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Editorial

Capturing context: Integrating spatial and social network analyses☆

> "[The] Chicago [School] felt that no social fact makes any sense abstracted from its context in social (and often geographic) space and social time. Social facts are *located*." (Abbott, 1997, p. 1152, emphasis in original)

Social processes take place within particular contexts. In recent years, the nature of those contexts, the dimensions that define them, and their effects on social processes have (re-)gained attention among social and behavioral scientists. Researchers employing social network and spatial analytic strategies in particular, have contributed important insights to social phenomena in relational and physical contexts. Despite these recent developments, many of the core ideas underpinning this importance of contexts for social processes can be traced to a century, or more, ago (Park et al., 1925; Snow, 1854; Wirth, 1928; see also Abbott, 1997).

Approaches to investigating relational and physical space demonstrate strong conceptual overlap. For example, while actors who are closer together tend to exhibit greater similarity than those who are further apart, this pattern carries different labels (e.g., network homophily or spatial autocorrelation) from researchers focused on relational versus geographic distance. Furthermore, when that similarity is the result of a direct transmission process, we know that closeness facilitates transmission (Rogers, 1995; Strang and Tuma, 1993; Wejnert, 2002). However, the media for transmission and the units used for assessing "distance" differ for physical (e.g., feet across which an airborne pathogen can travel) or social (e.g., number of intermediaries through whom a message can be accurately passed) space. This example highlights the ways that the context-focused methods underpinning spatial and network analyses specifically focus on the dependencies among actors. Despite these conceptual overlaps, the formal integration of social network and spatial analytic strategies remains relatively underdeveloped in the literature.

We therefore organized this special issue to examine the intersection between these two approaches. With this introduction we address three key aims: (1) to conceptualize the possible ways social network and spatial analysis could be combined, (2) to describe what has been accomplished at this intersection – both through the articles in this issue and elsewhere, and (3) to identify potential future directions for advancing their integration.

Possibilities for integration

Recent developments in network and spatial analyses have significantly enhanced our understanding of how each of these contributes separately to social processes. Advances in computing technology – both hardware and software – have improved capacity for accessing and formally analyzing large scale network and spatial data. Important theoretical and methodological contributions have reshaped our understandings of both approaches. Consequently, more researchers are gathering information about social networks and geographic positioning. Furthermore, the recent development of statistical models for both network and spatial data has allowed for more rigorous examination of commonly observed patterns. The juxtaposition of these recent advances lays the groundwork for the formal integration of network and spatial analytic strategies.

We identify and briefly describe five conceptual strategies for their integration, then we draw on previous literature and the papers in this special issue to comment on the state of efforts toward each aim. The possibilities we discuss are the ways: (1) spatial locations influence social networks, (2) social networks influence spatial location and environments, (3) social and spatial boundaries can be contextually defined, (4) integrated measures of networks and space can be constructed, and (5) combined network and spatial effects can produce social, behavioral or health outcomes and patterns.[1]

Spatial effects on social networks

Perhaps the best-known relationship between spatial and network characteristics is that people who are located closer together in physical space have a higher probability of forming relationships. This *propinquity* effect was first identified by Festinger et al. (1950). While this pattern holds across a wide range of samples and time periods, recent work explicitly examines the form of that relationship, whether and how it operates differently across multiple scales or social relations, and how readily different actor types exhibit the tendency.

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[1] A sixth that we do not address, but has been comprehensively addressed elsewhere in the literature, is networks of ties among spatial elements. For a review see Barthelemy (2011).

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In this special issue, the papers by Daraganova and colleagues and Preciado and colleagues are concerned with identifying the exact form relating spatial proximity to tie probability – known as the "distance interaction function" or "spatial interaction function." A number of features of the spatial interaction function are especially important for understanding how social networks are associated with spatial proximity. First, the baseline probability describes the tie probability for actors at zero distance from each other. For some relations (such as acquaintance) one might expect this probability to approach 1, but for other relations (such as exchange of resources that differ in geographic availability) the baseline probability of a tie might be quite low. Second, the specific function (for example a power law or an exponential decay function) models how tie probability decreases with distance (for example, whether probability declines slowly or precipitously) and the probability of ties at very long distances.

