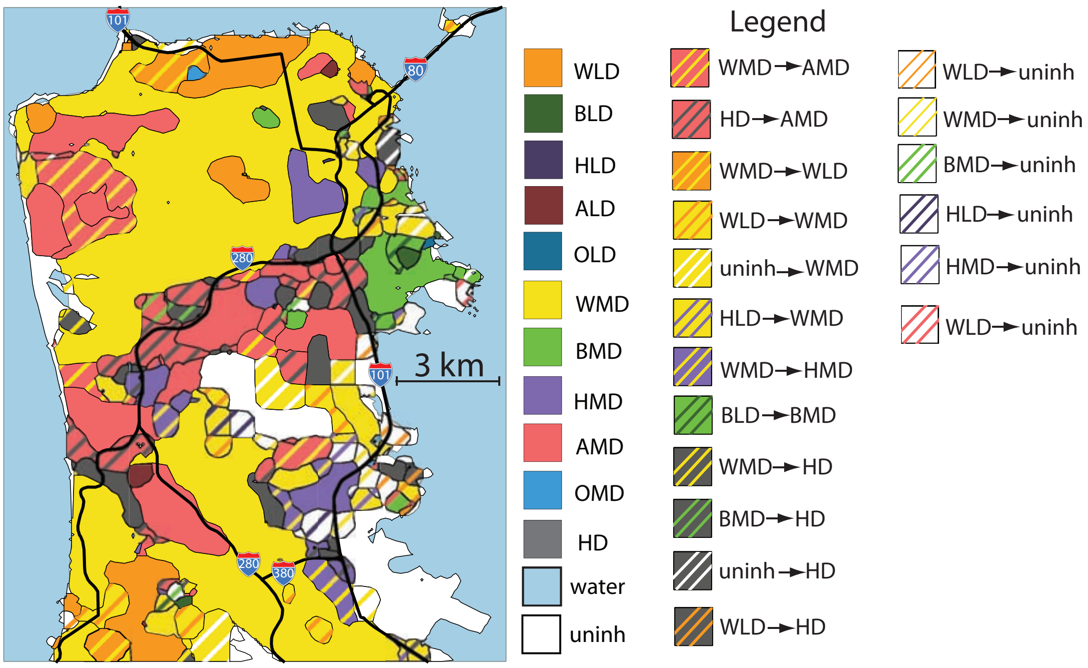

Figure 4: Map of areal change of different diversity/dominant race neighborhood types in San Francisco, California during the period of 1990-2000. Major highways are mapped for spatial reference.

located HLD area. The expansion to the west clearly shows a westerly progression of transitions. The HMD area immediately adjacent to the central HLD area transitioned into HLD. Next, the previously WMD area (which already included a minority of Hispanics) transitioned to the HMD area, and finally, the WLD area transitioned into the WMD area due to an increasing number of Hispanics. The expansion of Hispanics from the centrally-located HLD area to the south resulted in the transition of the WMD area into the HMD area. In the north a similar series of transitions took place in a northwestern direction. There has been no expansion of the Hispanic population into black-dominated neighborhoods. The boundaries of black-dominated neighborhoods (overwhelmingly consisting of BLD) remained stable during the 1990s. The small AMD area almost doubled in size by changing the makeup of the adjacent WMD neighborhood. A small HD neighborhood appeared in the northernmost extent of the mapped region where the WMD neighborhood existed in 1990.

Fig. 3 shows the changes in racial configuration during the 1990s in the Houston, Texas region. The racial dynamic in the Houston region resembles the dynamic in the Chicago region inasmuch as its major feature is the expansion of Hispanic-dominated areas at the expense of the white-dominated areas. As in Chicago, the progression of transitions from HLD to WLD took place along preferred directions of this expansion. The boundaries of black-dominated neighborhoods in Houston were less stable than in Chicago as some transitions from BLD to BMD or even to HMD did occur. Thus, unlike in Chicago, mixed, black-Hispanic neighborhoods emerged in the 1990s. Houston also developed more HD areas than Chicago, they all transitioned from the WMD areas.

