Shifting Granularity Over Geospatial Lifelines (Extended Abstract)

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Abstract

It is often desirable to consider an object's movement over space and time from the perspective of different levels of detail or *granularity*. Changing to a more detailed view uncovers information that otherwise is unknown. Conversely, moving to a simpler view can improve our understanding of the movement patterns of an object. This paper considers shifts in granularity over *geospatial lifelines*. A geospatial lifeline is a time-stamped record of all the locations that an object has occupied over a period of time. An approach to modeling lifelines at different granularities is presented, identifying different aspects of lifelines that are relevant at refined or coarse granularities.

Introduction

People move through space. They stay at locations where they meet other people and they undertake reoccurring tasks that cause them to move between variable or fixed locations in space. These movements often expose people to environmental factors that can lead to eventual health problems. Efforts to enhance approaches to the study of environmental health sciences include developing new tools for the analysis of spatially and temporally referenced medical information, and new methods for reasoning about movement and its consequences over space and through time. This coincides with an interest by the database community in spatio-temporal databases (Erwig and Schneider 1999; Sellis 1999a; 1999b) including moving object databases (Forlizzi *et al.* 1999; Güting *et al.* 1998; Sistla *et al.* 1997; Wolfson *et al.* 1998).

Tracking movement occurs at different levels of detail or granularity depending upon the task at hand. Granularity refers to the notion that the world is perceived at different grain sizes or *granules* (Hobbs 1990) and, in this paper, the use of granularity, relates to the cognitive aspects of selecting the appropriate level of detail for a task. The spread of a disease like measles, for example, can be monitored from a national perspective, corresponding to the number of cases that are reported by individual states and also from a local perspective, where the details of person-to-person contact is relevant to how the illness is spread. At high granularities, a view of the movement of people may include the time and place of departure, mode(s) of transport, time and place of arrival, travel speed, and the number of stops *enroute*, while a view at lower granularity gives only a general trend of movement, capturing basic facts. The person, moved, for example, from the East Coast to the Mid-west in the 1960s, where she lived for the next forty years.

Changing to a more detailed perspective uncovers information that otherwise is unknown. Who else has visited this location? How many times? To what other locations has individual X traveled? How did the speed of movement vary? Conversely, moving to a simpler view can improve our understanding of phenomena. Shifting between spatio-temporal granularities is a necessary routine for many tasks. The formalization of such shifts for implementation in an information system, however, is more complex. A set of temporal zoom operators has been proposed for aiding spatio-temporal knowledge representation over different granularities (Hornsby and Egenhofer 1999) including operators to assist with the summarization or coarsening of spatio-temporal aspects of large datasets (Hornsby 2000).

This paper examines the nature of shifts in granularity of geospatial lifelines. A *geospatial lifeline* is a time-stamped record of all the locations that an object has occupied over a period of time (Mark *et al.* 1999). Different lifeline models are possible depending whether the movement being modeled is discrete or continuous. A *lifeline thread* refers to a linear approximation of an ordered sequence of space-time samples capturing the *likely* space-time points at which an object may have been when moving continuously from *A* to *B* (Figure 1).

Alternatively, given two known locations and a certain travel speed, for example, it is possible to model the *set of all possible locations* that an object could feasibly pass through or visit (Forer 1998; Miller 1991; O'Sullivan *et al.* 2000). This is relevant for determining whether an individual could have come into contact with a known environmental hazard or disease, for example, or whether a ship passed through an oil spill, or an airplane through a storm (Moreira *et al.* 1999; Pfoser and Jensen 1999). The approach for modeling the set of possible locations for an individual given a starting or ending point in space-time and a maximum velocity is based on a set of geometric constraints that describe the intersection of two inverted half cones that form a *lifeline bead* (Figure 2). For cases where an object's spatial location is the

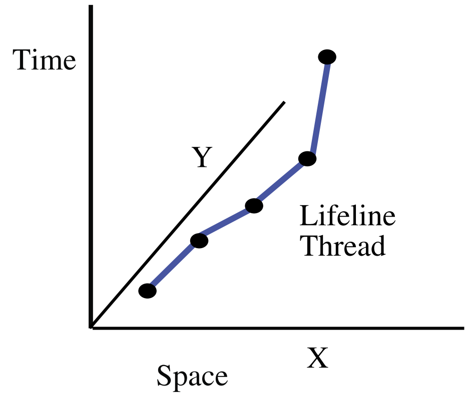

Figure 1: Lifeline thread.

same at two space-time samples, the set of possible locations forms a right bead (intersecting right half cones). All other cases result in an oblique bead based on intersecting oblique half cones. The area of intersection of two oblique half cones is projected onto the $x-y$ axes as an ellipse.

