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Future Directions in Spatial Demography

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> *Demographers have made much of time, conceptualizing it variously in terms of age, period, and cohort; individual, family, and historical time; and the like. There is no analogy in demographic thinking for space . . .*
>
> (Entwisle and Gutmann, 2001)

Spatial demography has been gaining momentum during the last decades. For example, in 2001 the Demographic and Behavioral Sciences Branch (DBSB) of the Center for Population Research (CPR) (National Institute of Child Health and Human Development-NICHD) included it among the topical areas to explore or to expand within the discipline. Later, two special issues of Population Research and Policy Review (26: 5/6, 2007 and 27: 1, 2008) and a special issue of PNAS (Proceedings of the National Academy of Sciences) (102:43, 2005) have been dedicated to this topic.

Several concurrent factors are behind this, among them the growing availability of spatial (geo-referenced) population data, improvements in computers and software (free and commercial) and, more broadly, the emergence of spatiality target (i.e., localized) policies and assessments of social and other contexts of demographic outcomes (e.g., neighborhood effects) (de Castro, 2007), all this within the framework of the spatial turn in social sciences (i.e., the consideration of social processes embedded within spatial context) (Goodchild and Janelle, 2004; Voss, 2007).

A spatial or geographic approach to social phenomena needs to take into account the effect of purely spatial factors like location and distance, as well as the effect of contextual and environmental factors that define specific places, for example local cultural characteristic or socioeconomic status (Wieczorek and Hanson, 1997). Spatial factors are usually defined in terms of distance and area, of intersection of space with specific social and physical contexts, and of the relative position in space and place. "Spatial dimension" includes variability across space, the effects of scale, and the significance of place. This dimension is implicit in the distribution of hazards, population settlements, and demographic processes; or in the effects of regional/local variability in vulnerability to climate changes impacts.

Both the relative position in relation to other points in space and the individual and social significance that people attribute to a particular locality are important in order to understand and explain the patterns of distribution of social phenomena in space. Consideration of the spatial dimensions of an event, phenomenon or process implies research on the definition and measurement of place, which is defined by the social structure, social relationships and living experience. "*Place*" is matched with "meaningful space" (Tuan, 1977), and explained by people's experiences. Within demography, it is common to refer to place as "local social and spatial contexts" (Entwisle, 2007: 687), where "local" could be as broad or narrow as rural and urban areas, or neighborhoods. Instead, "*space*" tends to be defined by topological rules, by Euclidean distances, as in Tobler's classical first rule of geography[1] (Tobler 1970:236).

If "place" and "space" are both part of spatial demography, how are they related? And how, in turn, are they related to scale? Work with space or place is always linked to the issue of scale—which could range from global to dwellings—and particularly to the *integration or articulation* across scales, to some extent similar to nested models linking different levels of analysis. Both the scale of the spatial unit and the scale of analysis affect the visualization of the processes and consequently our conclusions about them. For example, the IPCC has argued that "the choice of scale at which impacts are examined is also crucial, as considerations of fairness, justice or equity require examination of the distribution of impacts, vulnerability and adaptation potential, not only between, but also within, groupings" (Schneider et al., 2007). Selecting the right scale or resolution is an important step in the design, but this is not always discussed, made explicit or justified.

Growing availability, quality and appropriateness of geo-referenced data (from coarse to high spatial resolution) has been an important factor in the advance of spatial demography. Examples include the Landsat collection being available online, Google Earth, the attention to census geography and GIS (particularly to actually making it available) in the 2010 round of censuses, and the inclusion of GPS information in Demographic and Health Surveys and in the Multiple Indicators Cluster surveys. There is, however, ample room for improvement, as these developments are very heterogeneous across and within countries. In particular, the construction of spatial time series is challenge by diachronic and synchronic mismatches between population and spatial data.

Spatial demography can be approached from different points of view. Some researchers define it very broadly: "spatial demography extends across space and time, from the changing face of everyday world of present experience to glimmerings of our remote origins and interconnections. It brings sciences together: geography and demography, political and social sciences, mathematics, statistics, physics and biology" (Wachter, 2005). For others, it is "the formal demographic study of areal aggregates , i.e., of demographic attributes aggregated to some level of geographic hierarchy" (Voss, 2007) and or "demography viewed from a spatial perspective. Spatial, together with temporal, variations in mortality, fertility and migration are studied as preliminaries to the investigation of population structure in its entirety" (Woods, 1984).

Instead, other authors are much more specific, affirming that "spatial demography includes only research on the core of demographic analysis, defined by the three demographic components—fertility, mortality and migration—and by models of population size, change and composition. It implies the use of formal statistical modeling, such as techniques in spatial statistical analysis, geostatistics, Bayesian modeling, and spatial econometrics, as well as population models in three dimensions: age, time and space" (de Castro, 2007).

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[1] "Everything is related to everything else, but near things are more related than distant things"

These different definitions are a first glimpse of the different ways to address space within demography, from mapping demographic variables (visualization) to Bayesian models to autoregressive models. Along this continuum, there is certainly increasing methodological sophistication (de Castro, 2007), but I think that the question remains, does this welcomed sophistication in methods imply a better understanding of the underlying processes?

In summary, a number of challenges remain --among them confidentiality issues (VanWey et al. 2005), the implementation of interdisciplinary research, the development of theory and the implementation of training on spatial analysis (de Castro, 2007). I think that the timing of the Conference is excellent to take stock of the field so far, address the remaining issues, and plan future steps.

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Future Directions in Spatial Demography

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Where we exist in space guides whom we know and with whom we build families, influences our health, and determines whether and where we move. Demographers' history of "putting people in place," as Barbara Entwisle convincingly argues, makes us particularly well-suited not only to examine the influence of spatial relationships on fertility, mortality and migration, but also social outcomes that occur in between those events.[1] In this position statement I contend that two problems persist in our research on the topic that must be addressed in order to improve the state of research investigating spatial inequality: 1) determining whether contextual or compositional forces perpetuate spatial inequality and 2) the need for cost-efficient data collection tools adaptable to large surveys. Although both are typically treated as methodological, I argue below that the first is a theoretical problem for which demographers possess the necessary tools but insufficient theoretical orientation. I propose that we devote more research to developing how compositional forces perpetuate spatial inequality and briefly describe tools to address the second.

Compositional Influences on Spatial Inequality

Studies of "neighborhood effects" originated as a line of research to investigate spatially unequal patterns of social and economic outcomes. Researchers substantially narrowed their to focus to the methodological problem of identifying a causal effect of neighborhood exposures, usually by controlling away the selection problem of residential mobility, [2–4] and lost their more general devotion to explaining patterns of spatial inequality. Despite immense concern regarding the selection problem in neighborhood research, very few studies actually examine processes of residential mobility that lead to that problem in the first place. In place of study, researchers take for granted that extant patterns of residential segregation and neoclassical real estate market dynamics drive residential sorting. I present three ways in which I see these assumptions misleading the field and make a case for devoting increased study to forces that lead residents to live in their neighborhoods to partially explain spatial inequality.

Neighborhood knowledge and experience

Critics of neighborhood effects research, as well as most demographers investigating residential mobility, assume that residents are sorted into neighborhoods based on an efficient real estate market with some acknowledgement of externalities due to discrimination. Such an assumption does not account for the fact that residents lack complete knowledge of communities in the metropolitan area, a fact that might have considerable consequences as we investigate residential segregation and spatial sorting. For instance, Maria Krysan and I show that race significantly influences the knowledge metropolitan Chicago residents have of other communities in the metropolitan area.[5] These "racial blind spots"—or knowledge externalities in economics terms—might lead to differential residential and commercial investment that would lead to a decline in local amenities supporting salutary outcomes. Other externalities in the real estate market might emerge from the different experience of communities within metropolitan areas across racial/ethnic and economic groups, both at a personal level and through social networks of strong and weak ties that could pass along information. *Demographic researchers interested in spatial inequality should increase the use of survey instruments that measure neighborhood knowledge and experience rather than assume residents possess perfect knowledge of the residential market.*

Population-level avoidance versus individual-level selection

Research on spatial inequality focuses on residential "selection" as the primary obstacle to overcome in order to make causal inferences. This requires not solely knowing where residents move, but also *how* they make decisions about where to move. Based on the types of knowledge and experience I note above, residents form perceptions of neighborhoods that create schemas regarding the places they see as viable locations to move. In initial studies of these schemas, we ask residents about actual communities in their metropolitan area and we find that the prevalence of communities respondents avoid (i.e., would never consider) to be much higher than those they might select.[5] We also find that race dramatically influences these schema such that predominantly African American communities become places where very few residents would consider moving. While the difference between selection and avoidance might solely appear semantic (since avoiding means not selecting), the conceptual difference carries substantial consequences since residents act on these schemas in ways that direct flows of resources.[6] Furthermore, if population avoidance subsumes individual selection, then this calls into question intervention policies that advocate individual-level residential mobility. *Given the larger magnitude of population-level avoidance in comparison to individual-level selections, spatial demographers must devote greater resources to explaining the social psychological perception of spaces and their consequences in their research of spatial inequality.*

Demographic contributions to neighborhood composition

Finally, common among most neighborhood researchers is the notion that residential mobility alone creates neighborhood compositions, particularly neighborhood racial compositions. In part, this is because "white flight" continues to be a powerful image to describe institutional consequences of racism. Yet, considering residential mobility as the sole process creating neighborhood change neglects *demographic forces* that change neighborhoods: one born into a neighborhood or dying out of a neighborhood also change the compositional forces. In addition, the age-specific nature of many social and economic forces mean that only a portion of the residents—who might look different from the overall composition of neighborhoods—are at risk of a social or economic event, state, or behavior. *Spatial demography must re-incorporate* *demographic processes into compositional explanations of neighborhood processes and define at-risk populations appropriately for age-specific outcomes*.

Cost-efficient Contextual Data for Large-Scale Studies

Any assessment of spatial influences on individual or collective outcomes, whether compositional or contextual, requires valid and reliable methods to acquire data that are theoretically relevant to the outcome under investigation. Despite substantial progress on the question from methods such as systematic social observation (or, neighborhood audits) and the use of "non-routine" data sources for analysis, at least two challenges remain. First, the costs for collecting this data render its collection unaffordable for geographically dispersed samples. Second, with large multi-outcome studies (e.g., PHDCN, LA FANS, HRS) the appropriate spatial scale and definition of risk might vary by outcome, meaning measures of theoretically relevant measures must be adaptable across spatial scales.

Computer Assisted Neighborhood Visual Assessment System

Despite the promise of collecting data on neighborhood exposures to assess the influence of neighborhood conditions on individuals, such data is unaffordable for studies with geographically dispersed respondents. To overcome this problem, our research group developed the Computer Assisted Neighborhood Visual Assessment System (CANVAS) that uses Google's Street View product with standard neighborhood assessment instruments to collect data on a national sample of streets. We successfully piloted prototypes and found relatively high inter-rater agreement and inter-source agreement with in-person raters for many (not all) theoretically relevant items.[7] We will make this technology available so that it can be incorporated into existing studies easily.

Spatially Adaptable Measurement Methods

Research on spatial exposures focuses on two improvements: developing theoretically relevant measures and defining neighborhoods with appropriate boundaries and spatial scales. I demonstrate that researchers can combine the geostatistical method of kriging with the ecometric framework of neighborhood measurement to develop city-block level estimates of theoretically nuanced measures configurable into spatially meaningful units (e.g., t-communities, ego-centric neighborhoods, etc.).[8] Using kriging also opens opportunities to apply *spatial* samples of physical environments to improve coverage of exposures in non-residential locations, and with CANVAS methods described above, apply contextual analysis to large, geographically dispersed samples.

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Future Directions in Spatial Demography

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Many demographic phenomenon and related theories are implicitly spatial. Yet the methods of demographic analysis, and demographic data, are typically aspatial. This is true today despite substantial advances in technology and training over the past few decades. This point is constructively illustrated with the demographic study of urbanization, where my work has concentrated for the last 10 years.

The most significant demographic trend of the 21st century arguably [1] is urbanization. This is the century when the global population becomes more urban than rural, when almost all of the population growth will take place in cities (and the cities of Asia and Africa, at that) and where the growth in the number of and population size of gigantic cities is unprecedented. Placed in a spatial context, for example to study the relationship between urbanization and climate change, it is apparent that we need information on which cities are growing and at what rates, as well as their demographic and socioeconomic composition. Urbanization is an intrinsically spatial phenomenon—cities will grow at their edges as well as vertically becoming both more expansive and dense, their populations will age, and household sizes and composition will change. These changes will have wide ranging implications—e.g., for public health, education, public infrastructure and financing, housing, ecosystems and carbon emissions. Yet, demographers are ill-prepared to study these changes. They have neither the spatial tools nor the necessary data to study, let alone predict, our urban future. With Mark Montgomery, and colleagues from CIESIN at Columbia University and the UN Population Division, we have begun to address a few of these shortcomings (Montgomery and Balk, 2011; Balk et al., 2009a; Balk et al. 2009b). The study of urbanization requires information about cities—ideally at a sub-city scale—not simply the fraction of national populations that live in urban areas, which dominated demographic thinking and data collection through major advances in the 20th century (UN, 2009). In the absence of city-specific data, subnational spatial demographic data are a must and spatial tools act as the glue to assemble the data necessary to forecast city growth (Montgomery et al, 2011).

Demographic breadth comes from censuses whereas demographic depth comes from surveys. In the past decade alone substantial improvements in the spatial information of both these data sources have made. Major survey programs such as the Demographic and Health Surveys (DHS), the World Fertility Surveys (WFS), and the Multiple Indicator Cluster Surveys (MICS) have been instrumental to our understanding of fertility and mortality—and less comprehensively broad-strokes migration—in the developing world, where censuses and vital registration systems cannot kept abreast with the data infrastructures found richer countries. Yet these surveys indicate demographic behavior at the national, or first-order administrative level (like provinces or states). Owing to the usual indication of urban and

[1] With strong competition from Aging.

rural strata (required partly to assure accuracy of the sampling frame), we can compare urban and rural populations. But it is well understood that there is, conceptually at least, an urban-rural continuum rather than a dichotomy (Champion and Hugo, 2004; Balk 2009) and therefore something more than this approach is warranted if such survey data are to be used to study urbanization. Current rounds of the DHS and MICS data include spatial data for the survey regions.[2] The DHS, in particular, has shown great leadership by adding location information to the survey cluster. While nationally representative data such as these are not intended to be analyzed as if the clusters are representative, much can be done with the cluster data: locations can be identified in proximity to cities (sometimes even particular cities) rather than adopting the much coarser urban-rural survey classification (NRC, 2003; Dorelien et al., 2010), environmental and other contextual data—including city boundaries, when available—can be added to individual and household records (Balk et al., 2004, Dorelien et al., 2010). And such data can be used in new ways to generate population surfaces (Chin et al, 2011). To be most useful for understanding our urban future, and in particular the well-being and behavior of slum dwellers and the urban poor, survey sampling frames may need to be revised and increasingly diligent to include these traditionally hard-to-capture populations.

Similarly, census data have been quite relevant for understanding the spatial distribution of population and, in a more limited way, city growth.[3] The time-series data on city population size used by the Population Division who produces the *World Urbanization Prospects* is collected from national statistical offices and comes primarily from censuses data, yet these data are not reported with spatial boundaries or vital rates.[4] Nevertheless, improvements in the spatial resolution of census data in the past decade have been remarkable. Most countries of the world, even poor countries, release second-order (e.g., county or district-level) administrative boundaries associated with their censuses, and many—e.g., Vietnam, Peru, Malawi, Kenya, and South Africa—produce and release data at a much finer resolution. While these data permit a wealth of inquiry on the spatial distribution of population in public health applications in particular (e.g., Tatem el., 2011; Balk et al, 2006), they are inadequate in two ways: Only the basic demographic data—population counts—are available at the finest level and spatial aggregates, even very small ones, are less analytically valuable than micro-data. Furthermore, even when fine-resolution census data are available, a corresponding list of which administrative units belong to cities is often not available. This leaves the work of urban identification to other data, about which I'll say more below. Another important development with census data is the recent availability through improved collections and data delivery tools—e.g., IPUMS and Redatam[5]—for census micro-data which facilitate the estimation of rates of urban in-migration for subnational units, for example. Such estimates

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[2] Regrettably, for older survey rounds, and the WFS, spatial information is much sparser (and certainly not digital).

[3] The oft-cited study (Chen et al, 1998) indicating a 60–40 split of the contribution of natural increase and migration, respectively, to city growth depends exclusively on census data. That important study is woefully out of date and relies on a small number of countries. Its methods precede spatial data and methods, and conflate migration with administrative reorganization, where the latter phenomena is certainly in part the result of natural increase as well as migration.

[4] Details on how we use these UN data in a spatial framework—linking them with urban location and vital rates—in order to estimate and forecast city growth are found elsewhere (Balk et al., 2009a; Montgomery and Kim, 2008).

[5] See https://international.ipums.org/international/ and http://www.eclac.cl/redatam/default.asp, respectively.

are invaluable for estimating city growth. For those interested demographic estimation by ecological units beyond cities, flexible use of micro-data with user-supplied spatially boundaries (such as coastal zones) would be required. For this, additional attention would need to be paid to protecting the confidentiality of census (or survey) respondents (VanWey et al., 2005, NRC 2007, Fink et al., in progress) and improving the capacity of national statistical offices to work with a variety of geographic data.

While there have been many demographic uses of remote sensing data to study particular cities or the socio-demographic causes or consequences of rural land-use change, few studies have embraced satellite data to study urbanization. Yet, satellite data are an obvious choice because countries vary in their conceptualization and definitions of "urban." In my work on the Global Rural Urban Mapping Project (GRUMP)[6], we used satellite data—the "1994/1995 stable city night-time lights" data set (Elvidge et al, 1997)—as a consistent measure of urban spatial extent throughout the world. The imperfections and advantages of these data have been the source of much discussion (Balk, 2009; Tatem et al., 2011), yet there is general agreement that satellite data on urban areas has much to offer. To date, no analogous urban extent time-series data exist. Yet, change in these extents over time would be invaluable to demographers. To create (and perhaps even to use) such a data set would require that demographers become more competent and comfortable in the analysis of data many types of satellite data. Productive interdisciplinary collaborations are generally an important way to bridge this gap.

The study of urbanization poses questions for the way we demographers collect census and survey data, how we associate urban spatial extents with administrative boundaries, and our models for demographic analysis. I would argue that the investments in the data and research infrastructure of the 21st century need to revolve around cities much the way the world of 1950 was organized around countries, though with the added flexibility so that environmental parameters (such as coastal zones) will have as much viability for organizing our analysis as administrative units have had historically. It is inevitable that some important demographic questions will also require that demographers embrace new data sources, including those from Earth observing satellites. This is easier said than done as the skills and tools required for using some of these data sets are much different from those found in our current toolkit.

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[6] http://sedac.ciesin.columbia.edu/gpw/index.jsp

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Future Directions in Spatial Demography

The opinions expressed in this article are the author's own and do not reflect the view of the National Institutes of Health, the Department of Health and Human Services, or the United States government.

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I see a strong need to develop spatial demography as a tool to advance health research in the areas of chronic disease prevention, health promotion, and more sophisticated causal analysis related to energy balance—diet, physical activity, weight, and their consequences. Such developments could build on the prominent role achieved by spatial demography in the analysis of infectious disease. Achieving this goal requires at least three things. a) Developing and disseminating visions concerning how spatial demography can contribute to chronic disease research and control. b) Identifying and describing compelling examples of existing contributions by spy spatial demography. c) Achieving a greater presence at NIH both among staff and in study sections.

I do not have an overarching position concerning the scientific contents of spatial demography per se. Instead, I have an intense interest in several research topics that involve spatial demography. My desire to learn more about the discipline and my belief that it is worth developing have arisen organically from projects that began in behavior and population studies related to health behaviors and chronic disease.

Identifying consistent measures of the environment

How can we harmonize and standardize environmental variables related to physical activity? I have developed datasets concerning street connectivity and neighborhood walkability (e.g., Huang et al. 2009; Berrigan et al. 2010; Hoehner et al. in press). In each of these collaborations, we extracted multiple variables (e.g. nine measures of street connectivity, 15 + census data elements) and then used principal components analysis to reduce the number of variables. This seems like an imperfect method. At the workshop I would like to discuss and learn about how to conceptualize and measure key spatial influences on physical activity, diet, and obesity. Some of my future programmatic and research activities will focus on supporting efforts to harmonize and/or standardize measures of these key influences.

Analyzing interactions between contextual variables and behavior change

Much of the analytical work concerning context and energy balance has involved cross sectional analyses of behaviors. A few studies have examined longitudinal data, and some of these suggest that environmental effects may not be as important as hitherto thought (e.g., Ewing et al.

2006). I like to participate in discussions focusing on creative new ways to tease apart contributions of self-selection and environment on health behaviors, especially physical activity.

Better integration of spatial thinking into chronic disease research?

Geospatial analyses for health have a long tradition of focusing on infectious disease. More recently, a significant body of work has developed that explores the geography of chronic disease and its behavioral and environmental correlates. In 2011, an American Association of Geographers/NIH joint workshop emphasized the need to extend NIH's efforts in this area (http://www.aag.org/cs/projects_and_programs). I believe that additional thinking and discussion are needed to develop a clearer vision concerning the potential contributions of geospatial demography to chronic disease prevention and control and to research concerning the promotion of healthy behavior. One of area of special interest arising from my work on built environment and walking concerns the use of detailed spatial and behavioral data from devices such as GPS units and accelerometers. Such data are becoming more and more prevalent, both from stand-alone devices and from units embedded in phones, pads, computers and other tools. Creative plans, analyses and study designs are needed to obtain these data and use them to advance behavior and health research.

Immigration and acculturation

I am very interested in health and health trajectories of immigrant populations (Willis et al. 2010; Oh et al. 2011; Berrigan et al. 2006; 2010). Immigrants come from specific contexts and the process of acculturation occurs in a complex social and spatial setting. Better data and specific examples of how understanding dynamic effects of context on health behaviors and health outcomes can improve immigrant health could help make a strong case for further investment in geospatial research for health.

Conclusions

Geospatial demography seems to have the potential to make significant contributions to public health in part via improved understanding of relationships between environment and behavior. I hope that this workshop can help clarify a research agenda

Future Directions in Spatial Demography

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"Although spatial thinking and the use of new forms of geospatial data have grown rapidly in the social sciences, their implementation in the demographic sciences has lagged." This statement in the call for potential participants for this specialist workshop is particularly telling. In short, though there have been major advances and research commitments to the development of spatial data resources that can be used to address important issues in demography and health research, as well as both the development and dissemination of spatial statistical and modeling techniques that can used to analyze spatial data, such data and methods are only slowly permeating demography and related fields.

It seems to me that there are several approaches and opportunities for applying a spatial dimension to demographic work that have the potential to help in the formulation and solution of various demographic problems. Such approaches some of which are analytically contradictory, in fact share a great deal. In the cases below, with which I have had some experience, improved data resources and improved modeling approaches would certainly be of great value.

Analyses of Data from Individuals in their Geo-Demographic Context

Demographers and other social scientists now routinely add data from the neighborhood, community or other context to surveys or other information on individual respondents or events to both large scale (e.g., Census, data on hospital admission, mortality, etc.) and smaller scale (e.g., surveys or health, education or other activities) data sets. Analyses can then proceed to relate the neighborhood or community data to the information regarding the individual respondent. The default method for such analysis, of course, is hierarchical or mixed modeling, where information about the higher level units (e.g., neighborhood and community) is used to condition the modeling of the individual level information.[1] These methods though they do link individual levels to spatial units, generally do not make explicit use of spatial information (e.g., the spatial relationship of contextual units one to another.) In effect, the information related to the contextual unit is reduced to a series of measures of that unit, but not of its location. So, if there is a spatial effect, (for instance, the effect of poverty is exacerbated by it being spatially concentrated) remains unmeasured. Standardized methods to integrate spatial information into

[1] The general approach I am discussion can also use aggregated data at more than one level. For instance, census tract or block group characteristics can nest within county or place, however defined.

such modeling, along with characteristics of the so-called higher level units, is particularly important for the impact of spatial effects not to be overlooked.[2]

The Use of Spatial Location to Impute Social and Economic Status (SES) Characteristics

An issue related to, but seemingly in contradiction to the first issue, is the use of residential or other location to impute SES measures, which are then used for other modeling. Generally, when this is done, for reasons of endogeneity, it is not appropriate to use spatial variables in the models. Instead, the spatial term is used, in effect, to impute SES characteristics. Such methods are particularly useful in situations where it is infeasible to directly collect SES data. Two examples with which I have had experience include using such methods to add some information on SES to educational records and hospital discharge data. Obviously, in such an instance, it would be especially useful to be able to estimate the extent to which such an imputation was precise. This precision certainly can have a spatial distribution. Having geocoded the Early Childhood Longitudinal Study from Kindergarten (ECLS-K) for a number of waves, the National Center for Education Statistics invited me to analyze the extent to which using residential location was a reasonable proxy for parents' education, occupation and economic status for the National Assessment of Educational Progress (NAEP.) NAEP is a huge study of the performance of 4^{th}, 8^{th} and 12^{th} graders, along with a longitudinal study of a sample of 9, 13 and 17 year olds. For the major study, which includes testing and a student instrument, it is not feasible to collect from children information about their parents. However, to stratify the results beyond race and Hispanic status, free or reduced lunch status, and general geographic location, some sort of SES variable was sought. Since ECLS-K has a parent survey, it was used to assess the potential of using information about the residential location (most generally the student's address is available from administrative records) to create proxies for economic and social status of the parents. Having more information on how such approaches works in practice and where such proxies provide useful estimates of SES and where they do not, would be very useful. Then it would be feasible to add such information to a wide range of health, education and other types of records where address is routinely collected.[3] To understand the spatial distribution of the precision of such methods based upon the variables chosen for imputation and the type of location would be very useful.