Fig. 4 shows the changes in racial configuration during the 1990s in the San Francisco, California region. The racial dynamic in the San Francisco region is different from what we observed in Chicago and Houston as the major feature is an expansion of Asian-dominated areas. They have expanded into what in 1990 were white-dominated and HD areas. Hispanic-dominated areas, small in 1990, expanded slightly into WMD areas, and WLD areas expanded into the WMD areas. Thus, the second major feature of racial dynamics in the San Francisco area is a change toward a less diverse areal configuration as the higher diversity areas contracted and the lower diversity areas expanded.

Table 1: Selected metro areas

	Metro area	Abbr.	Region		Metro	Abbr.	Region
1	Atlanta	ATL	Southeast	20	New York	NY	Northeast
2	Baltimore	BAL	Southeast	21	Orlando	ORL	Southeast
3	Boston	BOS	Notheast	22	Philadelphia	PHL	Northeast
4	Chicago	CHIC	Midweast	23	Phoenix	PHX	Southwest
5	Cincinnati	CIN	Midwest	24	Pittsburgh	PIT	Northeast
6	Cleveland	CLE	Midwest	25	Portland	PPR	Pacific
7	Columbus	COL	Midwest	26	Providence	PRV	Northeast
8	Dallas	DAL	Southwest	27	Riverside	RIV	Pacific
9	Denver	DEN	Rocky Mtn.	28	Sacramento	SAC	Pacific
10	Detroit	DET	Midwest	29	San Antonio	SA	Southwest
11	Houston	HOU	Southwest	30	San Diego	SD	Pacific
12	Indianapolis	IND	Midwest	31	San Francisco	SF	Pacific
13	Kansas City	KC	Midwest	32	San Jose	SJ	Pacific
15	Las Vegas	LV	Rocky Mtn.	33	Seattle	SEA	Pacific
15	Los Angeles	LA	Pacific	34	St. Louis	SL	Midwest
16	Miami	MIA	Southeast	35	Tampa	TP	Southeast
17	Milwaukee	MIN	Midwest	36	Virginia Beach	VB	Southeast
18	Minneapolis	BAL	Southeast	37	Washington DC	DC	Southeast
19	New Orleans	NO	Southeast				

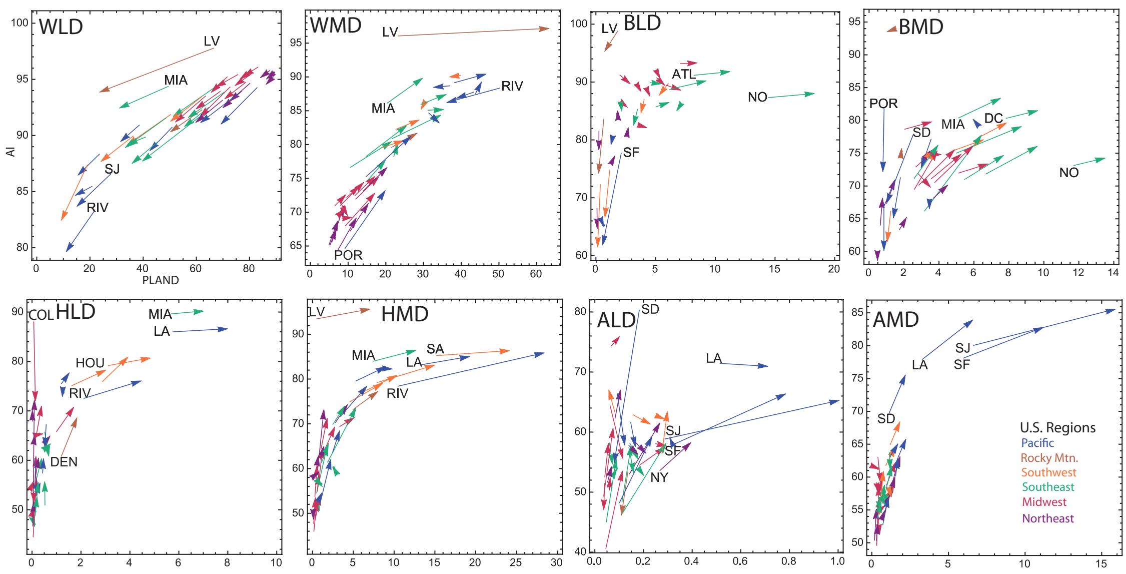

Figure 5: PLAND – AI diagrams for different diversity/dominant race neighborhood types. DDRTs in metropolitan areas are represented by arrows indicating changes in values of PLAND and AI from 1990 to 2000. See Table 1 for the list of included metropolitan areas.