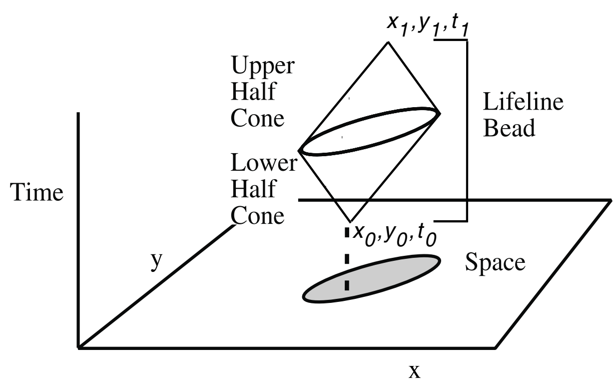

Figure 2: Lifeline beads based on all possible locations for an individual given a starting (x^0,y^0,t^0) and ending point (x^1,y^1,t^1) in space time and given a maximum velocity.

Granularity of Lifelines

A higher granularity returns a new, more-detailed view of an object's movements between two locations. Lower granularities correspond to less-detailed views. Views here are not defined as visual representations, but rather are refinements (i.e., more detailed views) or abstractions (less detailed views) of beads. All lifeline threads and beads have multiple views, each of them distinct from the others. Each view corresponds to a different way of perceiving movement over space and time.

Refining Granularity

An object's movement can be modeled as a single lifeline thread. At a higher granularity, the movement between two of the known locations along a thread, can be modeled as a bead, capturing more detail about the possible locations that the object passed through. Refining granularity further to create other views of a lifeline thread returns a sequence of lifeline beads forming a *lifeline necklace* such that the end point of one bead is the start point of the next bead (Figure 3). This sequence of beads traces an object's movement in space and time at a higher granularity, revealing more detail about the path of movement.

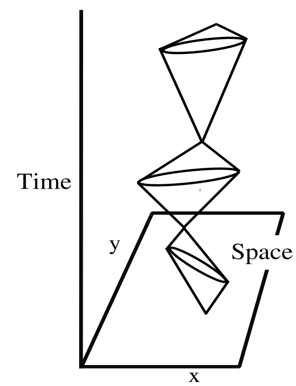

Figure 3: Movement can be modeled as a sequence of lifeline beads that form a lifeline necklace.

Refining granularity results in:

- expanded temporal detail such that more timesteps are relevant,
- additional locations through which the object passed become known, and
- more detail about the speed of movement between locations becomes known.

Now, at a higher granularity, portions of the movement may be revealed to be at slower speeds, such as corresponding to periods when the individual was in heavy traffic perhaps, or portions at faster speeds, as when traveling on a highway. More detail about the travel path becomes known through the addition of spatial information, revealing unknown or unexpected side trips. Perhaps the individual visited a location more than once. The varying lengths of individual beads corresponding to time spent on each segment of movement also yields useful information, for example, whether it is possible for the individual to have participated in certain activities or not.

Coarsening Granularity

Coarsening granularity returns a new, less-detailed view of an object's movement. This type of operation is particularly relevant to very large databases with detailed geospatial lifeline data. Very long lifeline necklaces may require abstraction into simpler, generalized views.

Abstracting lifeline beads results in:

- coarsening temporal detail,
- coarsening spatial detail, and
- coarsening the detail relating to speed of movement.

Coarsening temporal detail occurs such that start and end timestamps of all but the first and last beads in a lifeline necklace are abstracted. Fewer timestamps are relevant to this more general view of movement. Coarsening spatial detail results in fewer start and end point locations being modeled. Less detail is also maintained with respect to the speed of movement.

Coarsening granularity occurs through aggregating *1 . . . n* lifeline beads into a generalized bead. In this way, the overall trend of movement is preserved with the start and end point of a necklace forming the start and end points of the generalized bead. Deriving generalized beads from lifeline necklaces can be undertaken in at least two ways. Firstly, a generalized bead is derived based on the start point and end point location of a necklace together with the velocity at the start and end points (Figure 4a). Secondly, a shape-approximating approach based on the velocity at the start and end points of the necklace as well as selected point locations chosen from the rim of particular beads in the necklace (Figure 4b) can be used to arrive at a generalized bead. Depending on which rim points from the necklace are selected to influence the geometry of the composite bead, there are many different solutions that can be computed with this method.