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[2] I should note that the recently released SAS 9.3 does appear to include the ability to integrate spatial terms explicitly into hierarchical or mixed models, as well as enhancing a large number of Bayesian approaches. Some of these techniques have been developed in some procedures in R, including the recently developed spBayes procedure. Such methods are not yet mainstream. However, to expect more rapid dissemination of such techniques into demography, they need to be presented in a platform that people are familiar with and that is robust, so that the models can be reliably computed. The current statistical package of choice for newly trained population and health scientists seems to be STATA, if our five recent hires of demographers and health researchers at Queens are any indication

[3] With a collaborator I have geocoded nearly 100 million hospital discharge records in New York State to assess various health outcomes and relate them to neighborhood context. I have used similar methods to impute the race and Hispanic status of prospective jurors and voters. Though perhaps a somewhat utilitarian use of spatial information, it is nonetheless extremely important for many issues.

Adding or Recovering Land Use and Facilities Data for Use in Population Science and Health

Currently it is relatively easy to get spatially referenced data from the United States that has very well developed information on the residential characteristics of individual and households living in various census geographies. It is true that the advent of the American Community Survey means that larger samples at the typical census tract or other level now will apply to a longer time horizon of five years, but this will be offset by more frequent releases of data.[4] Though one knows from the typical Census tabulation of aggregate data reporting, who lives in certain areas, there is little or no information regarding the other characteristics of the area, especially when the area is the size of a census tract or even smaller. It is, of course, possible to know where the streets and roads, water features, and some landmarks are located from the standard Census map.

Though collected by the Census Bureau, there is no integrated set of data that relates population characteristics to the existence of business activity broadly defined (the Bureau collects business information including non-profits and public entities, as well as prisons and jails, while the NCES collects data on school and their location), as well as other features of land use. Obviously for the development and change of neighborhoods and communities, as well as the health and well-being of residents, the location of business and other facilities are very important, as are development of transportation, power, water and other infrastructure.

Having these sorts of data readily available would mean that large scale studies of population, population change and health could go beyond simply relating one demographic variable measured at some level to another. It would make it possible to bring to bear information regarding other features. There are a large number of studies that have brought in the location of specific facilities or other information (e.g., fast-food, pollution, transportation networks, business activity), to understand aspects of population distribution and change, as well as health status. If such data were regularly integrated with census and other demographic and health data, relationship that now can only be modeled in one specific location, could examined for much larger areas, perhaps for the United States as a whole.

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[4] I should note that the ACS is somewhat misunderstood by many, even demographers. In my role as a demographic consultant for the New York *Times* and consultant both formally or informally to others, it is obvious to me that few realize that the ACS is now the source for data that used to be collected by the Census long form survey. See my column for a discussion: "Under a New Name Census Data Stands Ready for Perusal." http://www.gothamgazette.com/article/demographics/20110811/5/3582 . There are also issues regarding the methods that the ACS used to compute confidence intervals. My exchange with Census Bureau on this topic is available here http://www.scribd.com/doc/61741043/Memo-Regarding-ACS-With-Response. The recent designation of the areas requiring language assistance in voting as required by law was based upon the ACS. This designation was done using model based (i.e., Bayesian) estimating procedures. See various documents at http://www.census.gov/rdo/data/voting_rights_determination_file.html (i.e., Bayesian), thus obviating the problems that I outlined. Though using such estimates to do this designation, at this writing the Census Bureau has not made public any model based estimates for small areas using such estimating procedures.

There are a wide variety of other issues, including: pervasive dissemination and use of population data, the acquiring and use of both micro and aggregated data in a form similar to that available in the US for the rest of the world, as well as others. Plainly there is much to be done to move spatial data, techniques and modeling into a more central role in demography and health research.

Enhancing Resolution of Population Distribution Data in Spatial, Temporal, and Sociocultural Dimensions: Advances and Challenges

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Human population distribution data provides a fundamental component to the sustainable development framework. High resolution (sub-Census local level) population data is essential for successfully addressing key issues such as good governance, poverty reduction strategies, and prosperity in social, economic, and environmental health. Geospatial data and models offer novel approaches to decompose aggregated Census data to finer spatial and temporal units. At Oak Ridge National Laboratory, our focus with the LandScan Global population distribution model has been on developing high resolution global population distribution data. LandScan Global database has a spatial resolution of 30 arc seconds resolution (approximately 1 km cells). Since its inception in the late 1990s, LandScan has emerged as one of the leading community standard for population data with globally expansive user-base, including key applications focusing on sustainable development including many social science applications. There have been two prominent desires from the user community: first on the verification and validation of the model and database, and second being the increasing resolution of the data in spatial, temporal, and sociocultural[i] dimensions.

Enhancing Spatial Resolution

In addition to the native Census resolution, the spatial data-driven model, nucleus to LandScan, is sensitive to the quality and resolution of the ancillary input variables, with land use and land cover (LULC) data being the primary driver. With the availability of higher resolution LULC data in data rich environments, such as the National Land Cover Database (NLCD) in the US, Africover for parts of the African continent, and Geocover for the world, development of population distribution data (for example LandScan USA at 3 arc seconds) at a higher spatial resolution has been possible. This has somewhat alleviated the tremendous difficulty for implementing the model in spatial data poor environments, such as the African continent where the availability of most national Censuses are at very large spatial units and the quality of available physiographic data is inadequate. Recent advancements in the development of thematic maps of impervious surfaces and human settlement utilizing high performance computing-based processing of high resolution, tera(byte)-scale earth observation imagery and its potential impact on rapid estimation and revision of population distribution data. Combining with the algorithmic advancements with emerging computational architectures such as GPGPU based processing, our recent experimental benchmarks indicate that increasing the spatial resolution of the global

LandScan database from 30 to 3 arc seconds can be achieved within a few years (and not a few decades as it appeared a few years back).

Enhancing Temporal Resolution

Increasing the temporal resolution of a population distribution database essentially requires assessment and mapping of human activities at various temporal scales. LandScan USA model has demonstrated the feasibility of developing time variant high resolution population distribution data when fairly detailed databases depicting various demographic groups (such as schools, colleges, universities, businesses, recreational areas) are available. Presently, the LandScan USA data depicts population at 3 arc second resolution for both nighttime residential and daytime scenarios. We have also demonstrated that the temporal resolution can be increased, at a variety of geographic scales, by two complementary approaches: utilizing such high resolution data with population dynamics models (activity based transportation models) and empirically deriving population distribution and dynamics from near real time data mining of open source data streams (traffic cameras, videos, and other sensors). While we make an ad-hoc effort to account for naturally mobile (tribal) population as well as population displacements from natural and geopolitical disasters for the annual updates of the data, there is a clear need for a consistent methodology and approach for such refinements combined with the lack of timely update of the Census estimations.

Enhancing Sociocultural Resolution

While recent advancements in moderate to high resolution earth observation have led to better physiographic data, the approach of exploiting very high resolution (sub-meter resolution) imagery is not only useful in generating accurate human settlement maps, but also it allows potential (social and vulnerability) characterization of population from settlement structures (tents, huts, buildings) from image texture and spectral features. Researchers (such as Weeks et al) have long highlighted the potential of mapping poverty from remote sensing data. Our recent work has not only validated that hypothesis, but has delineated a new paradigm of rapid ingestion and analysis of high resolution imagery to enhance such "neighborhood" mapping techniques. Quality and timely availability of input spatial data provides a cost and time effective solution for developing current and accurate high resolution population data. Image exploitation through differences in the distributions of the low-level image primitives like edge orientations turns out to be a good feature to map different settlement categories. Conditional Random Field (CRF) approach and features generation from histograms of gradient orientations (HoG) has proved to be very effective for automated settlement detection and socioeconomic characterization. Such progresses in GIScience allows us to move towards the goal of creating a global foundation level databases for impervious surfaces and "neighborhoods," hold tremendous promise for advancing the state of currency and timely flow of critical information to benefit numerous sustainable development programs.

On Verification and Validation

While some progress has been achieved on verification of spatially explicit population distribution models, understanding and assessment of variability and uncertainty in these databases is a critical but challenging issue, which has not been addressed adequately. Beyond the key issue of validation of model output, uncertainty representation and communication are very much immature for population databases. However, there is probably not a simple answer to the simple question "what is the uncertainty in the population database?" One can assess variability and uncertainty based on space (whether a particular location is populated or not). But the temporal dimension adds to the complexity when the database is attempting to represent population dynamics. Given most population dynamics models are driven by human activities, no single average of the temporal continuum may be considered since specific time segments such as workweek, weekends, holidays, seasons, and special events can all influence population of a location. Consequently, in addition to the uncertainty resulting from specific modeling methods, temporal variability in the activities must be assessed in order to ascertain overall uncertainty. Although feedback from global a userbase have traditionally served as a surrogate for field validation, the emergence and proliferation of volunteered geographic information (VGI) and transplantation of social networking principles for scientific exercises, such as crowd sourcing, has opened up an era of new possibilities for formalizing validation of population distribution data.

[i] This paper has been authored by employees the U.S. Federal Government and of UT-Battelle, LLC, under contract DE-AC05-00OR22725 with the U.S. Department of Energy. Accordingly, the United States Government retains and the publisher, by accepting the article for publication, acknowledges that the United States Government retains a non-exclusive, paid-up, irrevocable, world-wide license to publish or reproduce the published form of this manuscript, or allow others to do so, for United States Government purposes.

Future Directions in Spatial Demography

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Operationalizing the concept of "neighborhood" has proven to be a particularly vexing problem. Analyses of neighborhood effects on youth risk behavior—an area of rapid development in the neighborhood literature—often assume equivalent exposure to the neighborhood aggregate chosen (e.g., census tracts). However, to date, few studies have offered empirical evidence to support this assumption. Given the inherent ambiguity of the concept of neighborhood, some have argued that *activity space* approaches—where activity spaces consist of all of the locations that individuals come into contact with as a result of their routine activities—are likely better measures of "neighborhood" exposure. The extant literature also largely omits an additional potentially important source of contextual variation—*non-residential neighborhood exposures.* For example, a recent study that tracked youth travel paths over the course of a day found that "half of the subjects spent 91.5% or more of their outside-the-home time in a census tract other than the census tract where their home was located" (Basta et al 2010). Consequently, theoretical approaches to contextual effects (and measurement strategies) that consider the intersection of individuals and actual behavior settings are likely to yield more insight into the processes by which contexts shape outcomes.

From Neighborhoods to Communities

Tracking individual activity spaces offers an advance over the typical assumption of equivalent neighborhood exposure characterizing the vast majority of neighborhood research. However, individually defined activity spaces do not offer information on the embeddedness of activity space locations in larger systems of interconnected places. Just as individuals may be influenced by the larger social networks to which their specific alters are tied, the system of interconnection among places (as measured by overlapping routine activity locations) may be relevant for structuring the pattern of social exposures individuals are likely to encounter. Indeed, this is one of the typical assumptions behind conventional neighborhood effects research—measures of neighborhood are seen as encompassing an actual or potential exposure space. We argue that this space may be more accurately captured by conceptualizing links between subjects and the spatial locations of their key activities as dyads in a larger *actor-setting affiliation network*. We hypothesize that activity spaces are patterned across key sociodemographic groups and geography, the aggregated structure of which captures what we term "communities"—i.e., the network of actors and settings to which individuals are tied through routine exposure.

Although, in some cases, residential and community contexts may overlap considerably, we take the degree of overlap to be an empirical question. In some instances, youth from the same residential area will exhibit overlapping activity spaces that are also contained largely within the residential boundary. However, we hypothesize that this scenario is likely to be relatively rare. More critically, we argue that characteristics of the communities of residentially proximate youth may vary considerably with potentially important developmental implications. Aspects of communities including structural resources (e.g., the affluence level of network members) and informal social control (e.g., the level of supervision characterizing youth behavioral settings in the network; the average proportion of time spent in structured vs. unstructured settings) may be highly influential in the lives of youth *independent of residential neighborhood contexts.* Moreover, the effects of setting characteristics (peers, supervision, activity structure) may depend on the characteristics of the communities in which those settings are embedded. For instance, a given setting characterized by unstructured socializing may be less likely to lead to risk behavior when tied mostly to more structured settings in a larger community context. Behavior in unstructured settings within such a community may be influenced by the more conventional normative orientations of typically encountered settings in the network.

By allowing community and neighborhood to be distinguished, research may shed light on "mixed" findings regarding the role of typically operationalized neighborhoods in children's lives. Children who reside in economically disadvantaged neighborhoods may nonetheless tap into highly resourceful communities. For example, Small (2009) finds that child care centers in high poverty neighborhoods maintained extensive ties to other organizations. Access to organizationally brokered resources such as referrals to other youth programs and beneficial activity settings (and associated communities) by some mothers in poor neighborhoods may result in better outcomes for their children when compared with other geographically proximate residents. Significantly, Small argues that ties to extracommunity resources through organizational affiliations are rarely a result of informed, instrumental action. Rather, consequential organizational ties often occur as a by-product of more mundane social transactions. Thus the origins of community affiliations are unlikely to be straightforwardly determined by the purposive actions and resources of individuals (i.e., a selection model of community membership). At the same time, community affiliations may confer significant benefits. In the absence of effective measurement of community, divergent outcomes among youth who share the same neighborhood will be spuriously attributed to individual or family characteristics.

Current Projects

I am currently working with a number of colleagues, including Mei-Po Kwan at Ohio State University and Kathleen Cagney at the University of Chicago, to collect activity space data that will allow these ideas to be tested and refined. A recent grant from NIH/NIDA ("Adolescent Health and Development in Context") will involve collection of data on 4–5,000 youth ages 11–17 and their caregivers. The study will gather one week's worth of GPS data on the locations of youth activities and real-time information on mood, behavior, and social interaction using Smartphone-based "ecological momentary assessment." The objective of the study is to understand how residential neighborhoods, "communities," social networks, schools, and families shape mental and behavioral health during adolescence. The project will gather two waves of data on youth, replicating the GPS/Smartphone protocol at wave 2. We have also received funding from the WT Grant Foundation to supplement the NIH award. This related project will oversample youth from a low-income region of Columbus in order to gather more precise information on how adolescents from economically disadvantaged areas use their (potentially quite variable) communities to promote successful development. This project will be among the first, large-scale probability studies to combine detailed, longitudinal information on the geographic locations of youth activities with real-time data on youth social interactions, mental health, and behavioral outcomes.

Initial pilot data demonstrate the feasibility of constructing communities from precise address data offered by youth. Figures 1 and 2 show the actor-setting affiliation networks (actors in red; locations in blue) for a high- and low-income census tract in Columbus, OH. Although the data are constrained by census tract boundaries, they indicate that even with self-report data on 4-5 typical activity addresses from adolescents, the data still yield sufficient overlap in locations to generate an affiliation network. We weight nodes in the network (both youth and activity locations) by eigenvector centrality to illustrate one of the many ways these socio-spatial affiliation network data may be used to shed light on how places are linked more or less tightly to larger clusters of places (communities).

An abstract for the project may be found at the following URL:
http://projectreporter.nih.gov/project_info_description.cfm?aid=8210117&icde=0

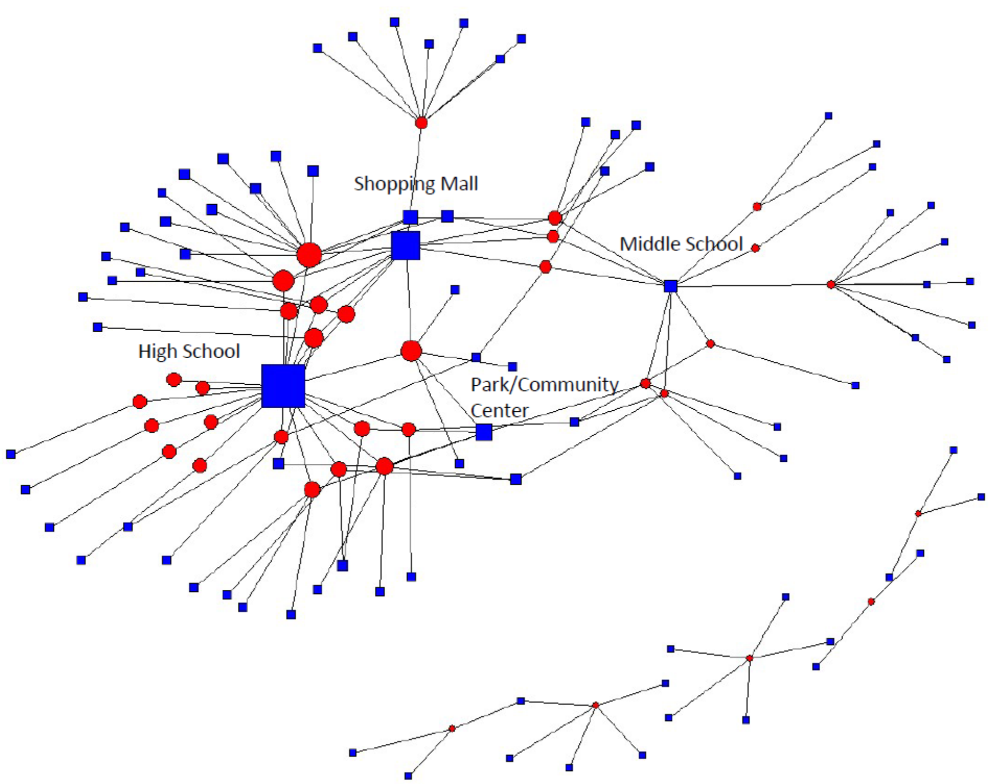

Figure 1. High Income Actor-Setting Affiliation Network (Nodes Sizes Proportional to Eigenvector Centrality)

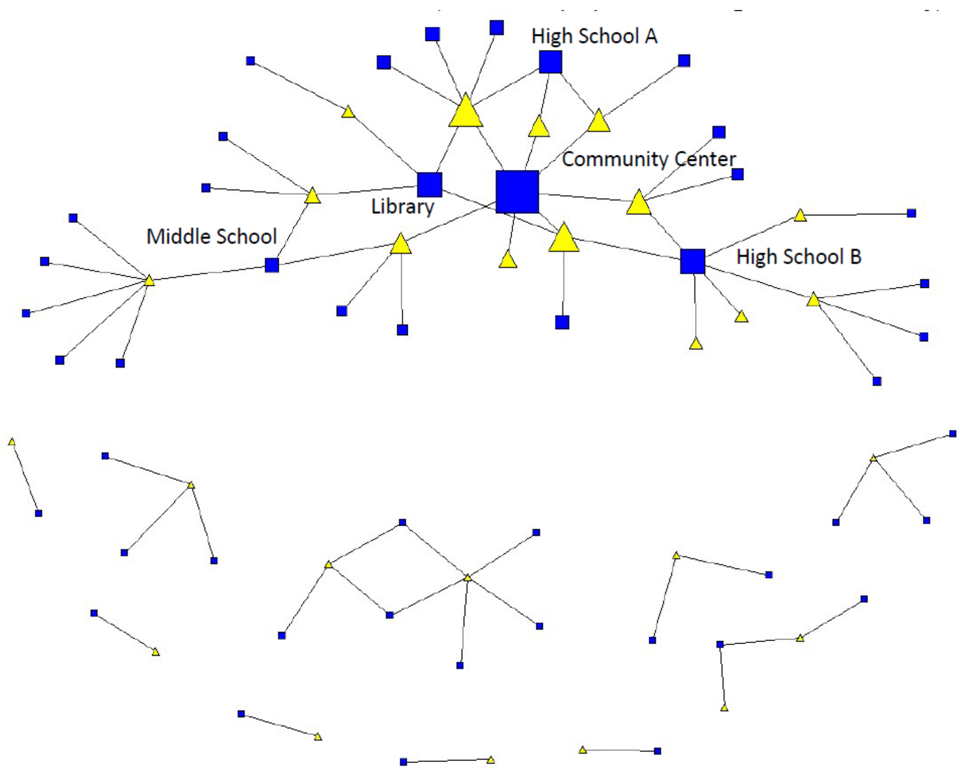

Figure 2. Low Income Actor-Setting Affiliation Network (Nodes Sizes Proportional to Eigenvector Centrality)

Future Directions in Spatial Demography

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In the past twenty years, demography has expanded beyond the core areas of fertility, mortality and migration to population health. One key subarea that has emerged during this transition is spatial demography. Spatial demography is the application of the tools of spatial analysis to demographic research questions. A spatial demography perspective complements other analytic tools in the demographer's toolkit by explicitly incorporating dimensions of place into the analysis of both individual and aggregate-level human phenomena.

For spatial demography to develop into a leading subfield of demography in the next 10 years the following issues should be considered:

Develop conversations and collaborations across disciplines. Spatial demography is interdisciplinary. Anthropology, economics, geography, psychology, public health and sociology all claim some spatial elements as their own. Environmental sciences and engineering are emerging as the next frontier in spatial science. Collaborations across disciplinary boundaries need to be developed and nurtured.

Advocate for spatial science. Work together with colleagues to organize paper sessions at meetings and special issues of journals. Ensure that publications are accompanied by press releases.

Encourage colleagues to participate in peer review. Serve as a reviewer for NIH, NSF and other funding agencies. Spatial scientists are often a minority on NIH review panels. When serving on a review panel spatial scientists need to effectively communicate to the other scientists on the panel the added value of incorporating a spatial perspective for our scientific understanding of demography and population health.

Actively train. To move "beyond mapping" continuing education programs as well as predoctoral training are essential. The primary training challenges include: determining what the core spatial demography courses are and incorporating core spatial demography coursework into training programs.

Incorporate spatial measures into datasets. Revisit the measurement of place and the characteristics used to define place. For example, measuring "place capital." For individual-level datasets, identify ways to increase access to spatial data without compromising the confidentiality of survey respondents. Revisit "old questions" with new tools. Apply the tools of spatial demography to research questions in reproductive and population health.

Take advantage of new measurement and computing technologies. For example, combining GPS, actigraphy and diary methods can offer new insights into the measurement of health behaviors and activity at the individual level. At the community level, advances in satellite imagery and remote sensing, and improvements in the areal measurement of disease vectors all provide additional scientific opportunities for spatial demographic research. Desktop computing power that allows for the estimation of complex statistical models, including spatial models, has made spatial analyses more accessible. Spatial demography is well-positioned to benefit from all of these technologies.

The opinions expressed in this essay are those of the author and do not represent the views of the National Institutes of Health, the Department of Health and Human Services or the United States government.

Future Directions in Spatial Demography

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My interests in spatial demography stem from: 1) my own research on contextual effects; and 2) my role as Director of the University of Chicago's Population Research Center (PRC). I detail these below, with specific emphasis on a proposal to track activity space and network interaction in older adults.

Over the last several years my research has examined the relationship between features of neighborhood social context and individual health. I, with colleagues, developed a series of papers that demonstrate the unique effects of neighborhood social capital on physical functioning, self-rated health, asthma and other breathing disorders, and mortality during the 1995 Chicago heat wave (Browning & Cagney, 2002; Wen, Browning, & Cagney, 2003; Cagney & Browning, 2004; Cagney, Browning, & Wen, 2005; Browning, Wallace, Feinberg, & Cagney, 2006; Cagney, Browning, & Wallace, 2007). I also have argued that neighborhood age structure should be incorporated into neighborhood research on health (Cagney, 2006). These analyses move beyond extant research by testing theoretically motivated hypotheses regarding neighborhood-level social capital and other social processes that may influence health. For instance, we find that neighborhoods with high collective efficacy have a lower prevalence of asthma (Cagney & Browning, 2004). Neighborhood-level trust and solidarity may depress asthma rates through improving the ability to garner health-relevant resources, eliminate environmental hazards, or encourage dissemination of health-enhancing information. This research draws on and extends a theoretical model that links neighborhood structural disadvantage (e.g., poverty, affluence and residential instability) with lower levels of trust and cohesion among local residents and a diminished capacity to mobilize on behalf of collective goals. Developed in part during the 1940s by the University of Chicago's Shaw and McKay, with contemporary elaborations by Wilson (1987) and Sampson et al. (1997), my work has focused on an adaptation to this model and brought it to older adult health.

One important critique of the above described research is its reliance on administrative and related data sources to characterize the communities in which respondents live. In new research—that would benefit from others working in spatial demography—we build upon the theory but focus on activity space and on changes in health over time. This work examines older adults' health trajectories in real time, as changes unfold. Researchers often assume that older adults' circumference of turf constricts as they age but the actuality of increased time spent in the home or neighborhood is relatively unknown. Thus, we not only concentrate on reports of network, household, and neighborhood factors but also on the unique role of GPS-tracked activity space. Tracking older adults' movements—in, out, and across their communities—will provide insight into their span of engagement, the contexts most relevant for their health and well-being, and their access to social and community resources. These dynamic data, coupled with frequent assessments of health, combine to form an unprecedented data opportunity that will allow for an understanding of social context effects across time. We focus on the social and physical environments of Chicago, drawing on the rich history of urban social studies in this context.