3.3. Topology of change

Table 1 lists the 37 metro areas used in our study of topology of change (section 2.4). The panels in Fig. 5 show the PLAND-AI diagrams for eight different DDRT areas, as indicated on the panels. PLAND and AI values are calculated for areas occupied by a given DDRT in 37 MSAs. The purpose of the PLAND-AI diagram is twofold, first to observe a correlation (if any) between the degree of aggregation and percentage of area occupied by a DDRT, and second, to observe temporal change of area percentage/aggregation between 1990 and 2000.

There exists a clear correlation between the values of PLAND and AI for all DDRT areas; the bigger the relative area of a DDRT the more aggregated it is. Moreover, this correlation is non-linear, for relatively small DDRT areas the degree of agglomeration increases steeply with an increase of the area, whereas for larger areas the dependence is flatter. That means that DDRTs which occupy a relatively small area of a MSA most likely consist of small disjointed enclaves but as they grow the enclaves aggregate to form an increasingly more compact clump.

The 1990-2000 changes in topological properties of DDRT areas are shown by arrows. The collection of 37 arrows illustrates the trends of these changes over the geographically diverse set of MSAs. The arrows on the WLD panel of Fig. 3 show that all WLD areas decreased in size and underwent disaggregation. Thus, the transition of WLD neighborhoods to other neighborhoods (mostly WMD) occurred by their fragmentation. The WLD areas in MSAs located in the Northeast region, which relatively had the largest sizes, decreased the least, while the WLD areas in MSAs located in the Pacific and Southwest regions, which relatively had the smallest sizes, decreased the most. A different type of dynamic can be observed for BLD areas. In MSAs where the BLD areas were relatively large (in the Southeast region) they further increased their size, but in MSAs where BLD areas were relatively small, their sizes sharply decreased or they vanished altogether. For MSAs where the BLD areas have an intermediate size (5-7%) the black-dominated neighborhoods were stable. For DDRTs with small memberships, like HLD and ALD, there is no clear pattern to their dynamic, the corresponding diagrams show the existence of outliers – MSAs experiencing fast growth of those neighborhoods – while the remaining MSAs show mixed trends.

4. Discussion, conclusions and future directions

Census Bureau population projections (Colby and Ortman, 2014) indicate that the racial dynamic in the U.S. is steering the country toward a society with no absolute racial majority by 2044. How this overall prediction translates to a change in racial makeup of local neighborhoods is of great interest to academics, as well as to policy makers, due to their impact on economics, politics, social services, and urban planning. We started with the thesis (see section 1) that assessing change in racial makeup of neighborhoods by using census aggregation unit-based data yields inadequate information and can be significantly improved by using input data in the form of high resolution demographic grids.

Grids-based demographic data have a number of advantages over the aggregation units-based data (say, census tracts). First, it is easy to use. Aggregation units-based data, which is given at spatially irregular and size-variable sections, presents difficulties even for spatial analysis alone due to the modifiable areal unit problem. For spatio-temporal analysis these difficulties are amplified by the fact that units boundaries change from one census to another. Thus, assessing demographic change while using units-based data requires interpolation (Holt et al., 2004; Schroeder, 2007; Ruther et al., 2015). On the other hand, demographic grids for different years are spatially co-registered and are ready for a cell-by-cell comparison without any data preprocessing. Second, high resolution grids provide consistent spatial resolution throughout the entire country, which, even in the urban areas, is higher than that offered by the tract-based data. Finally, gridded data offer analytic possibilities, such as, for example, calculation of landscape metrics, which has not been utilized before because they cannot be calculated from census units.

Using newly available demographic grids by Dmowska and Stepinski (2014) we demonstrated three novel types of spatio-temporal analysis of change in racial diversity. These analyzes (U.S.-wide statistics of 1990–2000 transitions between membership of different DDRTs, mapping the change in spatial extents of DDRTs, and depicting changes in topology of DDRTs) provide comprehensive insight into the dynamics of DDRTs during the decade of 1990s. Such analyzes would be difficult-to-impossible to carry out using methods based on census aggregation units.