Networks within populations over varying spatial scales may also exhibit dramatically different patterns of tie formation with respect to spatial distance. Articles in this special issue reflect some of these possibilities, with articles that focus on tie formation within single, small, well-bounded populations such as offices (Sailer and McCulloch; Doreian and Conti), to much larger scales such as global twitter networks or residentially mobile populations (Takhteyev et al.; Viry). Furthermore, given the limitations of existing data that include both social networks and spatial locations, it is often difficult to observe those relationships directly. In response to this problem, Butts et al. attempt to estimate the potential network implications of a given spatial interaction function from more readily captured population patterns, such as population density.

Finally, the decay of tie probability with increasing distance applies not only to individuals, but to other actors as well. The article by Lomi and Pallotti demonstrates how similar processes shape the likelihood of collaborative ties among organizational "actors."

Social networks and the selection of place

Social networks are both a motivation and a means for the selection of the places people inhabit. Even as individuals around the globe become more mobile, we are drawn to the people and places we know (Ioannides and Zabel, 2008; Krysan and Bader, 2009). The connections among people within a place can help us interpret spatial arrangements (Grannis, 1998) and can shape future spatial patterns and social relationships – e.g., health or access to resources (Blacksher and Lovasi, 2011; Macintyre et al., 2002). The paper by Verdery and colleagues in this issue adds to this literature by demonstrating the strong – but highly variable – influence that kinship relationships have on the spatial arrangement of housing locations within a large sample of villages in rural Thailand.

Network and/or spatially bounded populations

A common problem for network studies is to determine the boundaries for the population under study (Marsden, 2011). Similarly, for spatial analyses, researchers must decide how to identify which portions of a physical location will be included for analysis (Amrhein, 1995; Flowerdew et al., 2008; Lee et al., 2005; Openshaw, 1984). While a variety of strategies exist for identifying boundaries (e.g., organizational membership for network studies or administrative boundaries for spatial analyses), often these boundaries limit observation of the study population, or might inappropriately align with real social units. The combination of network and spatial analytic approaches offers an alternate strategy, as demonstrated by Hipp and colleagues' use of peer network structure to identify neighborhood boundaries.

Co-integrated measurement of network and spatial analytic concepts

When researchers examine network and/or spatial effects, there are frequently substantial theoretical and empirical reasons to presume that each influences the other. Thus, modeling one independently of the other could lead to improper conclusions. To date however, few methods have been developed for providing "spatially informed" network measures or "network-informed" spatial measures. In one exception, Expert et al. (2011) developed a technique for identifying network community structure that factors out the contributions of space. One approach is to use relatively standard measures from one perspective, weighting their calculation according to information about the other – e.g., weighting the calculation of betweenness centrality by the physical distance between nodes (Brandes, 2008). It therefore remains an open question whether simple juxtaposition or weighting of standard measures – or other similar minimal alterations – can sufficiently account for the important ways in which these approaches influence each other or whether new, truly integrative, measures will be necessary or desirable. One approach, employed by several papers in this special issue is to incorporate spatial covariates into statistical models for social networks to examine their separate and joint effects (Daraganova et al.; Preciado et al.; Schaefer). Further answers to these questions will likely develop as research increasingly turns to the sequence of social and spatial processes influencing each other and their joint contributions to a range of subsequent outcomes among longitudinal study populations.

Multiple context influences on outcomes

The final aspect of integrating social network and spatial analytic approaches addresses their potential influence on other outcomes of interest – e.g., social networks can identify processes that promote or constrain the dissemination of ideas or pathogens through populations (e.g., Morris, 2004; Rogers, 1995), and spatial and environmental characteristics can substantially alter population health behaviors and outcomes (Mujahid et al., 2008; Pope et al., 2009; Rundle et al., 2008). Moreover, these processes can potentially influence one another, derive from similar sources and mediate or moderate the effects of the other. For many researchers concerned with aspects of health, crime, demographic events and other related outcomes, the ultimate utility of rigorously combining network and spatial analytic strategies lies in the possibility that such an integrated approach may better explain outcomes. Here, Mennis and Mason examine how spatial and social networks combine to influence adolescent substance use.