With multiple assessments embedded in three waves of data collection we will:

1. Describe the activity space that older adults, 55 and over, inhabit.
    a. To what extent do older adults move beyond the space of the household, and within and outside the neighborhood, as they engage in routine activities?
    b. When older adults do leave their homes, what do they do? Are older adults anchored within or drawn from their households or neighborhoods for different reasons, or to accomplish different goals (e.g., social engagement vs. medical care)?
    c. What are the differences across older adult subpopulations (e.g., social, economic, geographic, race/ethnic) in the geographic spread and resources available within their routine activity space?
2. Examine how social networks, households, and neighborhoods relate to activity space.
    a. What is the geographic proximity of social network members to the respondent's household and neighborhood, and how connected are network members to household members and neighbors?
    b. How might this vary by older adult subpopulations (e.g., social, economic, geographic, race/ethnic)?
    c. How do network composition and household and neighborhood contexts influence the range of activity space?
3. Explore the extent to which activity space, and the network, household, and neighborhood contexts related to it, affect short-term and prodromal changes in health including:
    a. Self-reported assessments of physical, biological, and psychological health and well-being.
    b. Biomeasures of health status and functioning, with a focus on measures of disease risk (e.g., CRP, immune function) and indicators of disease management (e.g., hemoglobin, blood pressure).
    c. Mild and/or transient health problems, including mild illness, fatigue, pain/stiffness, changes in mobility, respiratory difficulties (in other words, the "daily hassles" of health problems).

Observing older adults' movements—in, out, and across their communities—will provide insight into their span of engagement, the contexts most relevant for their health and well-being, and their access to social and community resources.

This research is just one example of work that can be supported through our GIS core in Chicago's PRC. Our central goal as a Center is to focus our efforts on the study of urban context with perspectives from sociology, economics, and medicine. The University of Chicago has a rich history in the study of urban space and the PRC hopes to contribute to this tradition through the support of new theory and methods aimed at urban social and spatial processes. As Director I would like to identify new approaches and interact with other scholars nationally who are developing demographic methods that related to space. I then can bring this information home and it can inform my own perspectives on how best to: 1) mentor junior faculty with interests in spatial demography; and 2) appropriately seed research projects through our pilot programs.

Future Directions in Spatial Demography

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With the world at 7 billion and counting, demographers will face many challenges in the 21st century in order to understand current and future trends of the population. However, the proper measurement, analysis and modeling of population depends on two factors: (i) availability of proper methodologies, and (ii) training of demographers on those methodologies. In this position paper I focus on challenges related to the field of spatial demography.

Methodological Challenges

The use of spatial analysis in demographic studies has been growing recently, with many applications on the study of fertility, mortality, and migration, the analysis of population size, change, and distribution, and on varied applied demography research [1]. Spatial methodologies facilitate the appraisal of regional inequalities, the investigation of diffusion processes during the demographic transition, and the identification of clustering patterns of demographic indicators, to name a few. Results obtained from spatial analyses provide unique information for the formulation and implementation of targeted policies.

Potential areas of future applications of spatial demography include the understanding of processes and patterns related to fertility and mortality, modeling of migration, improved small-area population estimates, monitoring and evaluation of programs (e.g., the Millennium Development Goals)—including assessments of regional inequalities, and the regular release of spatial demographic data, which could facilitate research in many different fields (e.g., health, education, and social security). Examples of such data include the Gridded Population of the World [2] and the Global Rural-Urban Mapping Project [3].

The challenges, however, are many. First, available data are not always appropriate for meaningful spatial analysis due to the sampling frame and/or spatial coverage. Second, the spatial scale of the data may be too coarse, and therefore not useful for improving current knowledge and aiding policy making. Also, the spatial scale may be constrained by confidentiality issues, limiting analysis. Third, combining data from different sources in one spatial database may be imperiled by the spatial and temporal scales in which they were collected [4], and by distinctions in the definition of spatial units (e.g., census blocks, zip codes). Fourth, some applications of spatial methods in the social sciences have failed to establish a sound conceptual framework linking the importance of spatial effects to the outcome of interest, leaving room to much criticism. It is imperative to hypothesize (and test for) the possible mechanisms through which space would impact varied population indicators—a good example is presented by Voss [5]—as well as how this impact could vary depending on the adopted concept of neighborhood [6]. When appropriate, the assessment of causal effects in a spatial framework would also be useful.

Also important is the need to adopt a multidisciplinary spatial analytical approach, combining cultural, behavioral, social, economic, political, and environmental aspects. Results obtained with such an approach could provide evidence for the need to establish multi-sectoral policies (e.g., integrating the health, education, and urban planning sectors of the government), and facilitate the monitoring and evaluation of these policies. The importance of this demand is reflected in funding mechanisms that explicitly require that research proposals include a multidisciplinary team of researchers (e.g., National Science Foundation, and the National Institutes of Health). Yet, the challenges are not negligible: data from different disciplines are not collected in a uniform manner, often do not have the same spatial and/or temporal scale, and may be of varied quality; and the same variable can have different jargons depending on the discipline, which demands special care when disseminating results.

Training Challenges

Demography training offered by Demography Departments is rare. Often, training in Demography is provided by departments of Sociology, Economics, or Public Health. Professionals graduating from these programs, previously referred as hyphenated demographers [7], do not necessarily have solid training on formal demography, but are very skilled on the use of techniques for the analysis of micro-level data—what could be called, micro-demography [8]. These professionals have much to enrich the discipline and contribute to the application of multidisciplinary approaches, although their research tends to focus on micro analysis, leaving the macro analysis of demographic data (analyzing aggregated events, and assessing population composition and change over time) neglected. This is aggravated by the fact that research funding for formal demography is practically nonexistent, offering no incentives for departments or professionals to invest their time and effort in such studies [7]. As a result, much knowledge is being generated regarding individual behavior and decisions, not accompanied by aggregated studies that assess population processes and dynamics [7,8], and a large number of spatial demography work also focus on the micro level.

Also rare are Demography programs that provide training on spatial analytical techniques [1]. First, there is the challenge of developing "spatial thinking" in the social science community, particularly among demographers [9]. The lack of spatial thinking often occurs before one gets a college education, and therefore this problem is not an exclusive concern of social scientists. Without spatial thinking we miss the visual power, the spatial exploratory investigation, and the understanding of the impacts that space can have on life outcomes (health, behavior, inequalities, etc). Above all, we miss the chance to provide adequate guidance for policy making [1]. In addition, most of the universities that host a population center (taking as reference the members of the Association of Population Centers—http://www.popcenters.org/) do not have a Geography department, and only a few offer regular classes on Geographical Information Systems (GIS) and spatial analysis.

These challenges in training suggest that a core curriculum should be considered by all programs that provide training in Demography, so that new generations of professionals would have the basic tools to apply methodologies that will be in high demand in the future, but also to develop much needed novels ones that could improve the measurement and analysis of population events. The area of Applied Demography was the first in the discipline of Demography to claim the need of specific training, and a Ph.D. program was developed to provide the necessary skills needed by applied demographers [10].

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VGI-enabled 4D GIS

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Conventional definition of 4-dimensional (4D) GIS refers to the integration of 3-dimensional space (i.e., x, y, and z) and the temporal dynamics of a geographic phenomenon in a GIS environment for spatial analysis and modeling. In physical science, it is possible to acquire 3D geographic data at different time to be used in 4D GIS (Tanikawa and Hashimoto, 2009). In spatial demography, however, the effort to track and gather space-time data of individuals is complicated by low response rate, sampling bias, and privacy issues. In fact, even the largest effort to enumerate individuals, national census conducted by the government, can suffer from serious underestimation (Anderson and Fienberg, 1999).

Therefore, one of the major bottlenecks in the realization of space-time integration in spatial demography is the lack of appropriate demographic data at the temporal resolution needed. The temporal problem includes practical issues of data unavailability both in [near] real time and at high temporal resolution to reflect the dynamic change of human population. Recent advances in Volunteered Geographic Information (VGI) research inject new synergy into space-time integration as the crowd-sourced data fill in part of the data gap and post new research needs. This position paper will illustrate two VGI applications of spatial demography and discuss related research frontiers.

The first VGI application highlights the emergence of web demographics as a new form of demographic data that are made searchable on the Internet by people finder sites like WhitePages (www.whitepages.com). The web demographics are personal-level microdata that include full name, address, age, phone number, etc. Based on surname analysis, it is possible to use surnames that are highly predictive to an ethnic group (e.g. Vietnamese-Americans) to solicit their associated web demographics and conduct a "web census". Comparing the spatial pattern of web demographics collected in 2009 and Census 2000 data revealed demographic trends that conform to general understanding of spatial demography, including the urban-to-suburban and rural-to-urban migration in major metropolitan areas of Texas (Chow et al., 2010). As web demographics contain personal level microdata, the spatial and temporal resolutions can be flexible for space-time GIS research. The integration of other VGI, such as CommonCensus (www.commoncensus.org), can re-define the cultural landscape to explore spatial demography at the neighborhood scale.

The second VGI application demonstrates the potential of VGI to empower neogeographers' role in spatial modeling and analysis. Kwan and Lee (2005) presented a real-time 3D GIS system to model the 3D shortest path of a multi-story building in a hypothetical bomb threat scenario. As message sharing by location-aware device, such as a smart phone, becomes a trivial task to many, such VGI would be valuable to describe the latest update of the disaster for emergency response. In reality, it may not be surprising that the optimal path modeled by GIS can be benefitted from the real-time updates, such as rerouting due to unexpected blockage. In fact, VGI has been instrumental to fire mapping and evacuation planning in the wildfire in Southern California. In spatial demography, VGI can be helpful to study the short-term and long-term impacts of natural disasters on population redistribution at various scales.

The integration of space-time GIS and VGI in spatial demography highlights an array of important research frontiers that includes the following (but not limited to due to page limit):

- Validation of VGI—The quality of VGI should be evaluated by their demographic attribute correctness, positional accuracy, and temporal currency. More research is needed to field validate the accuracy of VGI for spatial demographic applications.
- Appropriate space-time GIS tools—There are some existing tools, including path generation, pattern detection and cluster analysis, to conduct space-time GIS (Chen et al., 2011). As much VGI (e.g. tweets) include narratives, there is a need to integrate qualitative and quantitative analysis for contextual research (Kwan and Ding, 2008).
- Uncertainty analysis—A follow-up concern for VGI quality is the impact of error propagation for subsequent spatial modeling and analysis. Related to the data quality of VGI, an important consideration in using VGI for analysis is its blurry ownership and authority. Geocomputation techniques can be used to explore the uncertainty of subsequent analysis associated with conflicting views and provide possible resolutions.
- Multifaceted nature and integrative research—Future research should examine the role of VGI in spatial demography in light of Critical GIS (CGIS) and Public Participatory GIS (PPGIS). CGIS provides the foundation of social theories to examine important questions like "who are the VGI contributors," "what are their motivations," "how social drivers affect the quality of VGI and subsequent use." The empowerment of marginalized population in PPGIS is essential to warrant representative spatio-temporal data needed for a meaningful 4D GIS and enrich the spatial demographic research.

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Future Directions in Spatial Demography

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My primary concerns within each of the areas to be elaborated in the workshop on Future Directions in Spatial Demography are reflected in two specific issues: advances in spatially-explicit theory; and advances in space-time analysis.

With regard to advances in spatially-explicit theory, I suggest that spatial heterogeneity is too often overlooked in demographic research aiming to address spatial effects. In my research and teaching, I build from the position that spatial effects are either a heterogeneity process or a dependence process (e.g., Voss, Curtis, and Hammer 2006).[1] In my read of the literature, spatial dependence is given more attention relative to spatial heterogeneity. However, demographers and other social scientists do not always theoretically justify or fully explain the theoretical implications of using a spatial dependence model. There are exceptions, of course, as some theories of fertility, mortality, and migration invoke a dependence argument (i.e., the diffusion of fertility practices, the spread of infection, and the development of migration networks). Yet there is too often a mismatch between the theoretical model asserted and the statistical model used to test it, where theory suggests heterogeneity while the analytical approach suggests dependence.

There are two potential reasons for the mismatch, based on my interactions with graduate students as well as early- and mid-career scholars and researchers in my seminar and workshops. First, spatial heterogeneity is relatively more conceptually complicated. I do not claim that spatial dependence is simple to statistically model or substantively explain. However, in my experience, many if not most students and workshop participants come primed to analyze their data using a spatial lag regression model, assuming some "neighborhood effect" is driving the outcome. Even those who come with little interest in the spatial effect, per se, but with an eye toward space as nuisance approach the "problem" as one of spatial dependence, often thinking the spatial lag regression model is most appropriate because the problem is derived from dependence in the data structure. This approach can result in a statistically poor-fitting model. Of equal if not greater importance to population and health research is this: immediately resorting to a spatial dependence frame excludes the potential for a deeper substantive knowledge of the spatial process at play and, correspondingly, meaningful theoretical development.

Spatial heterogeneity can be conceptually complicated because of its multiple meanings. Spatial heterogeneity can refer to spatial variation in the distribution of an attribute. It also can refer to spatial variation in relationships between attributes. I assert that there is much promise in exploring spatial effects through both forms of spatial heterogeneity. In the first form, one is positioned to "explain" the spatial effect through measurable attributes. In the second form, one is positioned to reconcile inconsistent findings and identify contexts in which processes differ (e.g., Curtis, Voss, and Long 2011).[2]

Accomplishing either task is not necessarily simple or straightforward, yet it is essential to develop theory. In the first form, one must think carefully about the potential source of heterogeneity; it is measureable or immeasurable? Is it a product of a demographic process or is it an artifact of the data (measurement error)? In the second form, one must think carefully about the interplay among multiple attributes that give rise to different contexts and, ultimately, to different relationships between key demographic factors. In both forms, the researcher is challenged to think about the qualities of spatial units in terms of social, economic, environmental, political or geophysical attributes that are relevant to the demographic process or event of interest. That is, what precisely is "space" and why is it relevant? An important consequence of fully exploring spatial heterogeneity is more fully developed theory.

The second source of mismatch between conceptual and statistical models is that there are many ways to explore spatial heterogeneity and not all of them are considered "spatial" methods. Consequently, researchers exploring spatial dimensions seem to limit themselves to "spatial" modeling strategies despite the conceptual model. At the same time, researchers uninterested in spatial dimensions do not speak in terms of space, leaving the conceptual model underdeveloped. A simple illustration is the student who finds evidence of spatial autocorrelation in his data through a Moran's I or similar statistic. He analyzes his data with an ordinary least squares regression and finds no evidence of spatial autocorrelation in the residuals. He is disappointed because there is no longer a spatial effect. In fact, this outcome would be disappointing if the theoretical model claimed spatial dependence. Yet this outcome could be consistent with a theoretical model asserting spatial heterogeneity; the independent variables have identified the spatial patterning in the dependent variable. One does not equate OLS with spatial data analysis. However, an OLS can be used to test a spatially-informed conceptual model, one in which the spatial effect is a form of spatial heterogeneity.

The mismatch between conceptual and statistical models is rooted in training. I assert we, spatial demographers, should prioritize conceptual development in our training by integrating demographic theory and spatial analytical techniques. We have made significant advances in providing training in spatial analytical methods through courses and workshops. I suggest we integrate spatially explicit or implicit theories into already existing offerings and/or develop companion courses and workshops that address spatial theory. It is within this domain that we can make significant progress in addressing a variety of issues including, for example, measuring place and the interrelationships among places, assessing the validity of measures of neighborhood and context, and determining the most effective way to visualize and analyze data (including tools not yet available).

With regard to **advances in space-time analysis**, I suggest that we still lack the necessary tools to address the most basic demographic questions. Much of demographic research concerns trends—changes in trends, divergent trends, and factors underlying trends. We have the ability to describe trends among spatial units. However, we do not have available accessible, statistically rigorous tools to draw statistical inference or to simultaneously analyze temporal and spatial processes. The former is necessary to assess whether changes or differences are meaningful or negligible. The latter is necessary to correctly identify what is driving the trend. There have been significant advances in spatial regression in recent decades, in types and accessibility, yet space-time regression has not matured at the same rate or to the same degree. Moreover, statisticians developing the analytical techniques are disconnected from the demographic user community wanting and needing to apply the techniques.

This disconnect has stalled scientific progress. Researchers are unable to answer questions relevant to the discipline and to social policy because the analytical tools are not accessible to them. In my own experience, I began exploring spatial data analysis techniques in 2003. At that time, I took advantage of the descriptive tools available, engaged the literature on advances in space-time regression, and was informed that such advances would soon be implemented into existing software programs tailored to spatial analysis. In 2008, five years later, I published the work I began in 2003 without the intended space-time regression approach because the tools were still unavailable. Also in 2008, I sought a statistics collaborator to develop techniques that would enable me to answer questions about change in space over time. Now, in 2011, the collaboration is bearing fruit; we have one manuscript under review developing the approach (e.g., Reyes, Zhu, and Curtis 2011, developed in R).[3]

Such synergistic collaborations are important, appear to be necessary, should yield publically available data analysis tools, and should be sponsored by funding agencies or collectives already supported by these agencies. I argue priority should be given to space-time techniques that enable statistical inference because space-time questions are foundational to population and health research. At present, we are unable to address the most basic questions at demography's core because tools that are within reach are not available to all members of the demographic community.

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Advancing Theory and the Integration of Spatial Analysis and Network Analysis

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As a political scientist, I am very interested in how common concerns of interest to both political scientists and demographers can promote advances in spatial demography. Two interests of particular concern are: 1) much needed theoretical and empirical advances in understanding the proper distances and scales at which spatial dependence affects concerns of interest to demographers, and 2) advances in the integration of network analysis and spatial analysis in demography and political science.

The past decade and a half have seen considerable advances in the development of spatial econometric estimators that are utilized in both demography and political science. These advances are extremely welcome, but have not always been matched by equivalent advances in our theoretical models or empirical understanding of how space and context shape common interests of concern to both demographers and political scientists. As a consequence, we still lack significant understanding of both the distances and scales at which spatial dependence is most consequential for both demographic and political phenomena and for the interaction between these two concerns.

Questions of distance are particularly relevant for the construction of spatial weights matrices to estimate spatial dependence. Some fundamental theoretical questions remain in both demography and political science. For example, how does distance between actors affect the probabilities of interactions between these actors and thus their propensity to exhibit spatial dependence? Does geographic distance between actors have the same effects on demographic and political phenomena?

Too often, spatial weights matrices are ad hoc and do not reflect a theoretical conception of propensity for spatial dependence in either demography or political science. A closer examination of the nexus between demographic and political phenomena can provide a stronger theoretical foundation for the construction of spatial weights matrices. For example, population migration is often engendered by political instability and civil unrest while reproductive health and population health are highly contingent upon levels of political development. Conversely, demographic change is one of the principal sources of changes in voting patterns in both the United States and other countries. In short, demographics and politics are intimately connected. Better understanding how distance in interpersonal interactions in demographic (political) phenomena affects interactions and engenders spatial dependence in political (demographic) phenomena can provide significant theoretical leverage in the construction of spatial weights matrices for both disciplines.

Just as considerable work remains to be done in better understanding how distance shapes demographic and political behaviors, so also does considerable work remain in understanding how context shapes these behaviors. The modifiable areal unit problem (MAUP) is well-known and understood in both disciplines (e.g., Openshaw and Taylor 1979, 1981). MAUP is particularly consequential for both demography and political science given the arbitrary nature of the lattice objects used in these disciplines. Units such as zip codes, census blocks, census tracts, and the like are problematic for demography and political science alike in that these units do not identify distinct demographic or political contexts. Units defined for purposes of mail or census administration are inadequate for the theoretical tasks of both demographers and political scientists.

What is needed, in short, are measures of distinct demographic and political contexts (as well as economic contexts) that can be employed by demographers and political scientists. Recent work on "bespoke neighborhoods" provides some advances (see, e.g., MacAllistar et al., 2001; Johnston et al., 2005), although the use of arbitrary thresholds to build out these neighborhoods from a particular household is unlikely to distinguish precisely distinct demographic or political contexts. I am interested in exploring further the MAUP issue and identifying how demographers and political scientists can better identify distinct contextual units.

A second interest of concern is the stronger integration of network analysis and spatial analysis. The concepts that network and spatial scholars address are related, and could benefit from greater integration. For example, network scholars too infrequently examine how spatial distance promotes network formation and network interaction. Spatial scholars too infrequently map networks or examine the development of networks in their research.

The integration of network and spatial analysis is an important advance for both demographers and political scientists. A critical component of this integration is the discussion of new data sources for spatial and network analysis. The planned discussion on crowd-sourced data is of particular interest to me as a political scientist, as crowd-sourced data often carry a political dimension. There is a growing interest in crowd-sourced data within political science, particularly in the study of political networks. I believe much additional fruitful spatial work can be done employing these data in both demography and political science.

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Future Directions in Spatial Demography

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This position paper outlines my thoughts regarding the current state and ideal future directions of spatial data and methods used to support demographic research. My own experience suggests that general awareness of the value that spatial data and analytical tools bring to the research process is increasing. Awareness of techniques for dealing with spatial correlation in statistical analysis has lagged (pun intended) behind data availability but is still much greater than it was10 years ago. However, in many cases both spatial data and tools are being misused. I believe that to make progress, it is incumbent on geographers to put the genie back in the bottle by ensuring that existing tools and data we promote are applied correctly. I also feel that readily available theory governing spatial demographic processes has not kept pace with the evolution of the tools and data, and that we should direct more efforts toward linking spatial demographic theory with the statistical models we use to evaluate them.

Future Directions for Data

In the last 10 years we have seen a surge in useful spatial demographic data products. An increase in the availability of geostatistical methods (kriging and its cousins) has made it possible to produce high-resolution continuous surfaces of virtually any phenomena. This is not necessarily a good thing. High-resolution gridded surfaces of demographic data are useful for mapping and display purposes but these datasets are often used as input into both stochastic and deterministic models. Geostatistical methods generally rest on the assumption that the underlying process is some function of spatial proximity and it's not always clear that this assumption holds with demographic processes (just because they exhibit spatial correlation does not mean a spatial process is at work). Furthermore these datasets are generally compiled from a combination of survey and census data collected from different spatial supports, at different times, with varying degrees of accuracy. Despite their flaws though, integrated global datasets are useful and the demand is sufficient enough that they are probably here to stay. Our future direction then, at a minimum, should be to ensure that accompanying these datasets are error estimates that account not only for spatial uncertainty (how much error was introduced when changing spatial supports) but also temporal uncertainty (how long has it been since the source data was published). Ideally, despite their convenience, I think we should move away from publishing these datasets in grid form, and keeping them in whatever spatial support they were originally collected at (usually some set of sub-national administrative boundaries). For those that must have data below the spatial unit at which they were collected, the direction should be toward context specific small area estimation and simulation techniques rather than broad global interpolations.

Future Directions for Theory and Methods

A researcher faced with statistically analyzing a spatially correlated cross-section will usually proceed with one of four approaches:

1) Ignore the spatial component;
2) Use a cluster robust variance estimator;
3) Fit some form of spatial econometric model (toss a W matrix in there); or
4) Fit a hierarchical model.

Depending on the context one or more of these approaches is appropriate. It seems a lot of progress has been made in developing both the asymptotic theory and computational tools to implement approaches 2–4. Where we seem to lack however, is in clarifying the motivations for these approaches and connecting them to specific theoretical processes. I believe we need to do a better job of distinguishing between when spatial correlation is a nuisance to be corrected for, or a spillover process that you want to study in and of itself. In the former case it's not clear that simply fitting a spatial error model (the most common prescription) is the best cure. The biggest weakness in this approach are the assumptions that must be made when specifying the nature of correlation via the W matrix. There are several promising areas where W becomes almost unnecessary; specifically SHAC (Spatial Heteroskedastic and Auto-Correlated) and newer cluster robust variance estimators. I believe future directions should focus on testing, implementing, and communicating these techniques.

However, arguably the more interesting elements of spatial demography and analysis are when there is some specific spatial process that we wish to capture and analyze. In these cases we are stuck with W or some other representation of a pre-specified spatial processes. Here is the where the most difficult and interesting work lies ahead. To my knowledge (and I'm not a demographer) there are a paucity of concrete theoretical models defining spatial demographic processes that can be readily translated into statistical specifications. It would be an extremely valuable endeavour to compile a basic catalog of W specifications grounded in spatial demographic phenomena. Of particular use would be guidelines for specifying and estimating models where the nature of spatial correlation changes over time (dynamic panels and state space models). I am sure there is a lot existing work in network theory and peer effects that could be brought to bear on this process, but nothing yet that collects it into one compendium intended for use by the applied researcher. Our objective should be to assemble a diverse collection of spatial demographic theory with guidelines for translating that theory into testable models. This goal seems both attainable and fundamental toward making forward progress in the discipline

Space, Place, and Population Research: Challenges and Future Directions

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What do neighborhoods have to do with childhood/adolescent obesity? My dissertation sought to answer this question combining three of my research interests: childhood/adolescent obesity, neighborhood effects and spatial methods. While spatial methods have been used for well over 20 years, they have only recently been applied to neighborhood effects on health research. I was excited that I could contribute to what seemed to be a paucity of neighborhood health effects research using these methods (few studies have applied these methods to childhood/adolescent obesity). As a new postdoctoral fellow, I am still struck by how little spatial methodological approaches have been infused into social epidemiology, health geography and population research in general. So, what's the problem?

Theory and Data

I believe that there has not been a full integration of spatial methods in population health research due, in part, to implicit theories of health and determinants of disease. While there is undoubtedly an increasing appreciation of a social determinants framework to heath, sadly, a large number of epidemiologist still embrace biomedical individualism such as a lifestyle behavioral perspective to disease etiology, which ignores (or minimally recognizes) the social and spatial context. In biomedicine, the implicit notion of causal potency is linked with distance—i.e., the closer the cause (proximal factors as compared to distal factors), the greater the effect (Krieger, 2008). As argued by Nancy Krieger (2005), ". . . the framing of scientific questions [and methods] depends heavily on assumptions, usually more implicit than explicit, regarding the appropriate time frame, level, and scale of analysis" (P. 2157). This is one reason that I believe that some researchers have not taken advantage of geospatial data, which has existed for some time now. I think it is also important to recognize that creating and managing GIS data requires a variety of skills, such as understanding projections, which may hinder creation and use of such data. My sense is also that many researchers (who do not have training in geography/GIS) are increasingly hiring GIS analysts to create and manage their geospatial datasets. Still though, without knowing the enormous capabilities of GIS, geospatial datasets may not fully reach their potential and relevance for the processes being studied.