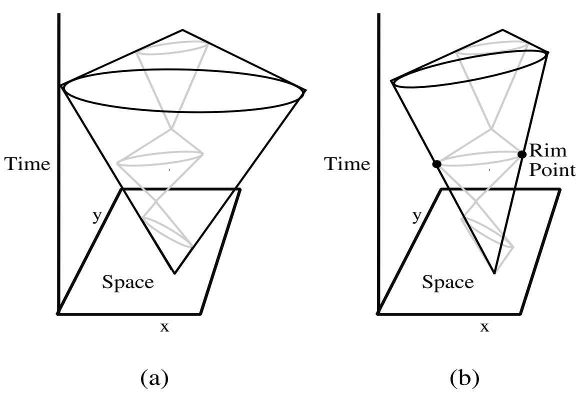

Figure 4: Aggregations of *1 . . . n* beads resulting in a generalized bead (a) based on the velocity and locations at the start and end points of a lifeline necklace and (b) using selected point locations from the rim of certain beads to create a generalized bead.

Both approaches have their shortcomings. Although attractive due to its simplicity, the first approach suffers from being too coarse. Depending on the geometric properties of the beads comprising the necklace, the set of all possible locations derived using this approach might be larger than the set of locations actually described by the necklace. Additionally, parts of the necklace might lie outside of the generalized bead, resulting in possible locations being omitted from the model.

Although the result may indeed be closer to the form of the necklace, the second approach also is weakened by not including parts of necklace beads in the generalized bead (i.e., parts are outside of it). In certain circumstances, therefore, both approaches fall short of capturing all possible locations that an individual has visited. Coarser views of necklaces are also obtained through an approach based on convex hulls computed from the geometric properties of the necklace (Figure 5). The tube structure resulting from the convex hull approach is a coarser approximation of a lifeline necklace and, unlike the methods described above, it captures the complete set of possible locations modeled by the necklace.

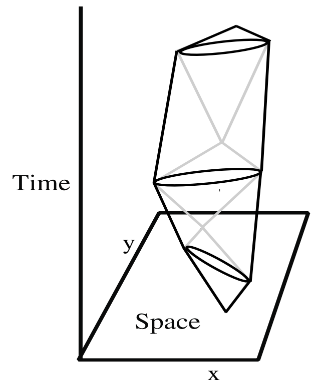

Figure 5: Coarser views of necklaces are obtained through an approach based on convex hulls computed from the geometric properties of the necklace.

Conclusions

Spatio–temporal knowledge representation often requires shifting from one granularity to another such that users can carryout a desired task. This paper examines the effect of shifting granularity with respect to geospatial lifelines. Depending on the desired granularity, varying views can be modeled as lifeline threads, beads, necklaces, or tubular approximations based on the necklace and derived from convex hulls (Figure 6).

Refining granularity shifts the view from threads to beads or from threads to necklaces, resulting in each case in a more detailed view of movement. Coarsening granularity shifts the view of movement from the details captured by lifeline necklaces to the more general representations based on convex hulls and to the most general case of lifeline threads. Shifting from beads to threads and from necklaces to beads are also types of coarsening.

This paper has described some of the interesting aspects relating to granularity of geospatial lifelines. Further work is necessary on operations that move views between different granularities and especially relating to operations that result in coarser granularities of lifelines. The tubular approximations of necklaces and transformations from the tubes to threads are among some of the interesting aspects that require further investigation.

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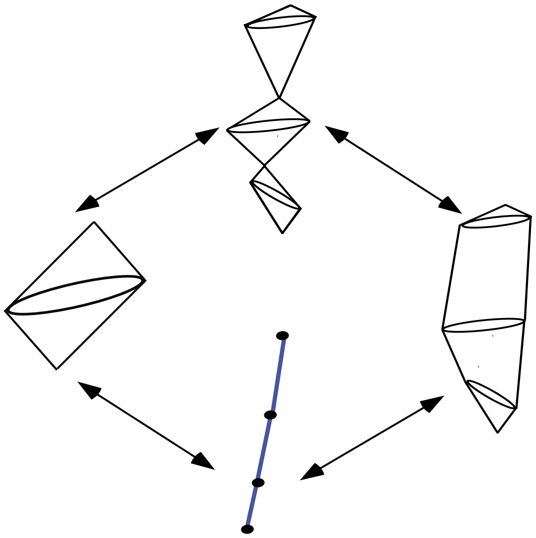

Figure 6: Shifting granularity between a lifeline bead, a necklace, a tubular approximation based on convex hulls, and a lifeline thread.

