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Reimagining GIScience for relational spaces

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Abstract

A mismatch between largely absolute Newtonian models of space in GIScience and the relational spaces of critical human geography has contributed to mutual disinterest between the fields. Critical GIS has offered an intellectual critique of GIScience without substantially altering how particular key geographical concepts are expressed in data structures. Although keystone ideas in GIScience such as Tobler's "First Law" and the modifiable areal unit problem speak to enduring concerns of human geography, they have drawn little interest from that field. Here, we suggest one way to reformulate the computational approach to the region for relational space, so that regions emerge not through proximity in an absolute space or similarities in intensive properties, but according to their similarities in relations. We show how this might operate theoretically and empirically, working through three illustrative examples. Our approach gestures toward reformulating key terms in GIScience like distance, proximity, networks, and spatial building blocks such as the polygon. Re-engaging the challenges of representing geographical concepts computationally can yield new kinds of GIS and GIScience resonant with theoretical ideas in human geography, and also lead to critical human geographic practices less antagonistic to computation

Keywords

critical GIS; relational space; regions; distance

If a critical GIS is to become more relevant to wider audiences in geography and beyond, it will not only be for its intellectual critique of GIS, but also for its commitment to changing practices of GIS, to "doing GIS" differently (Schuurman and Pratt 2002; Wilson 2015). Here, we explore how small shifts in the approach to key geographical concepts such as region, distance, relations, and the observer can lead to more productive dialogues with broader swaths of contemporary geography than computation can presently engage.

We find inspiration not only in critical human and process-relational geographies, but also in quantitative geographical work that was *not* meaningfully antecedent to contemporary GIS. GIS has been successful in developing the intellectual and technological infrastructure of

instrumental map-making and of ever more accurate representations of the world within absolute space. Today, the type of “geographic information” that mainstream GIS approaches embody consists of objective descriptions of individuated entities referenced within the coordinates of an absolute, Cartesian space (Goodchild et al. 2007; for other approaches, see Miller and Wentz 2003; Bergmann 2016a). Yet geographers of the quantitative revolution had also pursued a “theoretical geography” built on a “meta-cartography” that recognized many approaches to representing geography (Bunge 1966). They found multiple perspectives on underlying process-relational geographies by bending traditional maps beyond the point of breaking (Tobler 1961). Early quantitative spatiality drew on many sources such as Hägerstrand's (1957) migration geographies, Thompson's (1917) morphometrics, and Lynch's (1960) mental mapping of the city. In these settings, a major quantitative textbook could suggest that, “The shift to a relative spatial context is still in progress, and is probably the most fundamental change in the history of geography as it opens an almost infinite number of new worlds to explore and map...” (Abler et al. 1971, 72–73). Signaling a move beyond the focus on absolute space that would paradoxically come to dominate geographical computation a mere two decades later, this is a more congenial starting point for conversations with contemporary human geography, where space is relational and often seen to be produced as an active moment within sociospatial process, or as a splintered geometry shot through with power and meaning-making practices.

But aren't the spatial primitives of GIS themselves admirably flexible, neutral, and expressive? At the least, aren't points, lines, and polygons; fields and objects; and geo-atoms and geo-dipoles good starting points for spatial representation (Goodchild et al. 2007)? In fact, these basic representations, however productive and useful, still bias our computational vision away from phenomena of interest to contemporary human geography. Tobler's First Law of geography calls on us to recognize that, “everything is related to everything else, but near things are more related than distant things” (Tobler 1970, 236). It is no accident that Tobler's pithy, seemingly throwaway remark has become a shibboleth of contemporary quantitative geography. Its brevity masks considerable depth and it is a productive starting point for thinking about why geography matters, and how the degree to which it matters might be measured (see Sui 2004). However, the typical interpretation of Tobler's remark, in terms solely of distances and proximities measured in absolute space, focuses attention on contiguous areas that have relative coherence within themselves—on cases where nearby points exhibit relatively strong interconnections. Perspectives that embody strong interdependence at distance or a messy lack of such autocorrelation are deemphasized and unlikely to find direct representation in our data.

It is in this world of localized, (usually) positive spatial autocorrelation and distance decay that the polygon—so fundamental to contemporary geographical computation and particularly to GIS—takes up an ontological importance beyond that of mere container used to count up phenomena within arbitrary boundaries (the similarly central role of the pixel has long been challenged in remote sensing; see Fisher 1997). These difficulties, long debated in geography (e.g., Hartshorne 1939), are partially recognized in contemporary GIS under the rubric of the modifiable areal unit problem (MAUP) (Openshaw and Taylor 1979; Hameed et al. 2010). MAUP is centrally concerned with how a polygon (or set of polygons), considered as a thing in itself with intensive properties, is arbitrary—the world could be

partitioned differently. But like Tobler's law, this only scratches the surface of the trouble with this kind of polygon. Such a polygon is a data structure that promotes regions as uniform and ontologically self-contained. Consequently, the region becomes a territory aggregating locales that share similar intensive properties. Relations with distant places are of secondary importance, intellectually and representationally.