Contents of the special issue

Roughly half of the papers included in this issue come from participants in two conferences: the "Capturing Context Conference" was held at Columbia University in June 2009, and the "International Workshop on Social Space and Geographic Space" was held at the University of Melbourne in September 2007. The discussions that these conferences offered, and the articles presented here, describe some of the important recent advances for integrating network and spatial analytic work, and should serve to spark future efforts to further explore their integration.

The paper by Daraganova et al. focuses on two issues: determining the specific form of the relationship between geographic distance and the probability of a tie between a pair of individuals, and examining the extent to which endogenous social network factors affect tie probability even after accounting for the effect of spatial proximity. The data in the paper come from a two-wave snowball sample of individuals. Individual's residential locations were recorded by noting the name of the street, the type of street, and the suburb of the residence. Since street addresses were not recorded, individuals were randomly assigned a street number, which was then geocoded. Distances between individuals were calculated as the Euclidean distance between their assigned locations. Network data consisted of responses to two questions: "who are you close to?" and "with whom do you discuss employment matters?" The authors then use a series of models to investigate the form of the distance interaction function, considering versions of power laws, attenuated power laws, and an exponential decay function. They find that the best model is an attenuated power law with baseline probability equal to 1. They then use statistical models that include both spatial and network effects and find that even after accounting for spatial proximity, endogenous network effects are important in explaining interpersonal tie probability, and these network effects are robust to omission of spatial effects.

Preciado et al. use a three stage modeling strategy to investigate the functional form relating spatial proximity to adolescent friendship and the effects of proximity and other institutional factors on the existence, creation, and maintenance of friendships. Their data consist of three waves of friendship nominations among adolescents in a Swedish town. Student's household locations were geocoded and distance calculated as the linear distance between households. In contrast to Daraganova et al., Preciado et al. use a nonparametric approach to estimate the form of the relationship between proximity and tie probability and find that the logarithm of distance provides the best fit to the log-odds of friendship. This function is then approximated using logistic regression. Finally, they use stochastic actor oriented models to examine how distance and other factors affect friendship existence, creation, and maintenance through time. They find that for this sample of adolescents, distance is more important for friendship existence and creation than for friendship maintenance, and the log odds of friendship existence and maintenance are modeled well by a smooth function of log of distance. With respect to context, they find that the distance effect on friendship is stronger when students do not attend the same school than when they do. Like Daraganova et al., Preciado et al. also find that network structural effects are important in accounting for friendship, even when distance is included in the model.

Doreian and Conti likewise explore the degree to which spatial arrangements constrain social interactions. They present 5 scenarios: alliance and conflict in the Bank Wiring Room, friendship formation in a police academy, a communication network unfolding during the response to a small tornado, warfare among the Gahuku-Gama sub-tribes of New Guinea, and trading relations along the Dalmatia coast. A range of social network analytic tools are deployed, including sociograms, matrix arrays, block modeling, quadratic assignment regression, and exponential random graph models. They focus on fixed spatial arrangements and changing social networks, but note the need for temporal data on spatial contexts as well. The clear message across examples is that spatial proximity and location influence the formation and nature of social ties, but more subtle and provocative points are made on the implications of adjacency that vary across different types of ties and different types of actors.

Sailer and McCulloh focus on how spatial proximity influences social interaction in the relatively constrained spaces of four formal organizations, with a variety of physical office configurations. Rather than using Euclidean distance to measure spatial proximity, Sailer and McCulloh explore other ways of capturing spatial distance as provided by "Space Syntax". They examine which method of capturing the distance between actors more readily accounts for the likelihood of observing social interaction between actor pairs. Using a series of exponential random graph models, the paper identifies the best way of accounting for spatial distance, and estimates whether office layouts have an independent effect on tie formation beyond other conceptualizations of proximity. For three of the four studied cases, they find consistent propinquity effects, and that "metric distance" – or the shortest possible walking distance between pairs – best captures that effect.