Methods, Models and Choices

Marcia Castro ends her quarter-long "Spatial Methods for Public Health" course with a quote by Griffith and Amrhein (1997), which states, "Not surprisingly, most students find the study of statistics hard, and the study of spatial statistics very, very hard!" This is a reason that I suspect that spatial approaches have not been fully integrated into population health and demographic research. In addition to complexities of spatial statistics, my sense is that only recently have researchers had geospatial software to implement various geospatial modeling techniques. Still though, we (researchers) tend to stick to the software (packages, programs, etc) that we have mastered and grown to love (myself included). Further, while there are established methods in several aspects of spatial econometrics, my sense is that in other areas of spatial modeling the methods at present are still in a developmental phase (e.g., perhaps Bayesian spatial methods for non-Gaussian data), leaving a novice (and sometimes more experienced) spatial analyst with little direction in terms of method selection. It is clear that this is a field where there is room for the development of cutting-edge methods. Lastly, when modeling data (spatial or not), researchers always have a myriad of options. However, my sense is that with geospatial modeling techniques there are *many* more options than in standard statistical approaches. To illustrate, the infamous spatial weights matrix is at the crux of most geospatial modeling techniques and is an added feature of standard models. Although the specification of the spatial weights matrix can heavily depend on the structure of the data, there can be multiple reasonable specifications of a spatial weights matrix for the same data. For example, should you choose a KNN of 4 or 6? What about 10? What about an inverse distance spatial weights matrix? Does it matter in practice? The specification of the spatial weights matrix can influence the results—sometimes in substantial ways, leaving the investigator with many choices, including to model the data with different spatial weights matrices.

Training

It is clear that training is a reason for the lack of integration of spatial approaches in population health and demographic research. One must have some understanding of geography and advanced statistics (in addition to the social epidemiologic and demographic theory, depending on the topic area). Specialized seminars, workshops and short-courses will be useful for researchers to become aware of various methods and software for geospatial modeling. I have been very fortunate to be involved in such training; e.g., through the Advanced Spatial Analysis Training Program for Population Scientists. Because every scientist will not be able (or want) to attend such training programs, it is reasonable to say that field would move farther (and faster) not just from such training programs and the like, but also from working with and in interdisciplinary teams. Because interdisciplinary research is in vogue (e.g., being an implicit and increasingly explicit prerequisite for NIH and other grant funding institutions), I believe that this will not be a problem in the future and as such will promote spatial thinking and spatial methods.

Thinking and Acting Spatially: The Future

Following are some thoughts on three areas in spatial social science that I suspect will be gain prominence sooner in the field:

Spatial Data Quality and Representativeness

The quality of spatial data is usually not examined or even mentioned in research papers. However, by simply playing with local spatial data, or even crudely comparing two spatial datasets for a region on a neighborhood feature (such as schools), it can become readily apparent that the spatial data might not be as accurate as hoped. Indeed, geospatial data can have errors of omission, features that no longer exist and positional errors. I anticipate that spatial uncertainty in neighborhood features will be taken more seriously in the future, including in modeling techniques and ground-truthing geospatial data. Closely related to this point is the almost complete lack of discussion of geocoding methodologies in the existing 'geospatial' research literature. Most health studies using GIS data do not provide address geocoding methods or provide only limited information on the geocoding method used, e.g., only providing the match rate. As a consumer of research, it is frustrating how little information on geocoding is often provided and it is very difficult to judge any potential misclassification without mention of the geocoding done. Nancy Krieger argued the importance of discussing ones geocoding methods ten year ago (Krieger et al., 2001)! Finally, while I believe that researchers have done a very good job at creating spatial data out of existing data sources, to fully understand the spatial process, spatial sampling approaches will have to be explored, which will likely increase in years to come.

Dynamics of Place and Space

Often times, we live, work, go to school and play across spatial contexts. This idea of 'spatial polygamy' as argued by Matthews (2011) makes this point well. We, researchers, tend to study only the residential neighborhood environment. It is important that I make the caveat that a burgeoning (albeit small) amount of research has evaluated the school neighborhood environment for children/adolescents, but I am aware of very little work that has evaluated the work neighborhood environment for adults as a predictor of health and behavior. And, where we "play" is often not acknowledge in the literature, or assumed to be in the residential neighborhood environment. The vast majority of studies often ignore the complexity of our spatial behavior. I suspect that future work will embrace a broad range of contexts (beyond the residential neighborhood environment) including how the *contexts* influence health and other outcomes. Existing theories, such as ecosocial theory proposed by Nancy Krieger in 1994, appreciate the simultaneous realities of human existence and encourage such complex analyses (Krieger, 1994). Cross-classified multilevel models have long existed, which examine the relative contribution to different contexts, but are seldom applied. Although multilevel models are not inherently 'spatial', my point is that the context of the context needs to be rigorously modeled and I suspect that this will be done in the future in spatial and a-spatial ways. I hope that the neighborhood definitions selected (or imposed due to a previously collected scale of the spatial data) are theoretically relevant to the processes studied and for the population, as several individual- and neighborhood-level factors, including individual-level race/ethnicity, age, sex, education, income, nativity, urbanicity, neighborhood social ties, tract-level population density, tract-level age composition, tract-level socioeconomic status, individual-level daily activities and even body mass index influence the size and scope of what people call their neighborhood (Colabianchi et al., 2007; Sastry et al., 2002; Guest and Lee, 1984; Logan and Collver, 1983; Haney and Knowles, 1978).

Web-based Geospatial Technologies

Studies have begun to evaluate the validity of Google to measure neighborhood conditions (Badland et al., 2010; Clarke et al., 2010; Rundle et al., 2011; Taylor et al., 2011); similarly, studies have also examined the validity of Walk Score® for measuring the neighborhood environment (Carr et al., 2010; Carr et al, 2011; Duncan et al., 2011). There is more of a need to assess the feasibility and validity of these and other new publicly available web-based tools to see if and how they can be integrated into neighborhood research. Coordinated efforts such as sharing validation and assessment protocols will advance the implementation and widespread use of emerging web-based assessments of the neighborhood environment. Importantly, a next natural step is to examine if and how well these web-based tools predict health and related outcomes (e.g., migration). I expect this type of research will trickle into the research literature soon for several reasons, including because I suspect that traditional geospatial data (e.g., GIS data on park proximity and density created from a GIS park data layer) will become increasing available/used and not seen as novel, as perhaps it is nowadays in many fields.

There is obviously an increasing recognition of the spatial context in population health and demographic research. As a social epidemiologist, I am excited about the resurgence of interest in the spatial context and look forward to discussing (and learning about) the challenges and future directions in spatial demography at the meeting.

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Future Directions in Spatial Demography—An Advocacy Statement

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The contributions to spatial statistics have had important repercussions in the field of demography. It is not unusual to find the tendency for spatial autocorrelation in spatial data to be recognized and dealt with by those demographers who use georeferenced data. In addition, certain key concepts in demography, such as neighborhood composition and segregation, are often candidates for spatial statistical analysis. In my work with demographers, principally John Weeks and Marcia Castro, I find the need to extend the work I have done in spatial statistics in response to their need to come to grips with the nuances of fine resolution data. For example, in Weeks' et al. NICHD projects, in which I participate, I have offered such new spatial statistical ideas as spatial filtering, spatial clustering using the AMOEBA routine, and spatial variance. Much of this work is designed to give weight to the demographic concept of neighborhood.

The idea of neighborhood is fundamental to current research on the urban environment. Neighborhoods, once defined, become the building block on which the complexities of urban living are understood. The difficulty, of course, is deciding on a definition of a neighborhood. Conclusions about urban structure, growth, and change, are dependent on that definition. In our work in Accra, for example, we have defined neighborhoods in 21 different ways. The issue, of course, is which definition(s) make theoretical and empirical sense for the various problems at hand. In Accra, we study women's health as partly a function of neighborhood characteristics, thus we must think in terms of what may be considered as health neighborhoods.

The new spatial statistics allows for the consideration of the data characteristics of health neighborhoods. For example, spatial filtering makes it possible to separate spatially associated health variables from non-spatially associated health variables. This is done by means of using a statistical definition of spatial autocorrelation. A result of this type of analysis is the creation of the possibility of statistically significant spatial clusters. The *AMOEBA* algorithm allows for the congealing of observations into statistically significant neighborhoods. Finally, the new statistic by Ord and Getis, H_i, is designed to, among other things, find the consistency, that is, the degree of homogeneity, within neighborhoods. It is a variance statistic built on the same premises used for G and I spatial autocorrelation statistics. Boundaries of neighborhoods can be discerned from the application of H_i statistics.

Thus, my position is clear; the use of spatial statistics is useful for developing and analyzing demographic concepts that are built on the need to understand spatial variation within urban environments.

Future Directions in Spatial Demography

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I think it would be helpful to include in the upcoming Specialist Meeting a discussion of some of the larger initiatives that are likely to impact the social sciences in the next few years, and to provide opportunities for the development of spatial demography. In what follows I discuss three of these.

First, and perhaps least likely given the timing, is the initiative being promoted by Myron Gutmann, the NSF Assistant Director for Social, Behavioral, and Economic sciences (SBE), to express a vision for the SBE sciences in the next decade or so. This has taken two forms: a report by the SBE Advisory Committee, which I chaired until a year ago, and a call for White Papers from the community. The report builds upon one completed by the Office of Science and Technology Policy[1], and on another completed by the European Science Foundation—both with similar objectives. The call for White Papers led to more than 200 submissions, covering a vast landscape of the SBE sciences. I have not had the time to go through these documents in detail, but my sense is that spatial demography is not especially visible in them.

Second, the SBE directorate is currently funding a series of workshops to discuss the concept of social observatories. Modeled in part on the Long-Term Ecological Research program of the BIO directorate, the concept is of a distributed network of centers that will undertake long-term monitoring of various social patterns and behaviors, with the objective of advancing knowledge in the social sciences. One workshop was held in late 2010, building upon previous workshops, and another is being planned. The spatially distributed nature of the proposed centers plays well to a place-based approach. It seems to me that spatial demography could be a significant focus of the centers, and that it would be worthwhile exploring exactly what form such a focus might take in the upcoming Specialist Meeting.

Third, NSF's Office of CyberInfrastructure (OCI) recently funded a major four-year project on CyberGIS. The project is being led by PI Shaowen Wang at the University of Illinois, Urbana-Champaign, and includes partners at Arizona State University, the University of Washington, Oak Ridge National Laboratory, Georgia Tech, the San Diego Supercomputer Center, and UC Santa Barbara. CyberGIS is defined as a distributed set of services based on high-performance computing, and the project is making use of the facilities of the National Center for Supercomputer Applications at UIUC.

There have been many prior efforts to make the case for high-performance computing (HPC) in spatial analysis, including a 1990s book by Richard Healey. Unfortunately the common perception of the functions of GIS has them being adequately performed by traditional

[1] http://www.whitehouse.gov/files/documents/ostp/NSTC%20Reports/SBE%20in%20the%20Federal%20Context%20%28for%20NSTC%29%204-21-09.pdf

computing systems, and the costs of converting to high-performance environments, including parallel computing, are very high. But cyberGIS is about much more than high performance. Distributed computing, the Cloud, and service-oriented architectures have advantages that extend well beyond the speed of computing, and are being actively explored in many projects. Moreover, HPC allows us to model social and environmental processes with unprecedented levels of spatial and temporal resolution, leading to greater accuracy and greater confidence in models. And HPC allows us to avoid many of the shortcuts and approximations that have become common in the interests of achieving reasonable computing speeds. For example, it is common to compute distances on the plane rather than over the curved surface, because the latter requires intensive use of comparatively slow trigonometric functions.

More compelling, however, is the ability of HPC to handle very large and complex systems in reasonable amounts of computing time. The kinds of agent-based models being built in the social sciences, in areas such as spatial demography, require access to HPC if they are to be even approximately realistic when applied to ensembles of millions of agents. Moreover, spatially distributed social systems function essentially in parallel, and are therefore much better modeled in parallel architectures.

A host of questions follow from this line of argument. How exactly should a social system be mapped into a complex computing architecture? How can the current complexity of HPC be simplified so that it is not a deterrent to researchers? What kinds of user interfaces would be most attractive to social scientists?

I believe the CyberGIS project offers an unparalleled opportunity for the advancement of spatial demography. I suggest as a first order of business that the Specialist Meeting identify a small number, perhaps only one, of research projects based on agent-based models that could usefully be implemented in HPC. I will then undertake to discuss this with the leaders of the CyberGIS project, with a view to moving forward.

Futures in Spatial Demography

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Now, faced with the increasing amounts of spatially referenced data and computing capabilities that enable large data sets to be analyzed in a multitude of ways, population geographers and demographers must continue to examine how best to incorporate space into analyses. While demography generally is focused on three main areas—fertility, mortality and migration—each of which can be discussed in relation to spatial thinking, I focus on the following statement on spatial demography issues as they pertain to fertility and women's health, my primary research focus and an area generally under-represented in population geography research. Examining fertility trends using a spatial perspective—including attention to cultures and social norms as well as quantitative methods—has provided important insight into fertility differences over time or space. Beyond providing interesting empirical and case-studies describing fertility variation, examining the spatial variation in fertility provides another perspective on the dominant theories of fertility and population change. However, population geographers and spatial demographers face a number of challenges in applying spatial thinking and analysis techniques to contemporary research questions. I highlight a few of the challenges that I have faced in my own research and that I have seen handled (both properly and improperly) in related research.

Current trends in developing countries suggest that the applicability of some of the standard theories of demographic change may not be appropriate in contemporary transitioning societies. Among the most significant deviations from the European based demographic theories, arise in fertility and reproductive health research. After a society has entered into a demographic transition previous demographic research suggests that transition will be completed within a relatively short period of time. However, increasingly researchers have identified persistently high fertility, persistently low age at first birth and age at first marriage and a continually low rate of contraceptive adoption even after the official onset of the Demographic Transition[1]. One potential explanation for this seeming inconsistency between what theory tells us should happen and what actually happens is that the theories underlying the transition process have not been fully developed or that they are not being applied appropriately. In an effort to expand scientific understanding of population change and to generalizing theories of transition, increasingly researchers have begun to explore the usefulness of spatial thinking in their analysis of both theory and data. Viewing historical fertility trends through a spatial lens—specifically using spatial thinking in the application of theory, selection of variables, methods and interpretation of

[1] The Demographic Transition describes the shift in a population from high birth and death rates to low birth and death rates.

results—will certainly broaden the discussion of Demographic Transition theory and will also benefit research on contemporary fertility patterns that incorporate similar spatial approaches.

An important component to the success of updating theory through the use of spatial thinking is to ensure that the theory matches the research question, the data and the methods. Evaluating diffusion processes, one theory of why/how fertility declined in Europe during the 19th Century, for example, requires an identification of the idea being diffused (reduced family size, contraception, birth spacing, etc.) and matching this theory to the spatial process. Spatial analysts should therefore concern themselves with the following types of questions: What exactly is being transferred from individual to individual? How was this information transferred (or diffused) throughout the country? Was the method of diffusion dependent on certain place specific features? Is there a larger theory of human interaction being identified that would help to generalize or enhance understanding of fertility change? After these critical components have been identified then the challenge is to find data that properly support this type of analysis.

Additional issues that researchers must deal with relate to data and scale, particularly when examining population-environment related questions. In many cases the environmental component of a population-environment study refers to some type of remotely sensed or external geophysical data. Often times this type of data differs in scale as compared to the population data. Demographic and Health Survey (DHS) data, for example, contains spatial coordinates only at the cluster-level while remotely sensed data are often found at much higher resolutions. How do you merge data like this when such different scales are involved? This type of data merging issues is commonly faced when using population survey data and any type of landscape data. There is not a single answer to the best way to combine these types of data. Instead researchers need to return to their theoretical framework and identify the spatial process underlying the research question and the relationships between households and their environment. An emphasis on modeling the process that results in specific outcomes and variation in these outcomes, is vital to properly inform the research strategy. In some cases, for example, the best strategy to adopt would be to use climate averages of all surrounding communities, and in other cases the best strategy would be to use a measure that reflects the landscape characteristics of an entire region or an individual household. In other cases, it might be more appropriate to adjust your modeling strategy (the use of random effects, for example) to account for some contextual links among certain individuals.

Continued dialogue and research oriented towards identifying the best way to bring a spatial perspective to fertility and women's health research through theories and their application and in joining various types of spatially referenced data is necessary to keep spatial demography relevant.

Future Directions in Spatial Demography

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My perspective broaches several of the issues posed by the organizers, including questions of measuring place, the use of crowd-sourced spatially-referenced data, new methodological tools in the near-term, training challenges, and most promising avenues of spatial demography research.

• Place and Crowd-Sourcing Data. The measurement of "place" is much debated, especially among rural demographers. I think that we should think of the purpose of the concept for spatial demography. While the Census Bureau has maintained a set of places based upon both their legal (incorporation) and population concentration (designated place) nomenclature for several decades (although unrealized in place polygons prior to 1980), the approach that I advocate is the conceptualization of Wilkinson, owing to Kaufman: *interactional community or the community field.* My work with Porter has focused on dissecting counties into places and *non-place territories*. Further work to characterize the US land mass in terms of Wilkinson's population density, economic productivity, and land-use is planned. The incorporation of transportation and communication vectors will also be used to spatially cluster and characterize localities. Measures of spatial isolation and spatial pattern analyses will further elaborate this characterization of US places.

I have worked with the OpenStreetMap program while in Atlanta. It is a leading effort to crowd-source localized spatial data although woefully incomplete. The problems with OSM data and somewhat different than issues with TIGER data. Spatial demographers should seek to get directly involved with these efforts for more localized studies as well as to better understand how disparate GPS-data can flow into a large database. It remains to be seen whether a strategic infusion of financial support into the OSM effort in the US would pay off.

• Hare and Tortoise. For social demographers, data and analytical tools have raced ahead of theory. Moreover, fragmentation of theory has reigned. My thoughts are like the US Marine Corps motto of: Wanted-just a few good theorists . . . of the middle-range. As Lieberson and Lynn argued (2002), ". . . in social science we talk about theories being either right or wrong . . . It is a matter not of simply rejecting a theory, but rather of evaluating a theory, knowing at some point that it will have to be modified or even superseded…we are more likely to want to destroy a theory or . . . worship a theory and thereby resist its change or modification." Also needed is a revision of relevant theories in spatial terms as well as the infusion of new theories invoking spatial processes. For example, traditional concepts of "rural" measured in a size-of-place continuum rather than involving contiguity of places to densely populated localities. Another example is Greve's ecological theory of local density dependence as alternative to spatial contagion & competition. In short, we need to encourage the taking of theoretical and methodological "chances" predicated upon creative spatial thinking.

• New wine, New bottles. We can see a number of studies in social demography which purport to involve "spatial" concepts or analysis but we have no commonly-held definition for what *is* spatial analysis. I have proposed the following: A study involves "spatial analysis" to the extent that it is: (1) spatial in its key concepts, (2) spatial in the operationalization of variables, and (3) spatial in the procedures of analysis. This is a high standard. It should be used as a guiding principle and evolve as needed for pushing forward spatial thinking in social demography.

• Training Needs & Intellectual Claims. We need the implementation of training in spatial methods at both undergraduate & graduate levels. The model syllabi available online is a great start. But we need more boot camps for mid-career faculty. Until tenured faculty are imbued with spatial analysis perspectives, they won't appreciate it in tenure decisions, hiring, and so forth. Finally, we need to make appropriate spatial methods as much "ours" as any other discipline. Remember, the GOF Chi-square was not "demography" when Karl Pearson (1900) first published it. The LISA statistic should be just as familiar to demography faculty and students.

• Color & Motion. Demography must transition journals to publish color graphics since we cannot convey enough information in the current grayscale format of most print media. Moreover, the incorporation of data visualization approaches into spatial analysis requires motion video formats to communicate. This will likely occur through an online medium but tenured faculty must be willing to accept the change without discounting prestige from the outlet. My collaborator, Jeremy Porter, and I are leading the launch of such a peer-reviewed ejournal, *Spatial Demography* (www.spatialdemography.org) published by PressForward at George Mason University in early 2012.

• Data Granularity. The technical capability to assemble even micro-level survey data into spatialized form is clearly upon us. As a couple of essays of mine published in the *ICPSR Bulletin* and in the 2nd Edition of the *Handbook of Survey Research* (with Porter) have observed, institutional IRBs tend to react negatively toward "undefined" risk to human subjects (e.g., potential identification in surveys) but positively toward purported metrics attached to higher physical risk (1/10,000 experiencing an infarction). Spatial demography needs to establish standards for human subjects protection so that IRBs have a basis for consistent decision-making. This should concentrate on establishing a probability for identification in space and time as is done, for instance, in treadmill studies with subjects reaching VO^2-max. One approach might be to broaden a time interval in favor of spatial granularity.

• "Winning." Spatial demography should be used for public policy input as much as conventional economic has been, including the health sector. It is not and is not likely to be until "winners" can be demonstrated to selected policy makers. I have two suggestions: (1) establish scientific work-groups focusing on no more than 2–3 topics so that "winners" can be had in the near-term. Construct web-based collaborative facilities where specialists can have "best available" talent focused on the problem (reducing competition, increasing productivity). (2)

enhance work in spatial simulation of population and public revenue streams to raise credibility. At present, public revenues are captured by the lack of knowing "where" tax revenues will rise or fall. Population growth and behavior (migration, spending, employment, fertility) can be linked to local taxing entities in each state and, usually, for long periods of time. Increasing our understanding at small spatial scales of the behavior of public revenues in demographic terms will help bring spatial demography to the policy table. This will affect the health sector as much as any other one. In sum, winning credibility at both funding and policy-making organizations would prove to be the most enduring catalyst for this intellectual niche.

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Frontiers in Spatial Demography

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Spatial demography links the problems, data, methods, measurements, and principles of demography with the problems, data, methods, measurements, and principles of spatial analysis and representation. Over the past two decades this linkage has resulted in a slow recasting of demography's traditional problems, data needs, and research designs, as seen in the increasing number of spatial demography papers in sessions of the annual meetings of the Population Association of America. For John Weeks (see position paper) spatial demography focuses on the spatial patterns associated with the demographic transition—seen in terms of the health and mortality, age, fertility, family and household, migration, and urban transitions. In spatial demography, these patterns of transition may be seen in association with socio-economic changes, as revealed through application of spatial concepts, such as location, distance, region, scale, spatial dependence, and spatial heterogeneity.

<table>
<tr><td>Demography
Accounting for Demographic Transitions</td><td>Using Spatial Concepts to describe, explain, model, & predict</td><td>Spatial Demography
Link demographic variables with spatial concepts</td></tr>
<tr><td rowspan="2">Health & mortality
Age
Fertility
Family & household
Migration
Urban</td><td rowspan="2">Location
Distance
Scale
Network
Region/neighborhood
Spatial dependence
Spatial heterogeneity</td><td>Measures of association, diversity, & segregation
Densities, spatial gradients, concentrations, & clusters
Patterns of resources, opportunities, & risks
Accessibility & mobility
Regionalization
Spatial behavior (routes, locations, & activities)
Spatial interactions
Migration
Networks
Diffusion & spread effects</td></tr>
<tr><td>Frontiers for Re-conceptualizing Spatial Demography
Space-Place Reconciliation
Dynamic space-time human ecologies
Others?</td></tr>
</table>

The value of spatial demography is conditioned by how well it captures the dynamics of human transitions at a broad range of temporal and spatial scales. Significant progress has emerged in the development of spatial analytic tools, measures, and access to geo-referenced data, but the demography literature gives scant attention to the importance of space-adjusting technologies that impact individual activity patterns and transitions in the spatial forms of human behavioral settings. Information, communication, and transportation technologies, important drivers in the transformation of socio-economic processes and spatial patterns of human circumstances and behaviors, warrant a more central position in the re-conceptualization of spatial demography.

Space-Place Reconciliation

Time-space convergence and *human extensibility* (Janelle 1969, 1973) are process constructs that underlie changes in individual human activity patterns and the societal organization of space. Time-space convergence is a measure of the rate at which places approach one another in time-distance as a result of transportation and communication advances (e.g., Edinburgh and London converged at an average rate of 28 minutes per year between 1776 and 1966 via land transport improvements alone; patterns of convergence/divergence to other places within urban regions differ remarkably, with suburban parts of American metropolitan areas converging on average more rapidly than more central locations (Janelle 2004). In contrast, human extensibility refers to the capacity of a person (firm or other agent) to interact at a distance from their place of location, an affordance that has been especially responsive to telecommunication innovations but that results in differential access by socio-economic grouping and place of residence. Subject to conditions of access (income, education, technologies, and social or professional networks) convergence (and divergence) in space contributes to the potential extensibility of people and places. These concepts apply at local through global scales, they impact thought processes and consciousness at individual through group levels, and they alter the context for how problems are perceived and resolved. They are (or should be) fundamental to how social and behavioral sciences define problems, design research, measure change, formulate models, interpret research results, and position their understanding to advance science, address human needs, and educate future generations. We have not done so.

> Implications for spatial demography: The concepts of spatial dependence and heterogeneity (central to the foundations of spatial econometrics) are rooted for the most part in fixed measures of distance, spatial contiguity, and temporal continuity; not on a flux in the thresholds of distance (where distance is measured by the effort (energy, time, and money) needed to traverse space) that continually re-condition perceptions of neighborhoods and action spaces, or that render the experiential context of place across an expanding (or contracting) space, altering circumstances for the diffusion and spread of ideas and values, the formation of social networks, and the possibilities of people to satisfy basic human needs. Panel studies and other longitudinal perspectives, in general, treat the matrix of distances across historical time as static—yet, they are neither static nor Euclidian. For human movements in urban regions—roadway configurations, traffic densities (and congestion), and public transportation routings and schedules change with some frequency and individuals differ in access potentials that change over the life-course. Windows of opportunity for interaction are conditioned by the opening hours of service facilities and by the transfer of selected social goods and

commercial opportunities to the web, which may or may not assist individuals in different life circumstances.