But for both contemporary human geography and the quantitative revolution, proximity and distance have been plural, situated, more-than-Cartesian concepts (Abler et al. 1971; Simandan 2016). Instead of a closed-form distance formula expressing proximity between coordinate pairs—where proximity is produced or interpreted, not absolute—it is possible to represent distance through various sorts of interaction matrices and network representations. Distance is no longer necessarily tied directly to coordinates, as the observer and type of distance relation matter.

Understanding such relations benefits from developing a visual analytics adequate to such data—an analytical cartography (Tobler 2000). If matrices of relations are understood as distances implicitly defining spaces, various procedures can be used to approximately render those spaces within the two or three dimensions readily available to visualization (e.g., Gatrell 1983; Muller 1984; Dorling 2012), or even beyond. One approach illustrative of this point is a graph layout heuristic. In Figure 1, we show a visualization of the OpenFlights dataset (2015). Lines are flights between airports. The layout heuristic attempts to place airports in a three-dimensional space so that airports and groups of airports densely connected by many flights are closer together. Three regions of strong intraconnectivity emerge: North America in the upper left, with New York's JFK prominent; Asia, in the lower part, with Tokyo (NRT) and Beijing (PEK) especially visible; and Europe, in the upper right, beyond London's LHR. Strong interconnections between core parts of these regions pulls them to the centre of the layout. Parts of the flight system that are poorly linked to interregional hubs float to the edges, moving some relatively lightly-populated continental interiors out to the visual peripheries. Visualization of such emergent spaces remains an active area of research. Spaces where distances are not symmetric, or where they are subjectively perspectival, are areas where further inquiry will be beneficial if a reimagined GIS is to be better positioned to engage the insights of human geography (see Hägerstrand 1957; Wood 1978; Drucker 2009; and, in particular, feminist critical GIS, e.g., Pavlovskaya and St. Martin 2007; Kwan 2008).

Broadening a historically limited engagement by geography and GIS with the wider spectrum of relational quantification also brings analytical methods that are more congruent with relational geographic approaches to territory and regions. An illustrative approach is known as "blockmodeling," is a technique whose early development was mostly carried out by mathematical sociologists (e.g., White et al. 1976; Doreian et al. 2005). Its approaches have increasingly been of interest to statisticians, biologists, physicists, and even more geographically-minded world-systems analysts. Yet we argue it may also be developed to yield insights into reconciling contemporary geographic computation with human geography.

Blockmodeling neither solely clusters nodes into “communities,” nor only clusters edges into bundles, but does both simultaneously (see Doreian et al. 2005, Chapter 5 for a treatment clustering algorithms in this context). Blocks themselves are not communities; that is, they are not sets of nodes that are both strongly interconnected with each other and weakly connected with nodes outside the community, as is commonly pursued in network analysis. Rather, blocks are submatrices in a reordering of the matrix of interrelations among nodes. Different types of blocks express different types of relationships among equivalent sets of nodes sharing the same role—roles that are simultaneously defined by how nodes of a given role share common patterns of relations with nodes in other roles. A meaningful blockmodel is one in which the grouping and reordering of nodes of the adjacency matrix suggests meaningful interpretations of how a graph or network is composed of particular roles and relationships among them. Communities are one possible type of blockmodel result, as are core-periphery relationships and bipartite graphs, among others. Generalized blockmodeling approaches may thus be useful in finding equivalently positioned roles within complex and often unequal relationships (Doreian et al. 2005). The analysis of relations cannot be conducted independently of the analysis of entities—they are mutually constitutive in blockmodeling.

Here, we blockmodel relational spatial data using nodes as inputs (polygons whose geometries cover a landscape) and network edges that represent flows between the nodes. Blockmodeling groups nodes into aggregate, but not necessarily contiguous, regions such that sets of nodes have similar relationships to other sets of nodes. In doing so, blockmodeling offers one possible gesture towards computational understandings of regions that are relational.

Figure 2 blockmodels a commuting dataset linking places of residence to places of work in the approximately 1600 census tracts of the nine-county San Francisco Bay Area. The network graph visualization in Figure 2 maps resulting derived relational regions with arrows showing aggregated numbers of commutes (in thousands) from any given region to another. We estimated stochastic hierarchical layered blockmodels, with edges appearing in one of three layers binned by number of commutes. The model shown was selected as that with the best statistical support, based on the Minimum Description Length principle, in an exploration of thresholding parameter space (Peixoto 2015, 2016). We aggregated our data into tracts from US Census Bureau (2016) LODES 7.2 commuting estimates for 2011, originally at census block scale (note that the “block” in blockmodeling is unrelated to the census concept of block). In effect, we are reordering and grouping the tracts in the adjacency matrix that records commutes from tracts of residence on the rows to tracts of work on the columns, finding patterns, and abstracting territorial and commuting equivalences out of a bewildering complexity of tract to tract flows. Walker and Schafran (2015, 15) impose order on the complexity more conventionally, by showing county to county flows. This approach gives a general sense of regional structure, but reifies administrative boundaries that do not group “like with like” on the ground (compare Nelson and Rae 2016).