Viry's article examines the influence of prior residential mobility on the size, composition, spatial dispersion, triadic closure and level of support provided in later-life social networks. The paper draws from data on a national probability sample of adults from Switzerland to examine these varied relationships. The analyses find that neither prior mobility nor the distribution of alters influences the amount of social support received. However, more mobile actors demonstrated greater geographic separation and higher transitivity among their named alters than those who were previously less mobile.

Takhteyev and colleagues sample dyads of Twitter followers to examine how readily spatial proximity predicts Twitter "follower" ties. As with other examples in this issue, they find both that distance matters for the probability of observing a tie and that simple Euclidean distance is not the best way to account for that relationship. While many have postulated the Internet as breaking down traditional barriers to social interaction, consistent with previous empirical work on this question (including some by these authors elsewhere), face-to-face and online interaction appear to remain closely intertwined. In fact, in this case, the availability of airline travel between destinations is the most efficient operationalization of the propinquity effect on the probability of Twitter ties.

Spatial distance has the potential to serve as a powerful deterrent to social tie formation. This premise has allowed Butts and colleagues to infer the social structure of metropolitan areas throughout the US. Population census data at the block level reveals a topography of varying population density within micropolitan and metropolitan areas. If proximity is a key determinant of friendship, population density should predict greater local degree and connectivity of a friendship network. A simulation study is used to explore the consequences of real population distributions given a fixed "spatial interaction function" that specifies the probability of a tie conditional on geographic distance between individuals. A stratified sample of 16 micropolitan or metropolitan areas is generated, representing a wide range for both population size and density. Block-level census data are then deployed to examine the implications of local density variations and modeling choices for network structure. This paper rests on a parsimonious set of inputs and assumptions, setting the stage for further exploration of how other factors play out against this landscape to influence network ties.

The article by Lomi and Pallotti examines predictors of patient transfers among hospitals in the Lazio region of Italy. Accounting for hospital characteristics and sender/receiver effects – including overall patient load and the variation of specialties represented in individual hospitals and potential transfer dyads – the authors find strong independent effects of both spatial and endogenous network parameters on the probability of inter-hospital patient transfers. They find a propinquity effect, but also find that spatial "competition" (as represented by the degree of overlap in potential patient pools) significantly increases the likelihood of patient transfer between two hospitals.

Verdery et al. use data from 51 villages in rural Thailand to investigate the association between kinship networks and residential proximity. Their data consist of extended kinship networks constructed from spouse and parent–child relationships along with residential locations (geocoded from GPS measurements). Data were collected as part of complete household surveys in each village. Their analysis takes both a system level perspective by examining extended kinship groups and a dyadic perspective looking at pairs of individuals at different levels of kinship closeness. From both perspectives, closer kin tend to reside nearer to one another than do more distant kin, though household co-residence accounts for much of the effect. In contrast to many articles in this special issue that view social relations as conditioned by geographic proximity, it seems likely that, to a large extent, residential proximity in these rural villages is the result of kinship relatedness, as people consider proximity to kin in making their residential decisions. In addition, the association between kinship and dwelling unit proximity holds in some of the 51 villages but not others, providing a cautionary note for network case studies.

Social connections may in turn inform the definition of spatial units, as highlighted by Hipp and colleagues. They articulate the conceptual link between social network structure and neighborhood definitions, then set out to create and describe network-informed neighborhood boundaries. Adolescent social ties are used as a proxy for the larger set of social network ties that would ideally inform the neighborhood definitions. Social connections are used to effectively reduce the "distance" between neighbors. The validity of the resulting neighborhood set is assessed via agreement (high ICC) among residents about neighborhood characteristics (physical disorder, crime, cohesion, etc.), and the authors conclude that the network-neighborhoods surpass more standard approaches based on administrative boundaries (census block group or tract) or physical distance alone.