Without accounting for these many aspects of space-time variation in behavioral settings, can we be certain that spatial demography fulfills its expectations to assist public health and human wellbeing?

Dynamic space-time human ecologies

The Time Geography of a Canadian City project (TGCC) (Janelle, Klinkenberg, & Goodchild, 1998) made use of geo-referenced activity diaries to reconstruct the social geography of Halifax, Canada for any time of day, creating maps and graphics of diurnal changes in the human social ecologies of the city, demonstrating diurnal spatial variations in densities, concentrations, and integration of subpopulations, and raising issues (theoretical and empirical) about linkages between individual behavior and urban ecological structures. Since TGCC, new tools have emerged that permit refinements for documenting the dynamics and implications of ever-emergent social geographies of urban and other environments.

Implications for spatial demography: In principle, knowing who is where, what they are doing, and who they are with enables a greater understanding of the consequences of being at a location at a particular time (e.g., health and crime risks, education and job opportunities). Such documentation can help to contextualize individual behavior and traditional social demography (the events of birth, death, marriage, and livelihood) with a more nuanced understanding of social ecologies. Movements and migrations to different locations may be seen as either strategic choices or coercive challenges to one's livelihood and wellbeing, facilitating opportunity-seeking and risk-aversion activities and access to resources (recreation, education and training, health, security, etc.). Since TGCC, new GPS and tracking technologies, nearly ubiquitous communication possibilities with anyone at any time, Web 2-based volunteered geographic information (VGI), online social networking, and new tools for exploratory spatial data analysis and display offer potentials for acquiring and analyzing large archives of temporally responsive activity data. These new resources also pose issues for spatial demography and society, among them: (1) creating data retrieval and archival management procedures that permit unlimited flexibility for aggregations by any imaginable units of space and time; (2) verifying levels of uncertainty and limits to use of VGI sources; (3) extending exploratory spatial data analysis tools to permit more adaptive representations of space and that recognize the multiple-scale spatial existence of people and their behavioral interactions across space; (4) designing technologies that link geo-referenced individual paths with environmental sensors that measure threats to health and wellbeing; and (5) designing and verifying strategies to protect citizen rights to locational privacy.

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Future Directions in Spatial Demography

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I am a recent convert to spatial demography, coming from a background of the epidemiology of women's and children's health. Demography and epidemiology have long shared concern with the determinants and patterns of morbidity and mortality in populations, and continue to have much to offer each other. Just as "spatial" has long been a part of demographic research (1), the origin stories of modern epidemiology often begin with John Snow's spatial analysis of cholera in London in the 19th century. Such stories often highlight the "shoe leather epidemiology" of Snow's work and the systematic and comprehensive approach to identifying temporal and spatial patterns for those who contracted or did not contract the illness. In the pre-germ theory era inhabited by Snow social categories and spatial locations were tied to illness through miasma theory; the discovery of the etiology of infectious diseases led to a one agent-one disease causal pathway, but interest in the social and spatial connections persisted. It was in the 20th century (particularly post-World War II) when epidemiology (and perhaps demography to a lesser degree) shifted towards a focus on individual "risk factors." This new focus on the behaviors and exposure of individuals aligned with the epidemiologic transition from infectious to chronic forces of mortality and was closely related to decades of epidemiologic ambivalence about social determinants and spatial patterns of health (2). Risk factor epidemiology started with the lowest of all hanging fruit in terms of population attributable burden of disease—tobacco—and some argue it has struggled since.

Out of this context public health scholars including epidemiologists, interventionists, and policy experts are returning to a more comprehensive ecologic perspectives on the etiology of disease in populations, embracing the built environment, political economy, and social capital as topics of renewed interest (3). A rapidly expanding social epidemiology literature on neighborhood effects and disease (often chronic or reproductive) provides some evidence that these efforts can prove useful for understanding population patterns and developing novel health promotion/disease prevention efforts (4). What is largely lacking in this body of epidemiologic (particularly non-infectious) literature is an adequate attention to the roles spatial dependence and heterogeneity, and residential mobility and migration in the place-health relationship. Fortunately these areas are already more richly developed in the sociology, geography, and demography literatures, and—as evidenced by the preliminary agenda of this Future of Spatial Demography meeting—will continue to receive substantial attention. That virtually all health outcomes vary dramatically along social, economic, and spatial patterns has been well described for some time. What we need is movement towards better understanding of pathways and mechanisms which can inform effective programs and policies to reduce health disparities and improve health outcomes. The potential for increased synergy between spatial demographers and social epidemiologists is great, and I am honored to participate in this meeting.

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Making a Place for Space: Spatial Thinking in Social Science

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There has been a steady growth of interest in a range of concepts and techniques in sociology that can be described as spatial. Much of this builds on a large body of work by geographers, and this review will offer some links to that literature. What is distinctive to sociology (and other social sciences) is the application of spatial data, measures, and models to a wider range of substantive questions with roots in other intellectual traditions. Sociologists are less interested in spatial patterns in themselves, and more interested in how they translate into social relations.

From the perspective of an urban sociologist, I am particularly attuned to the relevance of *place* to social life. Everything happens somewhere, which means that all action is embedded in place and may be affected by its placement. Abbott (1997, pp. 1152) tells us that this is a specifically Chicago School insight, "that one cannot understand social life without understanding the arrangements of particular social actors in particular social times and places… Social facts are *located*." I believe this insight is not unique to the Chicago School. Much of my own research in the last three decades is centered on questions of inequalities between places (Logan 1978). In the urban political economy tradition every place is socially constructed with a history and a future; where people are placed affects their fortunes and adds structure to their lives; place-based interests are at the heart of much collective and political action (Logan and Molotch 1987). Nevertheless for the purpose of this essay, the key concept is not place but space. And by space, I mean specifically location. Spatial thinking is about where things are or where they happen, and it is especially about where they are in relation to others. There is an implicit spatial reference in almost all studies of places. What is distinctive in the last decade is that space is being introduced more explicitly and more systematically.

In another review of spatial social science, Voss (2007) argues that traditional demography through the mid-20th Century was "spatial" in the sense that it was the study of ecological units like cities and counties. A shift of focus to individuals and individual-level processes (associated with increased availability of data at this level) pulled demography away from its spatial origins until the advent of multi-level modeling gave us methods to distinguish between processes at the individual and aggregate levels. This point of view seems to suggest that counties are spatial but people are not. I disagree. Counties and other areal units have p*lace attributes* that we certainly want to know about. If "where" is a certain residential district, we want to know whether that district is a blue-stocking neighborhood or a ghetto. But my view is that from a *spatial* perspective we want to know more (e.g., where is it in relation to other places, is it near the center city or out in the suburbs, is it close to a transit line, how long does it take to get to the daycare center, what else is in the vicinity?). Concepts that are critical to spatial thinking—distance, proximity, exposure, and access – are all rooted in relative locations. And questions of location are equally spatial regardless of whether the unit of analysis is a person, a firm, or a city.

One more observation will help to define what I mean by "location." By now the widespread use of satellite-based geographic positioning systems (GPS) has made us very aware of location as a set of geographic coordinates. And indeed coordinate systems have always been crucial to systematic mapping. GIS maps that make it possible to visualize spatial patterns and to make the measurements required for spatial analysis absolutely rely on measuring longitude and latitude.

Sometimes "location" refers to these points or to locations that can be represented by them—the location of a school or worksite, a crime incident, a riot, a case of measles. Perhaps more often it refers to a larger territory. We use terms like neighborhood or zone to identify a location that is not a single point or address on a map. Such terms seem natural, they are convenient, and they are necessary to spatial thinking. But they introduce two ambiguities. First, what is the geographic scale of the territory? Political studies often deal with world regions or nation states. River basins and valleys define territories for environmental research. Metropolitan labor markets, cities, and more local areas within cities are important to urban analysis. Second, are these territories bounded? Routinely social scientists deal with unmarked boundaries. It can be unclear whether the notion of a boundary is a social construction in the mind of the scientist or a concept grounded in local usage. Does it make more sense to think of boundaries as sharp edges or extended zones of transition? Administrative units that social scientists use regularly in their research, like census tracts, have established boundaries but their arbitrary character has led some geographers to replace them with continuous surfaces that they believe may better represent the underlying spatial distribution of population characteristics. Even when formal political boundaries have been established, so that there is a clear line of demarcation between one territory and another, one can question their impact or permeability.

When our object of study cannot be located as a point but must instead by thought of as a place, spatial analysis requires that we confront difficult questions about what constitutes the place. Here I treat the distinction between space and place with a different emphasis than did Gieryn (2000, p. 465), who dismissed space as "what place becomes when the unique gathering of things, meanings and values are sucked out." "In particular," he said, "place should not be confused with the use of geographic or cartographic metaphors (boundaries, territories) that define conceptual and analytical spaces." In fact places are not only geographically located and material, as Gieryn points out, but they are also spatial and their spatiality gives rise to fruitful questions.

These remarks lead to a definition of spatial social science. Spatial thinking is the consideration of the relative locations of social phenomena, the causes of the locational pattern, and its consequences. It encompasses phenomena whose locations can be thought of as discrete points as well as larger territories, and in the latter case, it requires that we consider questions that are posed as strictly geographical, like whether and where territories are bounded.

In fact, like most questions of method and measurement, the underlying issues are not technical but substantive. This is why as often as possible I use the term spatial thinking rather than spatial analysis. Although some leading geographers have sought to build from Geographical Information Systems toward GIScience (Goodchild 2004) as a distinct discipline, most scholars' interest in space is how to incorporate it usefully into their own research agenda. We can profit as much from seeing how others are thinking about space as we can from the advanced tools that are being made available from GIS and spatial statistics.

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Future Directions in Spatial Demography

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Migration, fertility, and health outcomes, like all social phenomena, are spatially dependent. In a world with a rapidly changing environment, demographic and health outcomes are increasingly relevant to environmental processes. Yet scholarship remains sparse on population-environment interactions. Why? One reason is surely that demography, while data rich for a social science, remains data poor compared to the biophysical sciences. This is changing. For example, since the 1990s, Demographic and Health Surveys (DHS), the largest ongoing social survey in the developing world, have produced geo-referenced clustered households. Similarly, Columbia University's Global Rural-Urban Mapping Project (GRUMP) data (http://sedac.ciesin.columbia.edu/gpw/) estimates population density across the globe at one degree latitude and longitude grids. But more work remains in order to approach the dense data coverage at the global and continental scales typical in the natural sciences.

More censuses and more DHS surveys with larger sample sizes and spatial and temporal resolution could help reconcile the space-time deficiency in demographic data. Adding environmental and resource use questions to DHS surveys as we did in Guatemala (Sutherland et al 2004) would help further integrate population and environmental data. To the extent advances in spatial and temporal demographic data resolution fall short of research needs, (and they always will!) the advancement of spatially-explicit and hierarchical models are critical.

While broader research questions may be addressed using extant data, and furthered with improvements in spatial and temporal resolution of the same, specialized questionnaire and survey design will always remain necessary to probe cutting edge interfaces at the penumbra of population-environment interactions. Surveys are often accompanied by qualitative tools, specially designed for the research topic and geographical context. Integrating qualitative and quantitative surveys with spatial modeling in population-environment research facilitates the interpretation of quantitative results while also fostering the potential for new, inductively driven research hypotheses (Cheon et al 2011).

We have much to gain from data and analytical advances in demography. For example, fertility transition research desperately needs enhanced data and modeling tools. Whether Earth peaks at 8 billion or 12 billion people in the coming decades, where those people live and what food they eat represent the greatest predictors of future land change. The main uncertainty surrounding population projections lies in the question of when, where, and how rapidly the world's poorest rural areas complete the demographic transition (the shift from high birth and death rates to low birth and death rates as a country develops socio-economically). While this topic is addressed to some extent in public health, it is scarcely researched in the human dimensions of global environmental change literature. Since the demographic transition in the developing world is altering family size and structures at an unprecedented rate, the potential links to environmental change are profound. The problem with adequately addressing this issue is that precisely where we need to know what is going on with the demographic transition—in remote, sparsely populated rural areas—we have insufficient data to measure these fertility transitions. For example, my work in the Maya Biosphere Reserve suggests fertility rates exceeding 8 births per woman (Carr 2008) and colleagues find similarly high fertility in the Ecuadorian Amazon (Bremner et al 2009). Yet DHS data will rarely reveal such high fertility levels at a sub-national or even a household cluster level. This is because the places where fertility is highest globally—remote rural areas—remain woefully under-sampled in DHS data.

Another data limitation of coupled population-environment research ostensibly emerges in the polar opposite place where data underrepresents the globe's highest fertility rates: the most developed countries where fertility has plummeted to below replacement levels. In these low fertility regions of the world, population-environment interactions become increasingly distanced in place and time relative to high fertility, (semi) subsistence-dominated human-environment landscapes. For example, hosts of studies now corroborate our ability to observe and measure, through surveys and remotely sensed imagery, the local and immediate population-environment interactions of, for example, deforestation linked to household size (often vis a vis both consumption and production) among frontier households in the Amazon. Yet population links to environmental change in wealthier nations are related more to demographic composition effects' (e.g., household age structure) influence on consumption. Consumption in turn increasingly impacts environmental processes relating to air, land, and water in distant parts of the globe over varying time lags (Lam Meyfroidt et al 2010). Future directions in spatial population-environmental research, by dint of spatial and temporal data challenges and opportunities, remain clouded and yet potentially bright.

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Future of Spatial Demography

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Many research and policy questions faced by demographers require analysis of complex patterns of interrelated social, behavioral, economic, and environmental phenomena. In addressing these questions, it is increasingly argued that both spatial thinking and spatial analytical perspectives have an important role to play. Indeed, demographic research on racial/ethnic segregation and other forms of social stratification and inequality, on health behaviors, morbidity and mortality, on fertility, and on family structure/transitions and aging—today and in the past, in the US and overseas—increasingly depend on the collection and analysis of individual- and contextual-level data across a wide range of spatial and temporal scales (Entwisle, 2007).

What does the near future hold for spatial demography? While demographers know that prediction is dangerous, we can confidently predict that things will change. Indeed, the geospatial data and methodological development environment has changed just in the last few years (i.e., since recent reviews offered by Weeks 2004; Voss, 2007; and Castro 2007). New types of data and emerging statistical methods coupled with reciprocal enhancements in conceptual models will help promote spatially informed demographic research.

Data:

The volume, sources, and forms of available geospatial data are growing rapidly. Recent developments in participant generated data or volunteered geographical information (e.g., Twitter, Open Street Map, GPS traces), in next-generation wireless and sensor technologies, and in data storage and handling (e.g., cloud computing, geospatial data warehouses, data mining techniques, and relational databases) are already, and will continue to, change what, how, and when we collect data on individuals and their environments. New data formats will be tagged with both a geographic location and a time stamp to provide unparalleled spatial and temporal precision. These technological developments and new spatio-temporal precision has enormous potential to permit better functional understandings of human spatial behavior and to contribute to new ways of thinking about relative and absolute utilization and/or exposure to place, to issues of spatial embeddedness, and of scales of analysis (Chaix et al, 2009; Matthews, 2011).

We also should anticipate changes in how demographers conduct fieldwork as new data collection technologies fundamentally change the quality, scope, and flexibility of measures we collect and use on the social, built, and physical environments. With little doubt the developments in data collection (e.g., the use of mobile computing, remote sensing, wireless technologies, and volunteered geographic information) foreshadow other innovative ways geospatial data will be used in future demographic research. The collection of new types of individual and area-based geospatial data will greatly facilitate the measurement of appropriately defined contexts and individual exposure to contexts. In turn this will generate closer links between theory, data, and method in multilevel analysis of demographic and health outcomes (Entwisle, 2007).

The data environment is changing in other ways too. In the US, the American Community Survey is a new form of demographic data based on estimates not counts that introduce users to "margins of error" associated with area based demographic characteristics and a set of new challenges for small area analysis or the study of sparsely populated areas. Many other challenges exist, the most obvious ones relating to data privacy, data validation, utilizing data on non-representative samples of people and places, data preservation (historic data) and archiving.

Methods:

While there are several established spatial analytical techniques—spatial econometrics, pattern analysis, geographically weighted regression—developments in spatial methods are ongoing and the analytical arsenal is expanding rapidly. To identify a few recent developments consider, space-time analysis (Rey & Janikas, 2006), spatial panel data models (Elhorst, 2010), spatial filtering (Griffith, 2010), Bayesian hierarchical modeling (Banerjee, Carlin, and Gelfand, 2004), and spatial scan statistics (Jung, Kulldorff, and Klassen, 2007). We also have recently seen the combination of methods hitherto separate. For example, a small number of scholars have explored the integration of quantile regression with different spatial techniques, such as simultaneous autoregressive modeling (Hallin, Lu, and Yu, 2009; Kostov, 2009; and, Su and Yang, 2007), M-quantile GWR (Salvati et al., 2007), Bayesian spatially varying coefficient process modeling (Reich, Fuentes, and Dunson, 2010), and geographically weighted quantile regression (Chen et al; in press).

An exciting research area also is emerging around the integration of detailed social and spatial networks (Entwisle et al, 2007; Butts and Acton, 2011). Another is the emergence of complex systems approaches and techniques such as agent based models, autonomous agent models, and micro-simulation. These approaches are filtering into many different fields of inquiry and appear to have wide applicability in a field like demography (Bruch and Mare, 2006). As we strive for a better understanding of levels of analysis, multilevel relationships, feedbacks and interactions, these methods can help focus our conceptual thinking, and encourage the testing of alternative scenarios. With the right kinds of data, the adoption of complex systems dynamics will be explored more fully by demographers.

Establishing Spatial Demography:

I anticipate that upcoming cohorts of demographers will increasingly utilize new forms of geospatial data, analyze them with spatially explicit methods, and that this will ultimately be reflected in publications as well as grant applications that generate new demographic knowledge. Spatial analytical methods will be applied to important demographic research questions regarding health disparities, access to health services, child malnutrition, urbanization, poverty, income inequality, unemployment, crime, migration, immigration, and the relations between population and environment. Getting there may not be so easy.

Although the instructional environment for introductory GIS and spatial analysis courses are improving, the application and use of advanced spatial analysis methods in population science appears to lag other fields (Matthews, Janelle & Goodchild, 2007). This lag is not helped by the limited availability of graduate-level training in geospatial data, concepts, cartography and GIS and more specifically, the lack of courses in advanced spatial data analysis with a significant social science or demographic content (and also a lack of courses in Bayesian statistics, Complex Systems, Agent Based Models, and Simulation Modeling). Note that within standard demography methods texts, the treatment afforded spatial analysis is scant to say the least. John Weeks' Population is a rare exception that now includes coverage to GIS, geospatial data, and spatial analysis. Currently no specialist text on what one may regard as "spatial demography" exists (unlike in other fields) though note there have been publications on spatial population analysis (Rees and Wilson, 1977; Woods and Rees, 1986) and multiregional demography (Rogers 1975, 1995). While several journals have had special issues on spatial demography no journal currently exists (see the new e-journal initiative being led by Howell and Porter, 2012).

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Areas of Research Interest Pertaining to Future Directions in Spatial Demography

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There is a critical need to specifically understand small area variation in chronic disease prevalence, because preventable or manageable diseases (diabetes, cancer, heart disease) are absorbing staggering resources in terms of potentially avoidable healthcare expenditures. We have understood for decades the importance of distinguishing between individual and population perspectives on risk behavior and health (Jeffery, 1989), yet when emphasizing that dichotomy between individual and macro-level perspectives we often overlook the heterogeneity that exists at the small-area level. Much of this oversight has been methodological; when researchers create and use community-level indicators, we often assume that aspects of contextual environments affect all people living in those areas equally. In fact, so-called cross-level interactions could be crucial, e.g., the potential moderating effect of age or sex on geographic factors affecting disease incidence. Similarly, different population subgroups may have different activity spaces, which may vary by age or socioeconomics or urbanicity. Thus geospatial heterogeneity is mirrored by an equally diverse socio-spatial heterogeneity in terms of *the geospatial contexts that are relevant* for particular studies or population subgroups.

I am very interested in socio-spatial heterogeneity in "relevant contexts." In our work on predictors of late-stage cancer at diagnosis (which results in unfavorable outcomes)—we have explicitly modeled, albeit in a limited way, the reality that socio-ecological environments in a particular place may actually be quite different from the perspective of various people living in that place. In our model of late-stage breast cancer diagnosis, we focused on a measure of residential segregation, which reflects the degree to which a person lives among persons of the same race or ethnicity in their community (which might confer some sort of social cohesion or support). We find that women living in the same communities have radically different prospects, which differ by race or ethnicity (Kuo, Mobley, and Anselin, 2011). Thus, interventions in a place may need to be quite different for population subgroups in that place, or indeed may be needed by some but not needed by others.

In ongoing work, we attempt to model three levels of influence to explain late-stage breast and colorectal cancers: personal, community, and state-level environments. We are particularly interested in how the state-level variation in health insurance environments is predictive of cancer outcomes through cross-level interactions with community-level factors that are specified from the perspective of the cancer patients in those communities. More specifically, the perspective of social support, which varies by race or ethnicity of the person in the place, is captured in the modeling. We find that women living in more segregated communities (in terms of their race or ethnicity) have significantly and substantially lower probability of late-stage breast cancer diagnosis, and in states with higher prevalence of minority enclaves, a state regulation mandating inpatient hospitalization following mastectomy confers an additional protective effect (Mobley and Kuo, 2011). In a model of late-stage colorectal cancer diagnosis, we find that cancer patients in states with continuity of care mandates (that insurers must allow patients to keep established providers when they become seriously ill and change insurance plans) have lower probabilities of late-stage diagnosis, especially in communities with a higher proportion of lower-SES cancer patients (Mobley and Kuo, 2011).

We are not aware of any other multilevel modeling research that examines state-level effects in addition to community and person-level effects, providing a richer model of the contextual environments impacting health outcomes. We hope in future work to be able to build spatial modeling directly into these multi-level models. Our goal would be to model both spatial autocorrelation and spatial heterogeneity (regimes) in a simultaneous modeling framework (rather than a conditional, Bayesian approach). In doing so we would focus on the regimes represented by larger multi-state regions which reflect geographic disparities among minorities (versus whites) that we have noted in both breast and colorectal cancer prevention (Mobley et al, April 2012).

Spatial heterogeneity—the fact that values of a variable and relationships among variables are not uniform across space—is manifest in the US. It is well-known that unmodeled spatial heterogeneity can result in loss of efficiency and bias in regression modeling. We have thought a great deal about the conceptual modeling of the contexts that are relevant for particular behavioral outcomes, and the potential for interaction among individuals and their environments. We have also thought a great deal about how to characterize the environmental heterogeneity a-priori, based on some conceptual or theoretical modeling of the system dynamics based on economic/market theory, as an alternative to using exploratory spatial data analysis to identify spatial regimes that could be modeled out with dummy variables. We see promise in characterizing the regimes directly using continuous variables derived from composites of regional characteristics reflecting different market types.

One approach that we think may have promise is as follows. Consider how one might characterize the contextual environment for states' health insurance. There are literally hundreds of regulations and mandates, and economists have done a great job compiling evidence regarding how these market interferences impact health insurance premiums and uninsured population rates, but impacts on health outcomes have not been studied. State-level data now exist on regulations that pertain to freedom of choice, litigation/liability, mandated coverage, access to services, and so forth. Other state-level data exist on the proportion uninsured by age group, the proportion of elderly with supplemental insurance or public support to purchase insurance, and the health insurance industry structure (monopoly-competitive). How can one combine these many variables into a few meaningful constructs? We expect that the application of two-way joining, or bicluster analysis, can be helpful in this regard, distinguishing groups of states with similar sets of value ranges for groups of contextual variables. This approach has been used extensively in genomics research to characterize places on genes and answer questions such as: What set of places have similar characteristics, and what characteristics make places similar to each other? (Maurizio, et al., 2009). The biclustering approach could be used to characterize "types" of places in the state health insurance environment, based on a comprehensive set of dozens of covariates. This approach follows attempts to characterize area types that used initial factor analysis to reduce dimensionality in the covariates, followed by k-means clustering (Talen, 2006; Yan et al, 2010).

We will avoid some limitations inherent in the k-means approach (i.e., path-dependent solutions that are not necessarily optimal) and define market types based on "patches" in the two-way hierarchical joining matrix that results from bi-cluster analysis (SYSTAT, 2004). These "patches" represent groups of observations (states) that are similar based on values of multiple factors. To our knowledge this approach has not been used to define area or market types, and may be a useful way to characterize area types that avoids some of the problems seen in using ESDA methods such as Geographically Weighted Regression (GWR). GWR tells us some conditional information for effect estimates for single covariates. By contrast, we want to characterize the heterogeneity in groups of explanatory variables using methods that allow us to model the heterogeneity directly.

<u>Areas of research interest include:</u>

- use methods for describing and characterizing spatial heterogeneity in relevant contexts, so that we can robustly conduct spatially-enabled analysis of variation (disparities) in treatment effectiveness, regional healthcare quality, health behaviors, health outcomes and access;
- use methods for combining behavioral, environmental, and geo-demographic factors in risk assessment that informs spatial patterns in the incidence and prevalence of disease;
- use methods which integrate knowledge from the laboratory bench and the field with the socio-behavioral, socio-ecological, environmental health, and population sciences in order to gain comprehensive understanding of health and disease, expanding the potential for spatial effects modeling in multilevel analyses;
- use of crowd-sourced geo-tagged data regarding environmental or social measurements, or patient-sourced information on symptoms from patient-centered medicine, in the integration of knowledge stated above.