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References

Erwig, M. and Schneider, M. 1999. Developments in spatio-temporal query languages. In Tjoa, A., Cammelli, A., and Wagner, R., eds., *Proceedings of the 10th International Workshop on Database and Expert Systems Applications, DEXA'99, Florence, Italy*, 441–449. Los Alamitos, CA: IEEE Computer Society.

Forer, P. 1998. Geometric approaches to the nexus of time, space, and microprocess: implementing a practical model for mundane socio-spatial systems. In Egenhofer, M., and Golledge, R., eds., *Spatial and Temporal Reasoning in Geographic Information Systems*. New York: Oxford University Press. 171–190.

Forlizzi, L., Güting, R., Nardelli, E., and Schneider, M. 1999. A data model and data structures for moving objects databases. Technical Report 260 - 10/1999, Fern Universität, Hagen, Germany.

Güting, R., Böhlen, M., Erwig, M., Jensen, C., Lorentzos, N., Schneider, M., and Vazirgiannis, M. 1998. A foundation for representing and querying moving objects. Technical Report 238 - 9/1998, Fern Universität, Hagen, Germany.

Hobbs, J. 1990. Granularity. In Weld, D., and de Kleer, J., eds., *Readings in Qualitative Reasoning about Physical Systems*. San Mateo, CA: Morgan Kaufmann Publishers, Inc. 542–545.

Hornsby, K. and Egenhofer, M. 1999. Shifts in detail through temporal zooming. In Tjoa, A., Cammelli, A., and Wagner, R., eds., *Tenth International Workshop on Database and Expert Systems Applications, Florence, Italy*, 487–491. Los Alamitos, CA: IEEE Computer Society.

Hornsby, K. 2000. Deriving summaries through an identity-based approach. In Gonzalez, A., and Towhidnejad, M., eds., *13th International Florida AI Research Symposium Conference, FLAIRS'2000*, (in press). Orlando, FL: AAAI Press.

Mark, D., Egenhofer, M., Bian, L., Hornsby, K., Rogerson, P., and Vena, J. 1999. Spatio-temporal GIS analysis for environmental health using geospatial lifelines [abstract]. In Flahault, A., Toubiana, L., and Valleron, A., eds., *2nd International Workshop on Geography and Medicine, GEOMED'99*, 52. Paris, France: Inserm U444 WHO Collaborating Centre for Electronic Disease Surveillance.

Miller, H. 1991. Modelling accessibility using space-time prism concepts within geographical information systems. *International Journal of Geographical Information Systems* 5(3):287–301.

Moreira, J., Ribeiro, C., and Saglio, J.-M. 1999. Representation and manipulation of moving points: an extended data model for location estimation. *Cartography and Geographic Information Science* 26(2):109–123.

O'Sullivan, D., Morrison, A., and Shearer, J. 2000. Using desktop GIS for the investigation of accessibility by public transport: an isochrone approach. *International Journal of Geographical Information Science* 14(1):85–104.

Pfoser, D. and Jensen, C. 1999. Capturing the uncertainty of moving-object representations. In Güting, R., Papadias, D., and Lochovsky, F., eds., *6th International Symposium, SSD'99*, volume 1651 of *Lecture Notes in Computer Science*, 111–131. Hong Kong: Springer-Verlag.

Sellis, T. 1999a. Chorochronos: research on spatiotemporal database systems. In Tjoa, A., Cammelli, A., and Wagner, R., eds., *Proceedings of the 10th International Workshop on Database and Expert Systems Applications, DEXA'99*, 452–456. Florence, Italy: IEEE Computer Society.

Sellis, T. 1999b. Research issues in spatio-temporal database systems. In Güting, R., Papadias, D., and Lochovsky, F., eds., *6th International Symposium, SSD'99*, volume 1651 of *Lecture Notes in Computer Science*, 5–11. Hong Kong, China: Springer-Verlag.

Sistla, A., Wolfson, O., Chamberlain, S., and Dao, S. 1997. Modeling and querying moving objects. In *Proceedings of the Thirteenth International Conference on Data Engineering, ICDE13*.

Wolfson, O., Xu, B., Chamberlain, S., and Jiang, L. 1998. Moving objects databases: issues and solutions. In *Proceedings of the 10th International Conference on Scientific and Statistical Database Management, SSDBM'98*, 111–122.