High-resolution measurement of time geographic entities

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Time geography is a powerful perspective for understanding human spatial behavior, in particular, constraints and tradeoffs in the allocation of limited time among activities in space. The development of *location-aware technologies* (LAT) raises the potential value of time geography in social research and in applications such as transportation engineering and planning. LATs, such as the global positioning system (GPS) and radiolocation methods can allow measurement of basic time geographic entities and relations at high spatio-temporal resolutions, as well as massive data volumes. These data have potentially enormous scientific value to time geographers, urban researchers, transportation analysts and social scientists.

A problem is that classical time geography is not ready for the measurement tasks demanded by LATs. Classical time geography is conceptual: analytical statements of its basic entities and relations do not exist beyond the informal descriptions of Burns (1979) and Lenntorp (1976). These are not effective for inferring time geographic entities and relationships from high-resolution measurement of mobile objects in space and time. They are not sufficient for analyzing the propagation of uncertainty when measuring these objects imperfectly. The looseness and incompleteness of these descriptions means that comparisons of detailed data and time geographic analyses across different studies may be difficult since the entities and relations are not strictly comparable.

Some recent formalisms by Miller (1991) and Kwan and Hong (1998) make progress towards the goal of an analytical time geography, but these are limited to the special case of networks. Hornsby and Egenhofer (2002) develop a framework for multi-granularity representations of space-time paths, prisms and composite paths/prisms to support space-time queries (although they unfortunately invent a non-standard terminology). However, their framework uses simultaneous inequalities to describe these entities. These are cumbersome for analytical statements about high-resolution time geographic measurement and uncertainty propagation since they describe the entities implicitly.

Representation and analysis of dynamic entities measured at high spatio-temporal resolutions also arise in geographic information science. The development of LATs and *location-based services* (LBS) is inspiring a growing literature on database design for storing information on moving objects. Since digital technologies can only sample an object's location at discrete moments in time, a key problem is interpolating an object's location at any arbitrary moment based on the sampled locations (e.g., Pfoser and Jensen 1999).

This presentation will address the lack of analytical rigor at the foundation of time geography by presenting a high-resolution measurement theory for its basic entities and relationships (Miller 2005a). Drawing from the literature on moving objects database design, this paper shows that the location or spatial extent of time geographic entities at any moment in time can be solved as compact spatial sets, or the intersection of compact spatial sets, derived from the sampled locations and auxiliary information such as a maximum travel velocity. These sets are simple geometric objects that have algebraic solutions in one or two spatial dimensions. These simple objects support evaluation of time geographic relationships such as bundling and intersections. Numeric solutions are required for some entities and relations in higher dimensions, but these are relatively tractable since they involve simple surfaces. Inferring relationships such as path bundling or path-prism and prism-prism intersections is also tractable since this involves simple geometry. An ancillary but useful benefit of the measurement theory is a generalization of time geography. The measurement theory allows analytical statement of time geographic entities in n-dimensional space rather than the strict two-dimensional space of classical time geography. The cases of direct interest in time geography are n = 1 (networks), 2 (planar space) or 3 (natural space), and the measurement theory can support consistent measurements and analysis of time geographic entities across these cases (e.g., a vehicle moving within and outside a transportation network). Although not addressed in this presentation, it is also easy to extend the measurement theory to include virtual interaction using information and communication technologies such as email, the world wide web and cell phones (see Miller 2005b)

Literature cited

Burns, L. D. (1979) *Transportation, Temporal and Spatial Components of Accessibility*, Lexington, MA: Lexington Books.

Hornsby, K. and Egenhofer, M. J. (2002) “Modeling moving objects over multiple granularities,” *Annals of Mathematics and Artificial Intelligence*, 36, 177-194.

Kwan, M.-P. and Hong, X.-D. (1998) “Network-based constraints-oriented choice set formation using GIS,” *Geographical Systems*, 5, 139-162.

Lenntorp, B. (1976) Paths in space-time environments: A time geographic study of movement possibilities of individuals, *Lund Studies in Geography Number 44*, Royal University of Lund, Sweden.

Miller, H. J. (1991) Modeling accessibility using space-time prism concepts within geographical information systems, *International Journal of Geographical Information Systems*, 5, 287-301

Miller, H. J. (2005) “A measurement theory for time geography,” *Geographical Analysis*, 37, 17-45.

Miller, H. J. (2005b) "Necessary space-time conditions for human interaction," *Environment and Planning B: Planning and Design*, 32, 381-401.

Pfoser, D. and Jensen, C. S. (1999) “Capturing the uncertainty of moving-object representations,” in R. H. Güting, D. Papadias, and F. Lochovsky (eds.) *Advances in Spatial Databases*, Berlin, Springer: Lecture Notes in Computer Science 1651, 111-131.