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Future Directions in Spatial Demography

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Micro- and Macro-Demography

Paul Voss has argued that much of the history of demography has been "spatial demography," and that it has only in the last few decades that the spatial component has disappeared from most demographic research. Voss goes on to distinguish between micro-demography, which is largely aspatial, and macro-demography, which is the study of population aggregates in space, and is often spatially explicit research.

This shift was largely driven by very real concerns over ecological fallacy; there is ample evidence that results can change with the scale of analysis. Demography, like many other social sciences, has shifted from macro data to microdata, under the assumption that microdata avoids the ecological fallacy problem. In fact, "macro-demography" has now attained a sort of second-class status within demography. Only a few demographers have been able to establish a prestigious career based on the study of macrodata. From the geographer's perspective, this assumption that microdata is superior to macrodata is most curious. Individual-level analysis, without space, is equally subject to the ecological fallacy problem; with individual-level analysis, any spatial, neighborhood, peer, or network effects are incorrectly attributed to the individual.

Methods now exist for analysis of individual in space. Researchers often point to hierarchical and multilevel models as promising methods for dealing with individual and spatial effects. Yet, true applications of spatial models with individual-level data are rare. A key obstacle for advancement in this field is the lack of spatially accessible data. Most public use microdata do not contain enough spatial detail to advance spatial demography.

Access to spatially explicit microdata is a key obstacle

It is relatively difficult to acquire access to spatially explicit microdata. Public use microdata do not contain enough spatial detail for most spatial analyses of interest, so these data are almost entirely ignored by geographers; many geographers do not even know that public use microdata exist. As a result, geographers are rarely trained to use microdata and quantitatively minded geography students in search of interesting topics and data are often pulled to physical geography. In demography, students are trained to use public use microdata, but they necessarily ignore the spatial elements of demographic processes. It is increasing possible to get access to confidential microdata, but it is still often an expensive and long process, and is out of the range of possibilities for most students. Geographers are not receiving the proper training to use these data, and demographers are not introduced to spatial thinking early in their careers.

In order to advance spatial demography, we will need to find ways to create easier access to spatially explicit microdata. Within geography, we need to do a better job of identifying available microdata, using them at conferences, and teaching others how to use them and gain access. Some confidential microdata are easier to get than others. Title 26 data, (anything using IRS records), is among the difficult. Title 13 data (anything using Census Bureau data) is slightly easier to get, but is still too difficult for most students to gain access to and use within the time span of a dissertation project. Some public health data are easier to attain. I have had some luck getting spatial microdata from Cancer Registries, but access varies widely across states.

It is important that spatial demographers, and especially geographers, gain more access to spatially explicit microdata and train students in their use. Even public use microdata, while less than ideal, can provide some suitable material for geography research. At the University of Tennessee, one of our Ph.D. students is using public use microdata to consider how the creative class thesis plays out across urban and suburban spaces. This student is contributing to spatial demography, and is also learning skills that would be recognized by more traditional demographers. We need to encourage more research like this so that geographers will learn the specialized techniques of using microdata, and will be prepared for future work with confidential data.

Another possible way forward is through the use of simulated data. I am currently working on NSF-funded research with Babs Buttenfield and Stefan Leyk at the University of Colorado at Boulder to impute spatial locations for public use microdata. By combining the public use microdata with tract- and block-level data, we are able to impute the location of census microdata. We will be working with the confidential microdata within the Census Bureau to validate the method, and we have begun collaboration with the Minnesota Population Center to make imputed spatial coordinates a part of the IPUMS datasets. This will create a set of spatially explicit microdata that will be available for public use. But important questions remain regarding the uses of simulated data in research. For what types of analyses are simulated data acceptable or not acceptable? It is possible to find this out if users have access to the confidential data, but most won't have this access. How can a user identify if a particular use of simulated data is valid?

Another possible way forward in spatial demography is through volunteered geographic information. These types of microdata are increasinglyavailable to geographers, but they introduce new challenges. How can results from volunteered geographic data be made generalizable to the public? Volunteered information often has high spatial resolution, but very few population attributes. How can volunteered information be combined with other data with more attributes?

Finally, geographers and demographers may have an important role in improving the quality of data that are already available for spatial demography research. Recently, Seth Spielman (Colorado-Boulder) and I were the first geographers to be awarded a grant as part of the NSF-Census Research Network. This project will allow us to work within the Census Bureau to improve the quality of the American Community Survey. Through original research quantifying the heterogeneity of American population within small areas, we hope to provide ways to improve sampling and estimation methods, and reduce the error of the American Community

Survey. We will also explore the possibility of a new public use microdata sample that will have less absolute locational precision than the current sample, but in return will have inter-point distances between microdata records. Such data will allow many more types of spatial research in demography than are currently allowed. There is much room for such collaboration between spatial demographers and the federal statistical agencies to create new and improved data products for demographic research.

Spatial applications to Demography: Contributions and Future Directions

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Discussions of Spatial Demography must begin with the realization that population characteristics are inherently spatial. Where people live, how they interact, survivorship and movement all have spatial components. Whether space interacts to influence demographic events in an endogenous or exogenous manner varies based on several factors and across multiple scales. It is precisely this characteristic of population that makes spatial demography exciting, complex and needing a scientific consensus for standards of data collection, analysis and publication to advance the field. Contributions in Spatial Demography have often fallen under the rubric of Population Geography likely because of the close link between human geographers and GIS-science. This area has immense potential as I describe below, but there are also other areas of Spatial Demography that have integrated space, but do not fall under this categorization, including methods for small area estimation, multi-state demography, and migration. Some of these methods helped establish the statistical foundation from which more advanced spatial methods have emerged. In sum, although Spatial Demography did not become a recognized area of demography until recently, it is an integral part of population science, has contributed to the development of several spatial methods, and will continue to play an important role in our understanding of demographic change. In the following sections I have outlined a few key areas where innovative spatial demographic techniques can be applied as well as opportunities that exist for improving either the theoretical methodology, standards for data collection, or transparency of the methods and approach used. For brevity, I have broadly labeled these areas as (1) population, health and environment and (2) integrated methodology. I conclude with a set of recommendations.

Population, Health and Environment

The study of population, health and environment (PHE) dynamics has emerged as a major area in research and policy over the past two decades. Environmental health scientists have long recognized the risks that environmental conditions pose on human health. Air and water quality are classic examples of how environmental conditions can increased the incidence of respiratory and enteric diseases, respectively, for large populations. Today, there exists a large body of research espousing the tenets of human-environment change influencing vector-borne disease, but this connection was realized more than a century ago, as depicted by John Smith in 1911 who described strategies for insect elimination through the draining of water near edges of forest and roads in New Jersey. The difference is that today we have an arsenal of tools available to help identify, eliminate, and monitor such strategies at very fine temporal and spatial scales, but we have yet to integrate and execute their full potential. A classic example is the development of early warning systems (EWS) for malaria. These systems generally rely on a wealth of environmental data consisting of land cover, hydrology, soil moisture, and climate and relate them to temporal incidence of human malaria, which if often computed as a slide-positive rate per slides taken. However, this approach fails to incorporate the underlying population at risk, their location of residence, population mobility, and entomological characteristics. While some of these data are outside the realm of demography, spatial demographers need to advocate for the availability of population data at very fine spatial scales and then apply appropriate spatial demographic and epidemiologic techniques to properly predict risk over a spatial field. EWS's are not limited to vector-borne diseases, but could also be applied to chronic disease through spatial applications of the built environment, such as accessibility to food markets, walkability, and other measures used to help predict obesity trends in urban zones. The major problems that prohibit such applications include the lack of environmental and urban spatial data that can be linked to population residence, the lack of refined methods to test spatial associations across temporal and spatial scales (discussed in the next section), and lack of trained scientists in spatial demography.

Another area of PHE where spatial demography can be applied and improved is in the area of migration research. Migration is a vastly understudied phenomenon in both population and health research, often implicated as a cause for environmental problems and increased health risk but with little empirical research to support the claims. Migration is difficult because it can be temporary (labor migration) or permanent, international or internal, rural-urban, urban-rural, urban-urban, or rural-rural, and, if studying migration patterns, migrants are hard to contact once they leave an area. The greatest contributions of spatial demography are likely for internal migration rather than international, due to the redistribution of a national population in which nations have a greater ability to respond. Here, there are two key contributions: (1) demographers need to continue emphasizing the need for civil registries that have the capability of tracing residential history. Population risks for cancer is a classic example of where spatial methods have advanced swiftly, but the lack of historical spatial data limits the inference on environmental effects. (2) Large-scale demographic studies, such as DHS, need to do a better job at tracking migrants spatially (in addition to generally providing better spatial data on households and land) rather than treating migrants are lost-to-follow-up. Migrants are key components of a household well-being, particularly if remittances are received or support for the migrant is provided.

Integrated Methodology

Small area estimation is a classic problem in demography dating back several centuries. Census tracts with small population counts or small geographic areas often have unreliable estimates when sample survey data are collected and used in conjunction with census information. Demographers were among the first to contribute methodology to this area, but has recently advanced with the development of Hierarchical Bayesian methods, which uses Empirical Bayes estimates to better account for spatial relationships, and Kriging methods, which is a more frequentist approach to handling small areas. While these methods are progressing at their own pace, it is important to note that they are progressing in fields outside of demography! If demographers want to properly integrate these methods into population research, it is imperative to endorse increased training in spatial demography that overlaps with training of spatial statisticians and quantitative geographers. The statistical aspects of spatial demography have been largely placed within the realm of spatial econometrics, which has significant limitations, particularly in applications that involve non-Gaussian distributions. In addition, introductory Spatial Demography courses often have modules in GIS, which is not analytical, but more descriptive in nature. Demographers need to become better versed in the language of spatial statistics beyond simple spatial interaction and autoregressive models. To encourage future demographers to get involved in spatial demographic training, it will become increasingly important for peer-reviewed journals that publish demographic research to promote the sharing and publication of data and analytical methods used to reporting findings. This type of transparency will not only improve our ability to conduct research in general, but it will help current and future colleagues better understand how to incorporate space into demographic research.

Empirical research

Recommendations for the future can be summarized as follows:

1) Promote the collection and release of residential history in both government data (i.e., civil registries) as well as in ongoing demographic research (i.e., DHS)
2) Health and environment are key components of policy and research, but require strong demographic methods for proper inference. Spatial demographers are needed to help connect this research to human populations
3) NIH should promote the training of spatial demographers in Population Centers through integrated training in mathematical demography and spatial statistics
4) Researchers and peer-reviewed journals should publish the data and analytical methods (i.e., statistical code) used to produce reported results

Future Directions for Spatial Demography

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Awareness is growing among demographers that space is an important component in population studies. Furthermore, spatial methods contribute to a better understanding of many topics of interest that are now growing in popularity in demography. Two areas of interest that I will discuss are population health, especially with regards to migration, and environment-population interactions. Spatial methods are inherently important in both of these subtopics and I offer my research as an example of their application in spatial demography, as well as a consideration of some of the problems and considerations associated with these new directions in spatial demography.

My dissertation research investigates malaria incidence and malaria parasite drug resistance in indigenous migrant populations along the Thailand-Myanmar border. The unique malaria epidemiological behavior in this region is attributable to several factors. One such factor is climate, as rain is important for the larval stage of the mosquito vectors of malaria. Another important factor is human migration. Whereas Thailand has been largely successful at eliminating malaria from most regions, malaria along international border areas has been difficult to control. Even when Thai authorities are able to eradicate malaria in the Thai population, there is heavy migrant traffic flowing to and from Myanmar (where there is almost no public health infrastructure). This region is also an epicenter for multidrug resistant malaria and, since malaria parasites can easily spread to other regions, the population health considerations of the Thai-Myanmar border area are important for many other regions.

Migration studies are inherently about space. The act of migration implies moving from one place to another and oftentimes the demographic processes that we are interested in are related more to this mobility rather than simply the demographic profile (age, sex, ethnic group, etc.) of the individuals involved. For example, in my research I have little reason to believe that specific ethnic groups are at risk of malaria infection simply because of their ethnic identity. However migration into or through specific regions is probably associated with elevated risk of infection.

Migration therefore demands a reconsideration of lived spaces. While demographers have been investigating contextual implications of lived space, defining those lived spaces has been problematic. Some researchers have noted that census tracts and neighborhoods, while important, may not adequately define the spaces in which people spend most of their time[1]. In

[1] Matthews SA (2011) Spatial polygamy and the heterogeneity of place: studying people and place via egocentric methods. Pp. 35–55, Chapter 3 in L Burton, S Kemp, M Leung, SA Matthews and D Takeuchi (editors) **Communities, Neighborhoods, and Health: Expanding the Boundaries of Place** Springer *Social Disparities in Health and Health Care* series edited by W. Avison and R. Angel.

the case of migrants, the space is likely to be much larger and more fluid than it is for non-migrants.

Studies into such contextual and/or spatial processes are plagued by methodological and ethical issues. Often migrants are the subject of ridicule and discrimination. They may therefore prefer to remain hidden and certainly may not want to be tracked. Beyond their personal concerns, there are also safety and legal concerns associated with identifying and tracking migrants. In an age in which we could literally strap GPS units on individuals and follow their movements across a landscape, there are some obvious ethical dilemmas to consider.

This brings me to what I think is an important question: Should I (we) want to track individuals that may not want to be tracked? Furthermore, are there other ways to get at the questions that we are interested in without actually tracking migrants? In my research, and in others as well, I would say that the issues surrounding migration are so important that it is in fact necessary to study migration pathways and patterns, but that we should err on the side of confidentiality for the vulnerable populations that we are studying. Perhaps one way to do this is to find indirect measures of migration.

One proposed method for measuring migration routes has been through the use of network analysis, human energetics research, and topographical maps. For example, given certain characteristics of a landscape (e.g., mountains, narrow points in rivers, etc.), a network model can be used to calculate the most efficient route from one point to another, controlling for energetic efficiency and distance. Archaeologists have recently been using this method in order to calculate most likely routes, then comparing the simulated routes to what they actually find in the archaeological record[2]. In my research, it may be possible to use this method to see if most likely routes are geographically related to malaria hot spots. I am sure that there is a plethora of other possible ways to get at a better understanding of the spaces that migrants inhabit.

The growing interest in population and environment interaction is also inherently spatial in nature. In fact, if not for changes in places and spaces we may not be interested in this interaction at all. In ecological sciences researchers have been using remote sensing to measure changing environments. In some situations, changes in environments are directly related to changes in population health. Clearing forests for agricultural purposes has long been associated with an increase in mosquito-borne diseases because the changes in the environment (irrigation, increased standing water, etc.) can lead to increases in vector populations. Spatial demography has a special place in this area of research as we already have some tools (spatial regression and hierarchical models) and can borrow others (remote sensing, etc.) in order to quantify the impact of environmental changes on populations. As our tools improve, I expect more possibilities to open up in this arena.

However, there are also several limitations and problems to consider in environment and population studies. Perhaps one of the largest issues is scale. As an example, meteorological

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[2] (2006) Wood, Brian and Wood, Z. "Energetically optimal travel across terrain: visualizations and a new metric of geographic distance with archaeological applications" *Proceedings of SPIE Electronic Imaging* Volume 6060.

data are generally taken from various weather stations within a region but within regions meteorological patterns can be highly variable. Is it important to smooth the data from many weather stations across an entire region? Or should we use the raw individual station data in order to include the actual variation that occurs at a specific place? Which is better for measuring the impact on a population that inhabits and lives in an area that is much larger than a single weather station? Furthermore, while some factors are important in one region, the same factors may not be important in others. While increased rainfall can lead to higher malaria incidence in one place, in other places it will have no effect at all (for example, if there is no malaria in that region!) Once again, there is frequently a contextual component to what is important.

The recurrent theme of context leads me to Geographically Weighted Regression (GWR), a method that is growing in popularity among spatial demographers. GWR takes advantage of the rich data sets that are increasingly becoming available and provides a means of visually understanding the way that important predictors influence outcome variables. In my own studies this will be important as I will be able to map the changes in relationships between covariates and outcomes across different scales and geographical subregions. I expect that different covariates will be more or less important in different subregions. Perhaps an interesting dimension that could be added to GWR is the temporal scale. Overall, this is an area where I think that spatial demography will have a lot to offer regarding public health and policy. The few population health studies that have already been done with GWR have shown that different things matter in different places, context matters. This simple fact is important for efforts to (for example) eradicate malaria, because place-based interventions are therefore most likely to be effective.

Emerging Trends and Challenges for Space-Time Analytics and Software in the Social Sciences

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The availability of software to support spatial data analysis has played a critical role in the adoption of a spatial perspective across the social sciences. Beginning in the 1980s the appearance of specialized code to carry out basic spatial econometric and exploratory spatial data analysis ushered in an era where these analytical tools have moved from the fringes of the social science toolkit to occupy central positions. By and large, however, the existing tools have been developed primarily for the cross-sectional context. Yet, all of the processes of interest to social scientists operate over both space and time. Demographers are not exempt.

The increasing availability of space-time data made possible through expanded data collection efforts by the volunteer geographic community and government agencies, the advent of sensor networks, GPS, and other geospatial data technologies have opened up a rich empirical context for the social sciences. However, this poses significant analytical challenges given the largely cross-sectional focus of our existing toolkit. I believe there is a critical need to develop new methods for space-time analytics that will enable demographers and other social scientists to leverage these new data sources. While there is a rich taxonomy of space-time data types (Goodchild 2008), I have focused my work on longitudinal spatial data (LSD), that is data observed for the same spatial unit over multiple periods. In what follows I describe the evolution of software designed to explore this form of space-time data together with some challenges I see going forward.

Space-Time Analytics: Evolution

My research developing space-time analytics had its origins in a long-standing interest in spatial inequality and regional growth dynamics. During the 1990s this literature was composed of largely separated groups of economists and sociologists studying the dynamics of income distributions, and regional scientists and geographers exploring spatial patterns and clustering in poverty and inequality. Both groups relied on different methodological frameworks with virtually no cross-fertilization between the camps, yet it was clear to me that the processes understudy had temporal, spatial, and distributional dimensions that needed to be considered in a comprehensive and simultaneous fashion. The toolsets of the day simply did not support this.

Space-Time Analysis of Regional Systems (STARS) was borne out of this need. It is an open source package that brings together a suite of new space-time analytical statistical measures together with an array of dynamic and interactive visualization tools (Rey and Janikas 2006). The space-time analytics consist of two broad sets of methods, the first departs from exploratory spatial data analysis methods (ESDA) and extends them to incorporate a dynamic component giving rise to methods of ESTDA. The second begins with methods that have previously been developed for exploratory temporal data analysis (ETDA) and proceeds to introduce space into the analytical framework (ETSDA) (Rey 2001).

ETSDA extends the workhorse Markov chain methods for income distribution dynamics to incorporate a geographical dimension. The spatial Markov chain explores the role of regional context in the evolution of income distributions and gives empirical expression to the construct of spatial poverty traps. Spatial rank concordance and mobility measures (Rey 2011) take a similar approach to enhancing widely used a-spatial measures of distributional dynamics to consider spatial dependence and heterogeneity.

ESTDA methods extend both global and local measures of spatial association to the dynamic context. These allow for an assessment of the temporal stability of the local spatial clustering as well as new indicators of space-time association. The latter include Directional LISA statistics (Rey, Murray, and Anselin 2011) and a LISA Markov (Rey 2001).

STARS provides access to these, and other, analytical measures through a graphical user interface following the success of the desktop application model of GeoDa (Anselin et al. 2006). Although STARS supports limited scripting for more advanced users, there is a clear need for a library of spatial and space-time analytics to support the development of the next generation of spatial analysis software. PySAL (Rey and Anselin 2010) represents collaborative work to help address this need.

PySAL includes modules for spatial dynamics; classic ESDA, regionalization and districting; computational geometry; spatial inequality; and spatial econometrics, among others. As a library, PySAL supports a number of delivery mechanisms such as in cyberGIS gateways, web services, web clients, ArcGIS and QGIS plugins as well as desktop applications. Examples of the latter include work at ASU on the new version of STARS (planned release Spring 2012) and GeoDaSpace (spatial econometrics—planned release January 2012).

Challenges

While the methods above have gained increasing adoption (beyond scratching my own research itches), I can see a number of challenges standing before us as we work towards the next generation of space-time analytics. Some of these are methodological challenges, while others are more cultural in nature.

Methodological Challenges

A particularly thorny, yet fascinating, problem in a space-time context pertains to the nature of boundaries when defining either regions, as is done in the economic inequality literature, or neighborhoods in the vast literatures in sociology, urban epidemiology, criminology and geodemographics. The dominant approach in the investigation of social dynamics has been to define neighborhood boundaries at one point in time and then to measure compositional or attribute change in-situ. Any inferences drawn regarding these dynamics are contingent upon these boundaries remaining fixed over the period, yet neighborhoods, housing markets, and labor markets are dynamic constructs and this calls the assumption of static boundaries into question. How to incorporate endogenous boundaries into the analytical framework is a major challenge (Rey et al. 2011).

A second methodological challenge is associated with the tremendous opportunities that are now becoming available in the form of high performance computing and cyberinfrastucture resources. Parallel and distributed computing will be increasingly common and can enable a massive expansion in the scope and nature of computational problems that can be addressed. Much of the existing spatial analytical software we rely on in the social sciences has not, however, been designed with these environments in mind, and a significant refactoring effort is required before this dream can be realized (Anselin and Rey 2011).

The third methodological challenge arises from an embarrassment of riches in the spatial analytical tools that social scientists have at their disposal. This diversity can be daunting to the untrained scientist, and we are far from consensus on many of the possible scientific workflows that would consist of a sequence of tasks necessary to carry out a particular type of spatial analysis. This situation will become even more complex when new space-time analytics are added to the toolkit. Ontologies for spatial data manipulation and provenance are receiving increasing attention, yet we currently lack anything remotely similar for spatial analytical workflows and models.

Cultural Challenges

To these methodological challenges I would add two cultural challenges. The first pertains to an often-heard criticism that social scientists applying spatial methods have failed to articulate the linkages between the uncovered spatial effects and the relevant substantive theory. Implicit here is that the problem lies with the tools at hand, yet one can also point to the overly abstract and reductive nature of most substantive theory as it pertains to spatial dimensions. Clearly there is a need for tighter linkage between spatial methods and substantive theory, but both ends of that linkage require development.

A second culture shift that, in my view, has to occur is from the current mode of scientist as *consumer* of spatial analysis software to scientist as *collaborative producer* of new analytical tools. The current situation is more akin to the cathedral model of software development (Raymond 1999) where small individual teams implement new analytical methods and release those packages to the wider research community. This is a recursive form of interaction, where scientific practice is very much constrained by the package functionality. This is problematic on several accounts. Gone are the days when the substantive questions of interest were easily addressed with off-the-shelf software. Increasingly novel twists extending theoretical frameworks will require new analytical tools. Scientists unwilling to get their hands dirty with the demands of scientific computation are likely to find themselves increasingly distant from the cutting edge.

In terms of new advances in tools, the cathedral model is also a constraint. I hope things begin to change to more of a bazaar model where larger numbers of geographically separated researchers become collaborators in the development of the next generation of tools. While this increases the start-up costs borne by the researcher, and requires new forms of training, it does rebalance the nature of inquiry to have scientific questions driving tool development rather than the reverse. Tapping into the power of open source development and communities offers a new way to advance spatial analytical software and the practice of spatial social sciences (Rey 2009).

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Promoting Spatial Thinking among Population Scientists and Demographic Thinking among Geographers

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Demographic processes exhibit substantial spatial variation at different scales (e.g., Allen and Turner 1996; De Castro et al. 2006; Entwisle 2007; Eschbach, Mahnken and Goodwin 2005; Riosmena 2009). In my view, describing and explaining this variation is paramount to understanding the nature of these processes substantively as it is in "contextual contingencies" that we comprehend and test the depth and limits of theories.[1] Looking at (population-average) associations is not as useful for policy purposes either, as policies should be designed to fit a variety of settings as they cannot oftentimes be unevenly applied across settings. Research aimed to understand spatial variation and, in the end, contextual contingency should thus be at the core of social scientific inquiry.

Many techniques have been devised to visualize, describe, summarize, and explain spatial dependencies (e.g., Fotheringham, Brunsdon and Charlton 2002; Goodchild and Janelle 2004; Singer and Willett 2003; Ward and Gleditsch 2008). While it is of course important for population scientists to keep abreast of the use of these techniques, it is perhaps even more relevant to instill a more general type of spatial thinking in population scientists in training. As such, I believe training efforts in Spatial Demography in the future should attempt to continue promoting a general spatial perspective that will survive long after the specific methodological toolbox learnt by the student renders obsolete, but which will also provide a very useful interface for years and one that will allow for the better comprehension of these conceptual tools.[2]

The efforts of centers and programs in places like UCSB, Penn State, Washington, Brown, and North Carolina, aimed to integrate spatial thinking into social and population science, need to be further expanded elsewhere. More importantly, spatial thinking needs to be further incorporated into the *core* of Demography, Sociology (of Population), and (Population) Economics graduate programs. A possibility would be to offer a population geography/spatial demography course analogous to the economic demography one offered in many departments.

In addition, Geography programs need to produce a larger number of graduates with a firm footing in Demography. We need more "hyphenated demographers" (as Marcia Castro calls them in her statement) that also possess thorough training in spatial thinking to help lead the

[1] It is generally more understandable that theories do not conserve their predictive power across different epochs. But they are expected to be applicable across larger spatial scopes (e.g., they should fit a variety of developing/industrialized countries, if not globally).