Here, regions themselves are no longer bounded polygons with internal attributes, but rather semi-discontinuous collections of tracts. Attributes and relations are not intellectually

separable. In their constitution of selves and differentiation from others, they enfold their relationships—not only internally, but with all other regions simultaneously (see Harvey 1996). Shadows of the results of such analytical practices can be recorded through existing data structures of the polygon. Yet extending the data structures we use—so that by default geographical representations included relations at their core—would bring a broader range of geographical phenomena and concepts into computational existence. Such a data structure might eventually be able to directly engage core concepts from human geography such as Massey's formulation of a "global sense of place" (Massey 1991) or Paasi and Zimmerbauer's (2016) relational regions.

Figure 3 deepens this approach by extending it to conceive of global regions as co-constituted along with a multiplicity of their relations, not just relationships of a single uniform type. We illustrate the principle by considering how worldwide regions and economic-ecologic relations are co-produced. Here, trade interactions are considered not only in terms of their monetary values, but also in terms of the amounts of carbon emissions that were required for their creation. The input data connect 134 territorial nodes (mostly those of nation-states) spanning the Earth's surface (as calculated by Bergmann 2016b using the GTAP 8.1 database). The blockmodeling approach is, similar to above, a stochastic hierarchical blockmodel, but one where there are four layers: two layers for each of the two flows (trade expressed in monetary value and in carbon embodiment). For each flow, a layer records edges between nodes where flows exceed shares of 5% of, alternatively, the totals incoming to the importing node or the totals outgoing from the exporting node. In the results, national economies are understood not as isolated pixels, polygons, or bounded territories, but as differentially positioned ecological-economic spaces co-produced with processes of geographically uneven development. Regions are positioned differently with respect to trade understood in terms of carbon versus money. Yet the approach we illustrate here does not enshrine any one particular regionalization of the world, itself merely one among an unknown many. Including other notions of connection seen from various points of view—such as those that more explicitly speak to power and processes of meaning-making also important to human geography—will yield a range of related regionalizations, roles, and derived patterns of interaction among them.

GIS that has sought to represent and analyze phenomena in a Newtonian space has been remarkably successful. However, that success has led to the dominance in computational geographical practice of an absolute approach to space that is dramatically out of step both with contemporary geographical thought, and, ironically, with early thinking in geography's quantitative revolution. It is time to broaden the ontological and epistemological possibilities of GIS by engaging both other quantitative traditions and a wider spectrum of contemporary human geography. In this paper, we have pointed to specific interpretations and practices of relational mathematics and network science as one set of pathways in this direction. Many others are possible including, but not limited to, time geography (Kwan 2008), qualitative representations and analysis (Wood 1978; Cope and Elwood 2009), and geovisualization (Guo 2009). Drawing on insights, representations, analytical methods, and data structures from all of these, a more fully geographical GIScience is possible. If so, existing efforts in GIScience to analyze network data, and even to build regions on that basis, are valuable. However, they need to be placed within representational, analytical, and interpretative

frames that are more relational. Recalling our question concerning the flexibility, neutrality, and expressiveness of the spatial primitives of GIS, these efforts and our own in this paper show that ultimately data structures and data collection practices also need to change to support process-relational approaches. Geographers may likewise find this prospect congenial to their research and their teaching, and offer their own contributions in support.

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Key Messages

- Critical GIS can more fully engage in changing geospatial technology at the level of its data structures.
- Relational conceptions of space, common in human geography, can fundamentally alter basic GIS and GIScience concepts such as the polygon.
- We present three examples of how network methods and relational representations can challenge standard GIS approaches.

Figure 2.

Blockmodeling results for California Bay Area commuter flows. Origin-destination matrices are shown, with darker blue representing larger flows, in (a) Census ID order and (b) reorganized into regions by the stochastic blockmodel, on the basis of relational affinities. Panel (c) shows one level of a hierarchical blockmodel, where areas that are primarily sources (green outline), primarily sinks (blue), or a mixture (cyan) are indicated in the blockmodel nodes. The regions are mapped in red in the small maps on each node. Links are labeled with commute numbers in thousands, and node sizes are scaled by total inbound commutes. The basemap is a cartogram rescaled by total inbound commutes (local jobs), with county names and highway numbers included for orientation.

Figure 3.

Global trade interactions among derived regions, seen in terms of price values (black) and carbon embodiments (red). Regions appear in green within nodes and result from a stochastic blockmodel of price valuations and carbon embodiments of trade flows among an original 134 regions (original flow data calculated by Bergmann 2016b.) The region that is visually obscure at this scale (middle right) is comprised of Germany and the United Kingdom.