The DDRTs membership transition diagram (Fig.1) not only shows the magnitude of membership transfers between different types of neighborhoods but also illustrates all the components of every transfer – incoming sources of membership (1990 DDRTs) which together constituted each 2000 DDRT and outgoing destinations of membership (2000 DDRTs) which together constituted each 1990 DDRT. This is valuable information that has not been previously available as the only published data on neighborhood transitions (Farrell and Lee, 2011; Holloway et al., 2012; Wright et al., 2014) referred to a number of census tracts that transitioned from one DDRT to another. Furthermore, with an exception of the study by Wright et al. (2014), previous studies were restricted to a handful of metropolitan areas rather than covering the entire U.S. For studying socio-economic change membership transitions offer a directly relevant information whereas tract transitions can only serve as an imperfect proxy for such information. Admittingly, DDRTs membership transitions could be calculated from census tracts, but this would yield a different and less accurate results due to the modifiable areal unit problem inherent to census aggregation units.

Our change maps (Figs.2, 3, and 4) show how boundaries between different types of neighborhoods changed in a fashion that allows further qualitative and quantitative analysis. For example, they show that in Chicago (Fig. 2) and Houston (Fig. 3) the expansion of Hispanic-dominated neighborhoods from HLD cores occurs in preferred directions, forming a progression of neighborhoods with a decreasing degree of Hispanic population. They also show that expansion of Hispanic-dominated neighborhoods is at the expense of adjacent white-dominated neighborhoods but not at the expense of adjacent black dominated neighborhoods. To fully appreciate the informational content of our change maps they need to be compared to previous cartographic depictions of change in neighborhood types (Wright et al., 2011; Holloway et al., 2012; Wright et al., 2014). As the change map (in the form of a grid of cell transition values) is calculated for the entire U.S. it can be used, in conjunction with other gridded demographic variables (for example, income and age) to explore questions of connection between neighborhood transitions and the socio-economic environment.

The topology of neighborhood transitions (Fig. 5) is an analysis made possible by using the grid – this information cannot be obtained from tract-based data. It has revealed that expanding neighborhoods first disaggregate the adjacent regions of a contracting neighborhood then aggregates their own extent in a fashion that resembles the results of geographical models of residential mobility (Torrens, 2007). It also shows that in the 1990s the spatial size and shape of different neighborhood types evolved differently, with a particularly sharp difference between WLD and BLD.

One disadvantage of using high resolution demographic grids by Dmowska and Stepinski (2014) is that, at present, no grids for 2010 are available. This is because Dmowska and Stepinski method of calculating high resolution grids is to disaggregate coarser SEDAC grids which are only available for 1990 and 2000. There are two feasible solution to this problem. First, to wait until SEDAC will make available 2010 grids, and second, to change the procedure for obtaining high resolution grids so they can be calculated directly from census blocks without using SEDAC grids. Calculating high resolution grid for the entire conterminous U.S. is computationally challenging. Dasymetric modeling from coarser to finer grid is the simplest and least computationally demanding procedure to obtain it, but disaggregation directly from census blocks is also computationally feasible and will need to be done if SEDAC will not publish their grids for 2010.

In addition, when working with the grids it is important to remember that they are models of population distribution rather then pure data. Uncertainties associated with accuracy of auxiliary data and with the dasymetric model itself are discussed in Dmowska and Stepinski (2014). Here we would like to focus on an additional assumption made when modeling spatial disaggregation of sub-population associated with a given race/ethnicity. We simply assumed that each sub-population is disaggregated the same way as the entire population. Thus, our model does not provide any additional insight into differential disaggregation of various race/ethnicity groups beyond the insight already provided by the land cover model. We are not aware of any potential auxiliary data that could provide information on differential distribution of different race/ethnicity sub-populations. Note that this assumption is only a concern on the smallest scale because: (a) populations are still kept away from uninhabited or sparsely populated areas, and (b) all segments of populations add up to the total population at the level of 1 km SEDAC cell (250 m cell in major metropolitan areas).

Finally, a new interesting analysis will become possible once 2010 demographic grid becomes available. With gridded data available for 1990, 2000, and 2010 there will be enough information to attempt the calculation of predictions for future neighborhood transitions at high spatial resolution using techniques originally developed to predict land use/over change (Mas et al., 2014). Such model could be used to predict spatial configuration of neighborhoods in 2020 and later checked for accuracy of prediction with the data from 2020 census.

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