[2] Just to further clarify: I am not diminishing the importance of learning the actual techniques but underscoring the relevance of the more abstract thinking skills that should be acquired during this process.

way. As most Geography departments in the U.S. have only a couple of population geographers in the Faculty (if any), students might also benefit from supplementary training on formal demographic techniques and on the discipline of Demography. Those of us in Geography Departments have a duty to continue attempting to train and attract individuals, but also to communicate population-minded grad students in Geography of training opportunities elsewhere too.

Although many population geographers participate in the Population Association Meetings and some demographers not affiliated with Geography programs or Spatial Analysis initiatives, more efforts aimed to bridge the relative divide in the two communities might be useful to get spatial thinking more into the mainstream of demographic thinking. Special sessions at either meeting, as that organized by Steven Matthews during the 2011 PAA Meetings, might help bring people to the AAG/PAA meetings that would have otherwise not attended.

A model similar to this has been the model pursued by the PAA and the Mexican Demographic Society to foster more exchanges between the members of the two communities that generally not overlap (and who would benefit from this). Along these lines, the Population Specialty Group at the AAG could organize a whole thematic (or even plenary) session at the AAG meetings featuring PAA members looking at spatial perspectives but who do not normally attend these meetings. By the same token, the PAA would organize a special session with geographers working on population issues at large, but who may not identify as demographers *per se* (e.g., some medical/health and economic geographers; many GIScientists).

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Future Directions in Spatial Demography

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The contributions to spatial statistics have had important repercussions in the field of demography. It is not unusual to find the tendency for spatial autocorrelation in spatial data As in other areas in the population sciences Economic Demographers are increasingly using spatial data in order to understand a wide variety of topics in the population sciences. Some of these studies simply attach place based measures and a pre-defined geographic level to individual level data in order to understand how place based differences in characteristics effect outcomes such as health or economic success. Other studies use the relative proximity between respondents and other important spatial features (e.g., schools, doctors offices etc) to gain a more refined understanding of proximity on important outcomes.

Economists are notoriously concerned about issues of "endogeniety." In much work, the use of spatial data is seen to reduce the issue of endogeniety and spatial data certainly has the ability to help in this regard. But the simple use of spatial data does not guarantee this. For example, David Card and extremely thoughtful scholar uses the proximity to a college as a way of constructing groups of students who are likely vs. less likely to go to college and by comparing the difference in their earnings estimates the return to attending college. This has lead to a good deal of debate whether distance is a reasonable instrument as parent's choose where to live and parents who value education more highly, and perhaps have other correlated earnings advantages that they pass to their children, may locate near a college campus. Living in Hillsborough, NC, home to the first NASCAR track built in the U.S. I can personally attest that distance to a NASCAR track is strongly correlated with all kinds of factors, most of which are causally related to nothing!

Very often, history plays a role in establishing causality in economic demography. There is a general idea that if the events that caused the current conditions to unfold are far enough back in time, then the danger that these historic events have direct effects on outcomes outside of the current conditions that they have caused is mitigated. As a general example, divorce laws that vary across the U.S. because the law reflects the original English, French or Spanish settlement are seen to be useful because variations in current law that stems from each locations colonial heritage may affect divorce related outcomes but not be related to outcomes such as remarriage rates except through the property division and alimony rules of the law. This is especially credible if over the 250 years since colonization populations have mixed in a way that the original colonial settlement has little resemblance to the current population composition.

In my own work, I have found that the use of historical data to be extremely valuable. For example, we have found that the railroad network in the late 19th century had a profound impact on which African-Americans migrated out of the South and the specific cities to which African-Americans migrated. First, African-Americans that lived in small rural towns that were serviced by a railroad line where 15% more likely to migrate out of the Confederacy than those who lived in small rural towns not on a railroad line; and where they migrated was strongly affected by which line they were near. African-Americans in Mississippi that were born in towns on the *Illinois Central Railroad* (*IC)* overwhelmingly settled in Chicago; those born on the *Mobile & Ohio* railroad ended up in Detroit. Similarly, Louisiana born African-Americans born on the *IC* also ended up in Chicago while those born on the *Vicksburg, Shreveport & Pacific* line overwhelmingly settled in Los Angeles. In this case what the historical geography gives us is a mechanism that caused the settlement patterns in northern cities which then had independent impacts on behaviors.

I believe that historical spatial data is likely to be extremely valuable to population scientists. And there have been some efforts to assemble historical data, especially at the county level from census data. But features that are not standard Census geographic units are less available historically and many of the spatially important historical features are the fundamental factors that lead to spatial patterns we see today. For example, a complete time-series on transportation networks would be exceptionally valuable and there are good historical sources for such data. In addition, data from the Census is available at the Enumeration District level but to my knowledge these boundaries are not available electronically although physical descriptions are available. Development and distribution of these sources to complement current efforts in historical demography may yield important discoveries in the population sciences.

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Future Directions in Spatial Demography

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Future research in spatial demography will require new and better data which, in turn, will challenge data providers and analysts to balance research data needs with adequate protections for human subjects.

New data for spatial demography will ideally include in-depth local studies, such as the Los Angeles Family and Neighborhood Survey (L.A.FANS) which I co-direct with my colleague Anne R. Pebley (UCLA), together with nationally-representative data, such as the Panel Study of Income Dynamics (PSID) on which I serve as the co-Principal Investigator along with several colleagues at the University of Michigan.

The in-depth local studies have the capacity to provide rich and detailed information on specific study sites. The concentration of study samples in a single area—such as Los Angeles County in the case of L.A.FANS or Chicago in the case of PHDCN, the Project on Human Development in Chicago Neighborhoods—offers the opportunity to collect measures that are otherwise extremely expensive or entirely impractical to obtain. For instance, L.A.FANS and PHDCN have both conducted systematic observations of the physical and social environments of study neighborhoods, which would be essentially impossible to do for a national study such as PSID. These two studies are also designed to support the construction of sample-based estimates of neighborhood social indicators, such as measures of collective efficacy, that have proven highly valuable for understanding the contextual social processes through which neighborhood structural characteristics, such as concentrated disadvantage, operate to affect outcomes for children, adults, and families in domains such as health, development and well-being. Finally, L.A.FANS is one of the few population-representative surveys that has collected detailed information on the spatial locations of activities (such as where people go to shop, worship, work, exercise, etc.). Analysis of spatial activity space is important for a better understanding of individuals' contextual exposures and how these exposures, in turn, affect a variety of outcomes of interest.

Among the shortcomings of existing in-depth local studies is that there are few of them and those that do exist tend to focus on a relatively small number of areas (including Chicago, Los Angeles, and New York City); they are often not collected with frequently enough to support panel analysis; and it can be difficult to place their results within the national context.

The last shortcoming can be addressed by studies such as PSID, which trade-off the detailed geographic information available in local studies with the advantage of having nationally-representative data collected at frequent periodicity (two- or five-year intervals, depending on specific study component). A study such as PSID is also better-able to study geographic moves away from study areas—which is a challenge for local area studies—and to collect a complementary set of measures on topics such as income, wealth, and consumption expenditures, family dynamics, outcomes over the entire life-cycle, intergenerational effects, and time use. This last topic—time use for children and adults—is one particular area of innovation for PSID which is ripe for integration with local-area studies or with the spatial location of activities. In particular, knowing the amount of time and the specific time of day and day of the week that individuals spend in specific locations conducting particular activities is likely to be incredibly valuable for understanding spatial patterns of time use, contextual exposures, and a variety of other topics. A final topic that national data sets such as PSID often have an opportunity to lead on is linkages with administrative records. Matching respondent records from surveys with detailed administrative data from schools, employers, health care providers, the criminal justice system, and other sources provides a new and unique set of avenues for future research.

There are, of course, a number of challenges associated with collecting new data for the next generation of research on spatial demography. First, the costs of collecting these data are high, and the difficulty of securing adequate financial support in a time of stagnant or shrinking government research budgets is an enormous challenge. This situation makes it extremely important that the data that are collected are used widely and effectively—which is facilitated, in particular, by providing the broadest possible data access within the constraint of protecting respondents' confidentiality. This is the second challenge: how to provide broad and democratic access to restricted data files that include the necessary geographic specificity to conduct detailed and in-depth spatial demographic analysis. Many of the necessary variables simply cannot be included in public use data files because of the possibility of deductive disclosure of respondents' identities. Yet the access to restricted data is vastly easier for established researchers at major institutions who have secured their own grant funding. Among the groups at a disadvantage are scholars are lower-tier institutions that do not have adequate funding for the necessary secure computing infrastructure, undergraduate and graduate students, and junior researchers and faculty. Efforts to help overcome access barriers through the use of new technology—while continuing to protect respondents' confidentiality—is an important priority. A final challenge, which is really an important opportunity, is for demographers to join forces with scientists in other disciplines to enhance the richness and depth of contextual and spatially-referenced data collected as part of, or in conjunction with, these surveys. The connection with geographers is an obvious one, but demographers should also be collaborating with environmental scientists, epidemiologists, education researchers, and others to establish and develop collaborative links.

Spatial Demography: Mashup for a new synthesis?

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Mashup is nowadays one of the most frequently mentioned and widely circulated buzzwords, and, indeed, many of today's proliferating web 2.0 applications can broadly be identified as some variety of mashup. Borrowed from the music industry, a mashup (also known as a bootleg or a blend) originally refers to a song or composition created by blending two or more songs—something that can be achieved by digitally overlaying the vocal track of one song seamlessly over the music track of another (Wikipedia.org). In the context of web-based applications, a mashup may have multiple meanings. At the functional/service level, a mashup may refer to a web page or application that combines data or functionality from two or more external sources to create a new service. In terms of the actual content, a mashup can be a digital media file that contains a combination of text, maps, audio, video, and animation, which recombines and modifies existing digital works to create a derivative work. The term mashup implies easy, fast integration, frequently using open APIs (application programming interfaces) and data sources to produce something new. A growing number of industry leaders such as Google, Microsoft, Yahoo, and MapQuest have developed new products and services that enable their users to develop their own APIs, and, undoubtedly, this has enabled millions of web users to develop a variety of creative applications. It is definitely one of the major technical breakthroughs since the WWW came into existence, but mashup is much more than a technical advance. I believe mashup's true significance lies in its promotion of a new habit of mind towards synthesis in the age of web 2.0. As cognitive psychologists have shown (Wallace and Gruber, 1989), synthesis, rather than analysis, is the defining characteristics of human creativity. Spatial demography, dominated by a predominantly analytical tradition until recently, is uniquely positioned to test the multiple frameworks and methods of synthesis. The overarching themes of my talk for the specialist meeting are how spatial demography has been practiced until recently following the spatial analysis tradition and how spatial demography may be better practiced by riding the wave of an emerging spatial synthesis trend—both conceptually and methodologically.

GIS Mashups: Back to its synthesis roots and implications for spatial demography?

For GIS users, mashup is not a difficult concept to absorb. Fundamentally, mashup is about data integration. Some observers have even commented that mashup is just the web 2.0 version of overlay in traditional GIS operations. Although the technical processes are quite different, mashup and overlay do share a conceptual similarity in that both aim to integrate and synthesize multiple pieces of information. Of course, GIS did not give birth to the concept of overlay. Pioneers in multiple disciplines, such as Manning, Dusseldorf, Lewis, and McHarg, used the manual overlay methods for a variety of applications (Steinitz et al., 1976). Although we now know that McHarg's manual overlay method of using light tables was flawed because he unwittingly used arithmetic operations on ordinal level data, the goal of his effort - integrating multiple layers of information for a comprehensive understanding of reality—is still admirable today. In fact, super imposition of multiple layers of information, whether via GIS or manual methods, is conceptually consistent with today's mashup efforts. Or perhaps it's safe to argue that mashup has long been done using traditional GIS or even manual methods.

During the early days of GIS, one of the major goals for software developers was to automate McHarg's manual overlay method using the primitive technologies available at that time. In fact, how to better integrate and synthesize multiple layers of georeferenced information was a top priority in the late 1960s and early 1970s. And yet in the 1980s and 1990s, information synthesis and integration played a less important role in driving the development of GIS. Instead, spatial *analysis* came to the fore. It's interesting to note that the development of GIS during the past 20 years focused primarily on improving the spatial analytic functions. The spatial analysis tradition often takes a reductionist approach, focusing on individual layers to identify spatial patterns rather than synthesizing multiple pieces of information. Not surprisingly, spatial demography has been heavily influenced by a GIS-based spatial analytical approach. What we have witnessed during the past five years is that the emerging mashup practices are reconnecting GIS back to its roots in synthesis, which in turn may inspire a new synthesis paradigm in spatial demography in the years to come.

My talk will review recent synthesis efforts at the conceptual, methodological, and data levels, and discuss their implications for the new synthesis paradigm in spatial demography. In particular, I will discuss advances in synthesizing 1) space and place; 2) space and time; 3) data in different media; 4) disaggregated/confidential and aggregated/encrypted data (homomorphic cyptography); and 5) certainty/known and uncertainty/unknown.

The ultimate mashup for spatial demography: Steps toward consilience?

Although reductionism has dominated scientific discourse since the scientific revolution in the 16th century, scientists in various fields have never abandoned their quest for a more holistic understanding of how the universe works. From the unified theory of fields in physics to the Gaia hypothesis in ecology, from evolutionary economics to Gestalt psychology and holistic health in medicine, humanity has never ceased to pursue a more comprehensive understanding of the world and ourselves. Although our scientific enterprises have been primarily oriented toward analyzing the parts, a synthetic understanding of the whole has always appeared more gratifying.

Perhaps there is no better word to capture the spirit of mashup than *consilience*, a term originally coined by British philosopher William Whewell in the mid 19th century but popularized by American biologist E.O. Wilson (1998) in his 1998 best seller "Consilience: The Unity of human knowledge." Consilience, literally meaning the "jumping together of human knowledge," has been used widely to capture the unity of human knowledge in the conceptual realm. Today, millions of web users, assisted by some very powerful web-based software tools like Photosyn, have put Whewell's abstract concept into practice, and, in the process, have seen something larger than the individual piece of information with which they have previously dealt. Web 2.0 technologies provide a golden opportunity for spatial demography to position itself to play a leading role in the effort to find a meaningful link of the natural sciences, the social sciences, and the humanities. To me, that will be the ultimate mashup, the consilience to which we need to devote our intellectual energies, because it will motivate us to sing and dance to a higher tune even after the technological fads fade away.

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Future Directions in Spatial Demography

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I am keenly interested in spatial demography and have been particularly focused more recently on many of the same issues that will be addressed in the meeting. A new population center was established at UCSB this year and my role in the new center is as the area director for Spatial Demography and Migration. A basic starting point for considering prospects for growth, challenges, and future directions in *spatial demography* is to establish what is meant when the words "spatial" and "demography" are stuck together. My definition for the area focus in the center is as follows:

> The spatial demography research area . . . focuses on place-dependence, relative location, and interaction to gain insights into population level processes and individual-or household behavior. One intellectual thread within this tradition is multiregional mathematical demography. These models extend life tables to study the spatial and temporal evolution of multiple regional populations that are connected by age-specific migration flows. They have had a particularly strong impact in applied demography and forecasting because migration is usually the dominant component of change in subnational populations. The core insights of multiregional demography can be linked to individual-level behavior through the life course perspective and multistate hazard models. At a more general level, there has been increasing interest in accounting for space and place in individual-and household-level studies. This has been driven, in part, by the rapid diffusion and adoption of spatial "tools" and methodologies such as GIS and spatial econometrics.

I would be interested to know whether others would agree or disagree with my definition. In my view, there is already a cohesive approach to spatial demography in the realm of formal mathematical demography that emerged in the mid-1960s (for example Rogers 1967) and by the mid-1970s had coalesced into textbook-length treatments of the topic (Rogers 1975, Rees and Wilson 1977). Indeed the Rees and Wilson text is titled, "Spatial Population Analysis" but the general approach is usual termed *multiregional demography* and it generalizes to any population subjected to increments and decrements (multistate life tables). There is a second realm of *spatial demography* that has emerged in conjunction with an emphasis on individual (or household) behavior where spatial technologies (GIS, GPS, remote sensing) and spatial statistics (spatial econometrics and MRF-style spatially correlated errors in mixed models) have served to extend and refine what would otherwise be aspatial analyses. This second realm is equally deserving of the label *spatial demography* but it is less cohesive and less integrated with some of the core theory and measurement constructs of demography. There are certainly frontiers in both realms but there are also some clear barriers that I think currently limit the applicability of spatial technologies/methods in the second realm.

Concepts and Measures

Demography is different from other social sciences in that the primary mechanism that binds it together as a field of study is the object of analysis, rather than a theoretical perspective on human or social behavior. It is also different in that historically the objects of analysis have been so few in number; the bulk of demographic analysis has focused on fertility and mortality, with migration running a distant third. Any theory base can be used to study *why* individuals change their residence, have longer or shorter spacing between children, etc. The core and unique theory base to demography has tended to focus on concepts and measures.

Events, exposure, and *age-period-cohort* (APC) are elements at the core of demographic measurement. Demography is the study of demographic events which include the core forces of population change (birth, death, and migration) but also any other events that can influence one of those processes. If we want to understand variation in events, or describe the process generating the events, basic measurement theory requires that we focus on the population that is at-risk of experiencing the event, thus *exposure*. APC, and the Lexis diagram, is a primary measurement and data architecture framework for achieving precise measures and meaning in aligning events with exposure. This framework is particularly dominant in formal demography. Multiregional demography is simply a logical extension of the framework to allow for multiple interacting populations. Since the extension is entirely logically consistent, the integration of the *spatial* component is complete.

Formal demography is obsessively focused on precise measurement and description of demographic processes, but it typically stops short of explanation. Attempts to explain why groups (perhaps regions) or individuals differ in their demographic behavior have focused on regression-type frameworks. Even those frameworks, however, share the same measure framework with formal demography. Survival analysis (hazard models) based on time-to-event data are also attuned to correctly characterizing the timing of events and the duration of exposure. These models are workhorses in building demographic theories of individual behavior because they allow for the inclusion of covariates and because they can be linked directly back to survival analysis based on life tables.

Frontiers and issues in individual-level analysis

One of the most direct ways that spatial technologies/methods have impacted individual level analysis is in placing individuals in context. GIS is a perfect tool for data integration across different scales and it has certainly contributed to better, and more creative, covariates that might be difficult or impossible to create otherwise. In this category I am also including the use of remote sensing imagery and its manipulation in GIS to extract covariates.

One problem in using GIS as a mechanism to create covariates is that detailed spatial cross-sections are unlikely to align correctly with notions of exposure. In most cases the covariates will only be able to measure very near-term influences. For any long-term exposure measure—such as those that would be appropriate in studying chronic diseases—the utility of GIS is likely limited. In general, I think there needs to be more attention given to the timing of measures in GIS layers relative to the timing of events being studied. Data collection based on mobile computing devices may have some ability to generate better exposure methods for near-term influences. For long-term exposure the best approach would be to build off of detailed residential and work histories.

There is relatively little work (that I am aware of) that accounts for spatially correlated errors in survival analysis and event history models. The only approaches I know of are mixed effects models where individuals are nested in zones and the zonal errors are partitioned into spatially-structured and random components. I am not sure how widely these models have been adopted in demography.

Frontiers and issues in aggregate-level analysis

Spatial analytic tools would seem to have a natural affinity with formal demography in its focus on ecological analysis. I think there is fundamental dissonance in the way that processes are conceived and in data architecture. While there is a rich tradition of conceptualizing space-time paths in Geography, the dominant framework in standard GIS representations is cross-sectional. There is also no ability to access and represent interaction among regions (except for standalone tools such as Tobler's flowmapper). To bridge this gap would require retooling GIS data architecture to fit the framework used in demography. A step in that direction already exists in Serge Rey's STARS (Space-Time Analysis of Regional Systems) software but it would also require further tweaks. Somewhere I have a proposal that Serge and I started to write that would make this extension.

Similarly, the basic spatial lag and spatial error models from spatial econometrics are not easily linked into the core analytic framework of demography. The problem resolved by cross-sectional spatial econometric models is that we only observe a single realization of the underlying spatial (-temporal) process. I know that there are many papers that have applied spatial econometric methods to summary indicators (e.g., Total Fertility Rate, Crude Death Rate, etc.) measured on regions along with covariates. But this is a decoupled two-step analysis. There is more work that could be done to integrate the well-defined process theories from demography (and multiregional demography) with underlying specification choices in spatial econometric models.

The frontiers in multiregional demographic analysis are primarily focused on its use in population forecasting. Three areas that have been the focus of recent work include model-based estimates of directional migration flows (especially for international data), incorporating uncertainty into forecasts, and the use of multiregional methods in small area analysis.

Training

One of basic challenges to training is that inclusion of spatial dependence or interaction into statistical or mathematical models only makes sense pedagogically after a foundation in more basic (non-spatial) methods has been established. In 2009 I offered a graduate-level Spatial Demography class and in a 10-week quarter it was challenging to provide the foundation and then engage students in spatial content in a meaningful way. In that class I started with standard content from formal demography—single- and multiple-decrement life tables—then on to increment-decrement tables using the specific instance of multiregional life table analysis. The next section focused on event history theory and the connection between hazard models estimated from data on individual event histories (single events, multiple events, and multiple recurrent events) and how the resulting model predictions are link back to the probabilities in life tables. This left relatively little time for covering applications of spatial econometrics in demography.

The obvious solution to the time constraints imposed by a single quarter (or semester) is to have a series of courses that provide sufficient coverage of foundational material before providing "advanced" spatial training. This approach requires that there is sufficient critical mass both in terms of instructional capacity and interests among students. I can only think of a few universities where both conditions are satisfied.

Some Reflections on Future Directions in Spatial Demography

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Since the theme is spatial demography, I focus my thoughts on the status of spatial data analysis, spatial core support, and spatial training in higher education in the U.S. I do so through the lens of the population centers supported by the NICHD Population Research Infrastructure Program (R24), Institutional Training Grants (e.g., T32), and similar awards both from NIH institutes and centers, NSF directorates and divisions, and private foundations.

The Present:

Spatial demography remains underdeveloped and under-supported in most population centers and training programs. While it's difficult to estimate with precision, it is fair to say that only a select few of the 30+ university-based population research and training centers provide core support and training in GI science and spatial data analysis. Several centers appear to have access to individuals or other campus units providing basic GIS support and limited spatial consulting, but most of the centers provide little or no direct support or training in spatial demography. [Resources used in this assessment include the 2011 directory of the Association of Population Centers (APC): http://www.popcenters.org/Final%20APC%20Book%202010.pdf and the partial guide to spatial demography research posted on the CSISS website: http://www.csiss.org/GISPopSci/research/links.php]

This strikes me as paradoxical. The past decade has seen many significant calls for more attention to matters of space and place in demographic research. Among these:

- √ 2001: NICHD Demographic & Behavioral Sciences Branch (DBSB) holds Long-Range Planning Workshop. Working groups include specific focus on Spatial Demography. Summary of meeting highlights the need for enhanced core demographic training in spatial statistics. [See: http://www.nichd.nih.gov/about/meetings/2001/DBS_planning/outlines.cfm#training]
- √ 2005: Proceedings of the National Academy of Sciences publishes special issue on spatial demography. Several leading U.S. demographers highlight convincing examples of how important issues of scientific investigation involve the comingling of geography & demography [See: http://www.pnas.org/content/102/43/15299.full]
- √ 2007: PAA Presidential Address calls on demographers to recover the early disciplinary importance placed on spatial context in demographic research agendas. [See: http://muse.jhu.edu/journals/demography/v044/44.4entwisle.pdf]
- √ 2007: Demography journal Population Research and Policy Review publishes double issue on theme of spatial demography. [See http://www.springerlink.com/content/v4571185g72643w7/]

√ 2008: Five year training program in Advanced Spatial Analysis for Population Scientists commences under joint leadership of CSISS (UC Santa Barbara) and Population Research Institute (Penn State University) [http://www.csiss.org/GISPopSci/]

√ 2008: NSF Geography and Spatial Sciences (GSS) 5-year strategic plan includes commitments to stimulate & strengthen interdisciplinary research in spatial sciences and allied fields [http://www.nsf.gov/sbe/bcs/grs/GSS_StrategicPlan_2008.pdf]

√ Throughout the decade: Inclusion of spatial demography sessions in professional gatherings of the PAA and IUSSP. [See, for example, partial listings provided at: http://www.csiss.org/GISPopSci/research/links.php]

√ Throughout the decade: Many NICHD-supported population centers are located on campuses that are dues-paying members of the University Consortium for Geographic Information Science (UCGIS). It is not unrealistic to guess that of 20 randomly selected research affiliates of population centers (even those at UCGIS member campuses), 19 will have never heard of the organization. [See http://www.ucgis.org/Default.asp]

My own population center at UNC was the first population center to establish a spatial core support unit, and this unit is absolutely vital to each of the signature research themes at the CPC. The Geographic Information Analysis (GIA) core of the Population Research Institute (PRI) at Penn State University is arguably the strongest of such support cores. This unit benefits not only from institutional support but also from extraordinarily strong leadership and continued national visibility. Beyond this, there isn't much to boast about. There are, of course, individuals and specialized units supporting spatial analysis in university settings that often provide somewhat hidden support for the formally recognized population research and training centers. These often are absent from our centers' organization charts. To illustrate the point, I note that the Center for Demography and Ecology (CDE) at Wisconsin-Madison turns to a spatial unit in a different campus location and, indeed, different college for GIA support: the Wisconsin Applied Population Laboratory (APL). This is a campus unit I know very well. It was established sometime around 1962–1963 (the exact founding is vague), working mainly to support state-level population estimates and forecasts in Wisconsin—such activities inherently spatial. In the 1980s the APL became involved in early spatial mapping efforts (at the time, still using SYMAP a line-printer-based, character-overstrike, mapping software package developed at the Harvard Laboratory for Computer Graphics and Spatial Analysis in the early 1960s). Following the 1990 Census, the APL, under contract to a state agency, developed an ARC/INFO-based redistricting application used by the legislative caucuses, the governor's office, and eventually the courts to carry out post-census statutory redistricting obligations in Wisconsin. That early success has continued through the 2010 redistricting ritual. While the computing technology underlying the activity has changed, the primary end product remains the same: maps that stand up to political and citizen scrutiny and the imprimatur of the courts. The APL provides support to research associates at the Wisconsin Center for Demography but is not organizationally part of the CDE.