Schaefer reveals how social network ties can enhance an understanding of geography in a different setting. Co-offending ties from juvenile arrest records are used to inform the investigation of social relationships tying administratively defined neighborhood units (census tracts) together into a larger community structure. Co-offending is more likely between census tracts that are closer geographically or within the same school district, as well as between tracts that are more similar socially (e.g., based on racial composition or prior juvenile criminal activity). Intriguingly, the two spatial predictors appeared to offer more explanatory power than the five indicators of social similarity. The salience of spatial relationships is also reflected by the largely contiguous communities detected using a Spin Glass algorithm. This focus on the ties among adjacent neighborhoods brings research on criminology to a scale that has received limited prior attention, and challenges assumptions sometimes held in the broader neighborhood effects literature that neighborhoods represent independent observations.

Juxtaposing social connections and spatial contexts, Mennis and Mason highlight their joint relevance to understanding substance use. This investigation uses non-residential activity spaces alongside home neighborhood, drawing attention to the ways that social behaviors and spatial settings can coalesce to influence the individuals involved. Results show that neighborhood concentrated disadvantage and social interactions in high-risk locations predict adolescent alcohol and drug involvement. The strength of both observed associations increased with age, and this parallel pattern of effect modification by age suggests that both types of contexts may be particularly salient to older adolescents as they gain independence.

Directions for future research

Previous literature and the articles in this special issue provide several potential avenues for further integration of network and spatial analytic strategies. We conclude this introduction by highlighting avenues that may prove especially fruitful.

First, the advances presented here provide additional motivation for future collection of network and spatial data. The articles in this special issue vary in their approaches to measuring spatial location and quantifying spatial proximity between units. Global positioning systems and electronic tracking devices readily record locations, and clever survey questions can elicit residential or other locations (neighborhoods, streets and cross streets) when precise locations are not required. Future data collection efforts should heed the detailed advice presented elsewhere (Cressie, 1993; Marsden, 2011), along with accounting for the considerations mentioned above. For example, the form of the spatial interaction for a specific kind of social relation informs the range of distances over which proximity matters, and how it matters and influences the potential utility of their combination. Even in the absence of information about social ties and locations for an entire population, information about the spatial interaction function, in combination with population densities for a region, can go a long way toward modeling the spatial distribution of social ties. Also, we may need to widen studies' population boundaries to gather information from people who are socially connected *and/or* geographically proximate (Lovasi et al., 2010). Adding geographic data to a social network study may be insufficient when it unnecessarily excludes unconnected but proximate people to compare with network alters. Likewise, adding social network data to a geographically bounded study may lead researchers to miss people outside of the immediate vicinity who are nonetheless important social contacts.

Second, the combination of spatial and social network information allows investigation of the effects of each on the other and on outcomes of interest. Several papers in this special issue found that both spatial proximity and social relations mattered. And perhaps more importantly, they were not substitutable. Further investigations should provide insight into exactly how these different proximity effects operate.

Third, there are possibilities for further development of analytic approaches that integrate spatial and social factors. A number of the papers in this special issue incorporated spatial covariates into statistical models for social networks (Daraganova et al.; Preciado et al.; Schaefer) and others looked more descriptively at associations between spatial and social relations (Verdery et al.). Few papers incorporated both space and social networks into novel measures of social concepts. The paper by Hipp et al. on neighborhood definitions provides an example. However, whether or not it is useful to integrate spatial and social proximity in the definition and explanation of other social concepts remains an open question.

Finally, time is largely absent from the discussion above. Recent modeling developments have significantly extended our understanding of dynamics in and on networks (Moody, 2002; Snijders, 1996). Likewise, longitudinal spatial data provide new opportunities to understand the temporal evolution of people's interactions with their physical contexts (Diez-Roux, 2007; Rainham et al., 2010; Wheaton and Clarke, 2003). Thus, a key element for integrating spatial and network analyses will be to consider how relationships evolve through time, highlighting ways that the dynamics of these processes compare to the (largely) static understandings established to date.

Moving forward, the joint study of spatial and social networks is complicated by the need to protect human subjects and their confidentiality, and by the potential for bidirectional causation. The need to consider processes unfolding over time at multiple scales – from interpersonal to organizational – further complicates the picture. Nonetheless, the potential for increased understanding through capturing context more completely makes the incorporation of spatial and social network analyses into study design and analyses worthwhile.

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