I have long argued that the science of demography, for most of its history, could be appropriately called "spatial" demography. However, about 60 years ago, large, representative social surveys came to dominate much of demographic analytic interest, and demographers momentarily forgot about space. "Place," "context," "neighbor," "distance," "accessibility" somehow become irrelevant. It took a few decades, but demographers eventually rediscovered the importance of demographic context. As wonderfully reviewed in Barbara Entwisle's PAA Presidential Address (cited above), geographic measures began to re-emerge as important adjuncts to traditional survey variables. Today, with appropriate confidentiality protections, nearly all large-scale scientific surveys used by demographers gather geographic location of respondents as a natural part of the survey activity. Moreover, following the primary data collection, respondent attributes and location generally are augmented by constructed geographic accessibility variables or complete "layers" of data generated elsewhere—e.g., remotely sensed satellite imagery, soil and hydrographic maps, digital elevation (slope degree and direction), transportation networks and air/water pollution levels. This renewed sense of spatial awareness has catapulted the field of demographic science to a new level—or perhaps one should say, "multi-level." Today, spatial information is as important as individual/household attributes and anthropomorphic/genetic biomarkers. Yet, at most (even the strongest) population research and training centers in the US these activities often remain outside the formal institutional structure.

The Future:

Most major population centers will include in their core research support structures and training programs a well staffed spatial analysis unit with individuals broadly trained and experienced. The skill range of these specialists will go well beyond traditional GIS mapping support to include a diverse array of GI tools, analytic approaches, disciplinary perspectives, and consulting support. These units will vary in focus from center to center, but the demographic research they routinely support will surely include the following:

- √ Spatial-temporal modeling. Space-time modeling and identifying space-time interactions will, of necessity, become routine. These analytic dimensions are inextricably linked. Support activities will include advanced visualization and exploratory analyses using specialized software packages—largely open source—and will be deeply rooted in formal space-time theories, modeling and data.
- √ Bayesian mapping and inference. These will become important because of the increasingly higher dimensionality of demographic research questions and data. Approaches will push beyond their current confinement to mostly spatial epidemiologic settings and applications.
- √ Simulation and computational models. Simulations (e.g., agent-based modeling), network modeling, and other choice-based or outcome-based analyses will become a routine part of spatial demography support activities.
- √ Augmentation of social survey and administrative records datasets with other geospatial layers. This is an established trend, and will surely increase in importance with several new and innovative areas emerging.
- √ A support network will emerge from within the population center community to promote cooperation in spatial analytic developments, share resources, and exchange expertise. This

network will be similar to the long-standing APLIC network of population communication, information, and resource professionals. [See http://www.aplici.org/about-aplic/]

Future Directions for Spatial Demography

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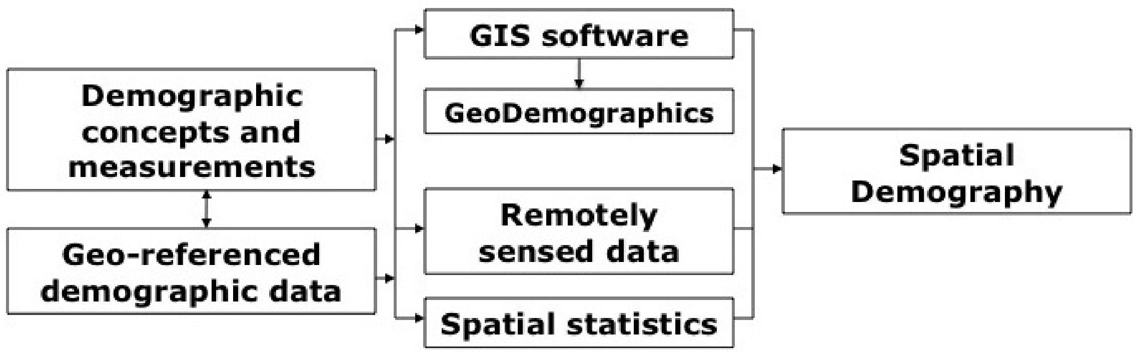
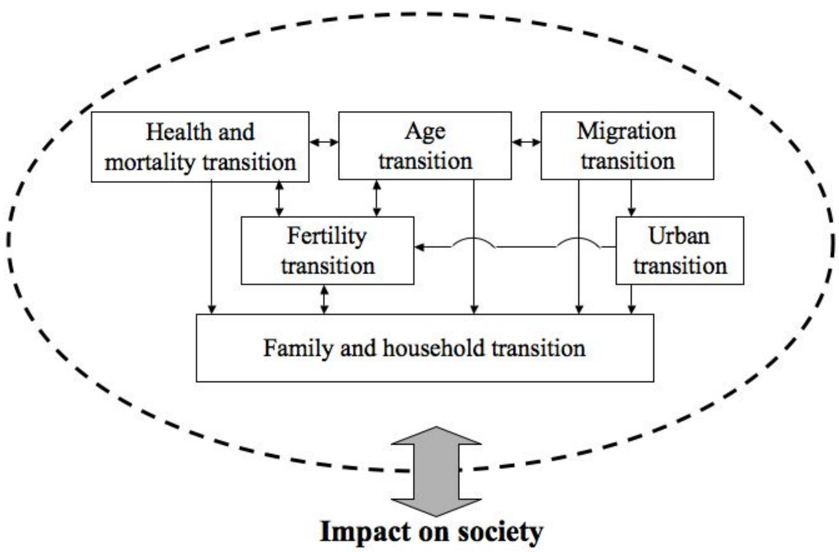
My perspective is that spatial demography needs to move to the point where all of the arrows in the figure below are connected by a substantial body of research:



Source: Figure 4.5 in John R. Weeks, Population: An Introduction to Concepts and Issues. Eleventh Edition (Belmont, CA: Wadsworth Cengage), 2011.

In the process of doing that we will add immeasurably to our overall understanding of the suite of transitions that comprise the demographic transition, each of which has its own spatial pattern:



Source: Figure 3.4 in John R. Weeks, Population: An Introduction to Concepts and Issues. Eleventh Edition (Belmont, CA: Wadsworth Cengage), 2011.

Perspective on Future Directions for Spatial Demography

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In this advocacy statement, I highlight research directions in three overlapping areas where demography/sociology and geography/spatial science intersect: measuring spatial segregation, spatial-analytical issues related to scale in evaluating spatial patterns, and the use of American Community Survey (ACS) data in spatial-demographic research.

Measuring segregation has been one of the main themes in sociological-demographic research since 1950s, if not earlier, when the famous index of dissimilarity (segregation index) was proposed. While a few sociologists, and more recently geographers had pointed out that this index and other popular segregation measures were aspatial in nature, some suggestions have been made. A flurry of publications starting in early 1990s proposed a series of spatial segregation measures, bringing space explicitly into the measurement of segregation mostly through some procedures of spatial smoothing of population distribution. One of the main arguments for developing spatial measures of segregation is that segregation, and some other sociological-demographic concepts, such as environmental justice, have significant spatial dimensions. One fundamental issue is how the concept of segregation should be conceptualized and defined. Different spatial segregation measures have been proposed partly because of the different potential roles that space can play in determining segregation levels. To advance segregation studies, we need to develop a more comprehensive conceptualization of segregation, explicitly recognizing the roles of space in determining segregation levels. Working with sociologists and demographers are critical to reach such a mutual understanding of what segregation encompasses from both the sociological-demographic and spatial perspectives. Ramifications of this definitional issue will become more apparent in later discussions. Such approach in addressing segregation is also applicable to enhance our understanding of other sociological-demographic concepts with spatial dimensions.

As only one segregation value is computed for the entire study region, traditional segregation measures can be labeled as global measures in the spatial statistics parlance. However, segregation levels are not uniform within a study region, and thus segregation levels at the local scale (neighborhood) should be evaluated. Local segregation measures have been introduced and adopted in public health and spatial epidemiology studies as a covariate to explain health outcomes at the neighborhood scale, advancing the study in environmental epidemiology. However, identifying the pathways of spatial segregation to health outcomes is still at its infancy stage, partly due to the fluid and inconsistent definitions of segregation adopted across different studies. How specific spatial aspects of segregation in affecting health outcomes should be elucidated. Similarly, defining precisely the roles of space in spatial demographic issues and concepts is necessary to address various public health issues.

Whether global or local segregation measures are used, these studies are subject to the MAUP. Regardless of how small a "neighborhood" may be, such measures are ecological in nature, inferring individual situations entirely based upon where people live (residential space) and the population mix within the neighborhood. An individual's experience beyond the residential space is completed ignored. Recently, using individual-level data, the activity-space approach have been proposed to evaluate segregation. Given the increasing availability of individual level data through various data gathering efforts, the VGI framework, and the adoption of location-based services, such individual level spatially-encoded data have the potential to support more in depth studies on activity space, and in turn, to assist public health and segregation research beyond the residential space. When individual level data are used, the concept of segregation may be different from using spatially aggregated data. Spatial concepts such as spatial interaction, accessibility and space-time trajectories also need to be considered in (re)formulating the concept of segregation in respect to specific spatial scale.

On the other hand, a common practice is to use spatial autocorrelation (SA) measures to detect clustering. While clustering is one of the dimensions of segregation, the logic is to use SA indices to measure segregation. However, the concept of SA is more general than spatial clustering (is SA sufficient to characterize spatial clusters?), and to what extent spatial clustering is synonymous to segregation needs to be clarified desperately. The literature is somewhat muddle in defining these terms conceptually and in implementation.

While census long-form and short-form data (SFs 1-4) have been the workhorses for supporting sociological-demographic and geographical research, but the appearance of the American Community Survey (ACS) data raised several significant issues. They replace the census long-form data, providing the main source of socioeconomic data in the U.S. now and in the future; data are gathered "continuously" over time but sparsely in space from surveys, and therefore are subject to relatively high levels of error as compared to decennial census data. Although ACS data became available several years ago, and sociologists, demographers and planners have started using them, geographers have been slow in adopting ACS data partly due to several issues mentioned above. Many social scientists and public health researchers are accustomed to using survey data, but GIScience and spatial analysis literature is relatively sparse in the handling of survey data.

Using ACS data in geospatial research and GIS encounters quite a few challenges, including the incorporation of data quality information in all aspects of using ACS. Tools in GIS have been developed recently to facilitate the incorporation of error information in mapping and determining if estimates are significantly different. Nevertheless, more geovisualization and spatial analytical tools are needed for a fuller utilization of ACS data in spatial demography. One issue of using ACS data in geographical research is missing data, as many data products do not have complete geographical coverage. Another major impediment is the relatively high levels of error, which, to some extent, is a function of geographical scale. Smaller areas tend to have larger errors. Thus, to facilitate the geographical use of ACS data at the local or neighborhood scale may involve data manipulations along the spatial dimension, and the development of new spatial analytical techniques. Experience we learn from using ACS data in spatial demographic research should be transferrable to the handling of other survey-based population data, such as the CPS.

Future Directions in Spatial Demography

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The field of spatial demography should endeavor to create new data collection, analysis, and visualization tools suited to the increasing availability of immense, high-resolution spatial datasets. The field should use theory from biology, anthropology, economics, and sociology to address fine-grained patterns of individual spatial movement and association, and the emergence of aggregate patterns at the household, community, and population levels. To meet these challenges, enhanced cooperation between computer scientists and social scientists is needed, as well as a greater emphasis on teaching spatial statistics, computer science, and demography within social science disciplines.

The Need for Innovations in the Measurement of Community Contextual Features

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Challenges to Collecting Detailed Community Context Data

Spatial data on community context is an increasingly important part of social, behavioral, and medical studies. These data are designed to capture aspects of a respondent's surrounding at a level of measurement above the single individual. There are several challenges, however, that impede the collection of accurate, spatially-explicit community context data.

First, precise spatial measures of community context are challenging to collect particularly in settings where comprehensive number address systems are not used. In developing countries, places are often identified simply by village, neighborhood, or district name. Thus the location of important community features, such as schools, places of employment, or health care facilities are collected with relatively low precision. Similar challenges emerge in rural and remote areas of developed countries resulting in poorer quality data for some groups, such as Native Americans, than others (Wey et al. 2009). Contextual data in these settings are often reduced to a dichotomy (does the village have the feature or not) or a general radial measure of distance (how far away is the nearest feature). Not specifying a precise geographic location creates additional measurement error because respondents must not only cognitively recall the feature in question, but they must also estimate physical distance or travel time to the recalled feature: a task that has high error (Horning, El-Geneidy, and Krizek 2008). The potential errors in these tasks are further compounded when respondents are asked to recall retrospective contextual data.

Second, because of the cognitive difficulty and time it takes to recall contextual features in settings that do not use numeric address systems, researchers often use a group of informants to increase recall and breadth of information. While this approach may result in reasonably comprehensive data, the resulting community measures may not actually reflect the exposure of any one individual to various contextual features: e.g., the informants may precisely locate the school nearest the community, but it remains unknown which community members actually use that specific school. This potentially creates mismatch when community-level data are merged with data from individual respondents.

The third challenge is that approaches have not taken full advantage of the visual cues or maps that are likely to increase respondent spatial recall. Maps are one of the most important visual aids for cuing the recall of spatial memory, but using maps in the field in developing settings is challenging. To identify features such as individual buildings, roads, and landmarks on satellite imagery, a very high level of resolution is needed: better than 2 meter/pixel resolution. It is not feasible to bring a complete set—at multiple zoom levels—of printed maps to an interview, page through them, and record a location identified by respondents.

The Need for Detailed Community Context Data

Although highly precise community context data are usually not collected in most developing settings, there are several reasons why these precise spatial data are needed. First, previous studies have reported strong associations between community context and individual outcomes, while others have found weak or no influence of community context, even when these associations have been strongly predicted by theory (Sastry & Pebley, 2010; Crowder & South, 2011; Wodtke et al., 2011). Imprecise measurement may be a contributor to these unexpected findings. The community context may not have been reported accurately by respondents or informants, or the context reported by a group of informants many not represent the context as experienced by an individual. The latter possibility is particularly problematic: while misreporting the distance to a local school by 400 meters, for example, is likely to introduce merely random measurement error, there could be severe biases if the school reported by a group of informants is not accessible to a respondent whose is matched to that community context measure. Perhaps the respondent is not wealthy enough or a member of the ethnic groups served by the most proximate or most frequently named school. In this case, the group nominated school is a poor indicator of the educational resources used by various economic or ethnic groups within the same community. Without detailed measurement, mechanisms such as proximity to contextual features (Barber, 2004) cannot be differentiated from actual participation in those features.

The second reason why precise community context data are needed is because new spatial methods are increasingly used to examine how the context of individuals' lives is associated with behavioral outcomes. These methods require detailed information on where each individual participates in various domains of activity, such as consumption, education, production, and recreation. Calder et al. (2011) used the detailed location data in the LAFANS to create a spatial map of individuals' "activity space." This allows a broader conceptualization of community context, because it is not necessarily tied to the respondent's home (Kwan et al., 2008). Inagami, Cohen, and Finch (2007) argued that ignoring exposures to community features outside an individual's immediate neighborhood may bias estimates of associations between neighborhood characteristics and health outcomes. This work expanding the conceptualization of context has mostly been conducted in developed settings due to the high demands of the spatial data, but there is reason to believe these same processes are occurring in rapidly developing settings characterized by increasing geographic mobility.

Innovations to Address These Challenges

We have been developing a project over the past 2 years whose aim is to collect better measurement of community context data. We use two innovative approaches: respondent-focused computer-assisted interface (CAI) design and efficient field-based GIS.

Respondent-focused design. We design the interface so respondents can collaboratively complete the community context instrument with the interviewer. We created a human-computer interface based on a multi-touch display, which has been shown to be superior to mouse and keyboard for collaborative work (Forlines et al., 2007; Cooperstock et al., 1997).

Efficient field-based GIS. Our respondent-focused interface requires complex GIS operations and visualizations. The traditional way to accomplish these complex GIS tasks is high performance software (ArcGIS), but these applications are not feasible for notebooks to process and visualize spatial data in real time. Instead, we use application frameworks that have been developed to offload processing from the field notebook to remote infrastructure (sometimes called "cloud computing"). The notebook is simply an input and visualization device.

In July and August 2010, we tested the instrument in the study area of the Chitwan Valley Family Study (CVFS). The aims of the pilot were to test how respondents could use the interface and recall where various contextual features were located using their spatial memories. Almost all respondents successfully completed the collaborative interview and precisely located contextual features on the tablet. The nearly universal success using the instrument is also encouraging given their backgrounds: education ranged from 6 to 16 years, and fully 35% had *never* used a computer before in their lives. We don't want to over interpret this finding, but perhaps the respondent-focused interface design is able to meet the needs of nearly all users; and/or visual overhead satellite imagery provides powerful spatial memory anchors that are useable even among those with little exposure to technology.

Future Steps

As we further develop and refine our techniques, we hope to conduct a formal comparison between our instrument and a different mode of data collection, such as a paper-based instrument or one that does not use maps. Our recent research is only one approach to collecting highly detailed measures of community context, but it is likely that any solution will need to draw upon novel combinations of mobile field technology and spatial visualizations that are easily understood by non-expert respondents.

Future Directions in Spatial Demography

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Trained as a macro-demographer with a strong training background in spatial statistics and mortality research, I am particularly interested in the questions of what new methodological developments in spatial analysis are possible in the near future, and how these new developments evolve from current mainstream spatial demography. I prepared this document to briefly discuss the limitations in current spatial analysis methods and development in spatial data, respectively. Drawing on these discussions, I will answer the two questions above by elaborating on the future challenges facing macro-demographers.

The essence of demography is to study the collective, rather than individual, behaviors [1]. As such, demographic changes and questions have traditionally been studied using data aggregated to various geographic units (e.g., counties and states), which is considered a macro-demographer's perspective [2]. However, this paradigm has been affected as a better understanding of ecological fallacy has made it clear that results gained from areal data analysis cannot be used to make any inferences about individuals [3]. Indeed, such conclusions may also vary considerably based solely on the levels of aggregation [4]. Micro-demographers, who emphasize individual behaviors, have since come to outweigh macro-demographers in the demographic literature [2]. More recently however, the resurgence of spatial demography has reinvigorated macro-demographers [5, 6], fueled by growth in the diversity and availability of spatial analysis tools and data [7].

Since the late 1990s, macro-demographers have benefited from the development of user-friendly spatial analysis tools [8, 9] to conduct complex regression models where spatial structure is considered. Numerous research projects were focused on enhancing the capability to conduct explanatory statistical analyses, such as GeoDa [10], packages in R [11, 12], and GeoBUGS [13]. These software programs share two methodological features. **First**, influenced by the first law in geography [14], the explanatory regression models offered in these programs attempt to tackle the issue of spatial homogeneity (dependence) and overlook spatial heterogeneity (non-stationarity). The emergence of geographically weighted regression (GWR) by Fotheringham et al. [15] has given macro-demographers cause to reflect on the conventional one-model-fits-all approach. **Second**, the ability to incorporate a temporal dimension into regression models is limited. While some developers have endeavored to address this issue, most space-time analyses are exploratory or descriptive, such as STARS by Rey and Janikas [16] and disease mapping techniques [17].[1]

[1] It should be noted that CrimeStat by Levine, is able to conduct some spatiotemporal analyses, but its focus is on geographic locations, rather than the features associated with the locations. This is why CrimeStat is not discussed.

The availability of spatial data at different geographic levels also contributes to the expansion of spatial demography and allows researchers to connect social conditions with a range of demographic phenomena [5]. Since 2010, the US Census Bureau has begun to release the American Community Survey (ACS) five-year estimates, a rolling survey that provides the most current information on population and communities. More explicitly, the demographic, economic, housing, and other important social variables will be available from the ACS on an annual basis and the geographic resolutions can be broken down as low as the block-group level. Many Federal agencies have already maintained their demographic data in a similar fashion. For example, the National Center for Health Statistics provides mortality data that can be summarized into county-level every year [19], and the Federal Bureau of Investigation [20] released crime records at various geographic levels (e.g., counties, cities, and states). Before the ACS five-year data are available, the major source of quantitative information on the social conditions of an area is the decennial census. Many population studies are constrained by being forced to use the data around census years (e.g., 1980, 1990, and 2000). It is foreseeable that macro-demographers will attempt to combine the information from ACS five-year estimates and various demographic phenomena (e.g., mortality) to construct a spatiotemporal dataset and hence the demand for a space-time explanatory data analysis tool would arise.

The discussion above reveals two methodological challenges in spatial demography. The more pressing of these is to develop a user-friendly program that implements spatiotemporal dynamic models. Specifically, the space-time data structure will lead macro-demographers to explore how the variable of interest (e.g., fertility) varies across time and space simultaneously, or to investigate whether there is a spatiotemporal lagged effect of a certain independent variable on the demographic outcome. The spatiotemporal process underlying the new types of data will not only help macro-demographers to better understand how a demographic phenomenon is associated with a set of social variables, but also provide micro-demographers insight into what spatiotemporal context matters most. While the spatiotemporal dynamics have increasingly drawn spatial statisticians' attention [21, 22], macro-demographers have not prepared, or at least not equipped, for a comprehensive investigation on space-time interactions in population studies. The proliferations of data that are spatially and temporally indexed would inevitably call for sophisticated spatiotemporal dynamic modeling.

The other challenge is to further embrace spatial heterogeneity into the spatial analysis landscape that is currently dominated by spatial homogeneity. While both spatial non-stationarity and dependence are unique characteristics of spatial data, relatively little attention has been paid to capturing the influence of non-stationarity in model implementation. These two features are not mutually exclusive [23]. Contrarily, spatial dependence and non-stationarity inform each other methodologically and empirically. Using the kernel density function, local spatial modeling (for heterogeneity) assigns more weights to the observations that are closer to the focal point. This is the process by which spatial dependence helps to explore non-stationarity. On the other hand, the non-stationary process may be found by visualizing the residuals obtained from the global modeling approach (e.g., OLS). If ignoring the non-stationarity and using global spatial models to account for homogeneity, the analytic results may be biased due to model misspecifications and the spatial process would be misinterpreted [24]. While some efforts have been made to create a general spatial analysis framework [25], the development in this area is still in its infancy. As the goal of macro-demography and spatial analysis is to account for all possible spatial processes in the data, taking both spatial dependence and non-stationarity into account would be necessary.

In sum, from a macro-demographer's perspective, in the near future, the spatiotemporally dynamic data on population structure and social conditions will challenge spatial demographers to integrate time into research questions and to develop useful tools to address these space-time issues. Moreover, the past methodological development in spatial analysis heavily relies on spatial homogeneity. The recent growth in local modeling, such as GWR and spatially varying models [15, 26], has led spatial demographers to rethink the existing spatial analysis structure and the need for a balanced approach to both spatial dependence and non-stationarity.

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Specialist Meeting

The organizing committee is chaired by
Michael F. Goodchild (UCSB)
Donald Janelle (UCSB)
Stephen Matthews (PSU)

Future Directions in Spatial Demography

December 12–13, 2011
Upham Hotel, Santa Barbara, CA

Objectives

Although spatial thinking and the use of new forms of geospatial data have grown rapidly in the social sciences, their implementation in the demographic sciences has lagged. This meeting will bring together specialists from demographic and health research, spatial statistics, and GIScience to discuss challenges and new directions for spatial demography. The objective will be to identify and define gaps in current knowledge regarding innovations in geospatial data and spatial statistical methods, including the integration of data and models. An overarching goal will be to prioritize a research agenda to enhance the science of spatial demography in population and health research.

Meeting structure

This 2-day specialist meeting is organized by the **Center for Spatial Studies** (http://spatial.ucsb.edu) at the University of California, Santa Barbara (UCSB) and the **Population Research Institute** (http://www.pop.psu.edu) at Pennsylvania State University (PSU). The meeting will include invited plenary presentations by experts on the state of the science of spatial demography, emergent geospatial data and measurement issues, and spatial modeling. Smaller breakout sessions will facilitate intellectual exchange on the core conceptual, data-related, and methodological issues that arise from the plenary sessions.

Specific questions to be addressed include:

- How are demographers measuring place and the interrelationships among places?
- How can demographers harness emerging developments in the generation of geospatial data (e.g., volunteered geographic information and crowd-sourced data)?
- How can new measures be validated for use in neighborhood and contextual research?
- What visualization and spatial analytical methods make up the current tool kit of the spatial demographer? What new methodological developments in spatial analysis are possible in the next five years and how might these be integrated into mainstream demographic research?
- What are the training challenges to the enhancement of future research in spatial demography?
- What research priorities will best advance the applicability of spatial demography to address issues in reproductive health, population health, and other areas of societal need?

Subject to approval, limited funding for travel and accommodation costs will be available to invited participants. Further details about this meeting will be posted at http://ncgia.ucsb.edu/projects/spatial_demography.

Call for Applications

To respond to this announcement, please send a 2-page résumé and a 2-page position paper discussing your interest in these issues to Stephen Matthews (matthews@psu.edu) by Sept. 30, 2011.
Based on an open call for applications, approximately 30 researchers will be invited to participate.
Participants will be selected by the organizing committee and notified by Oct. 15.

Population Research Institute
Population GIScience UCSB
Center for Spatially Integrated Social Science

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See http://www.csiss.org/GISPopSci

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