Extended Abstract:

Dynamic GIS – The final frontier?

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1 Introduction

A proper integration of dynamic aspects in Geographic Information Systems (GIS) still remains a major challenge. Textbooks usually define GIS as a system that models representations of the real-world, preserving the structure that exists between entities. The world we live in is highly dynamic; its structure is not a static one. Processes, events, and actions shape and influence both the Earth on a macro-scale and humans on a micro-scale.

Current GIS are capable of analyzing static spatial data but fall short in the spatio-temporal domain. GIS can answer static questions related to *Where* something is located. More interesting, however, are answers related to questions *When* something happened or will happen (Frank, 1998). It is widely acknowledged that most of human decisions involve a spatial component. The influence of temporal aspects, however, should be at least as highly rated. Current approaches fail to model our dynamic world, revealing the mismatch between what GIS claims to represent and what it actually is. GIS simulate time through a series of snapshots. Series of spatial data allow a meaningful interpretation only if they incorporate the metric and ordering relations of time (Frank 2001; Galton, 2004). A general problem arises, however, as this approach generally fails to capture the actual underlying changes, i.e., there is no way of knowing the state of an entity between two snapshots.

The benefits of an integration of time in GIS are two-fold. First, it allows for a better understanding and analysis of geographic phenomena, thus having significant influence on many decision processes. For instance, the importance concerning the political realm were addressed by Frank (1998). Second, it fosters the prediction capabilities of a system allowing for better planning processes (Christakos and Serre, 2002). Addressing "What if" questions and their ramifications would add significantly to the benefits of GIS.

The focus of this work is to provide the common ground for the foundations of a general-purpose framework to represent change in GIS. This paper discusses its needs and requirements. Recent endeavors in the domain of spatial-temporal reasoning and modeling needed a thorough investigation to address differences and find similarities. The result presented here illustrates some of the key requirements that further research needs to consider when the vision of a dynamic GIS is to be achieved.

2 Related Work

Various efforts to integrate and model time in GIS exist. Notable fundamental research include the space-time composite model discussed by Langran and Chrisman (1988) and subsequent work by Chrisman (1997).

In order to move towards dynamic GIS it seems natural to agree on a common notion of the underlying spatial concepts: object and field. From a human perspective, objects and fields are simply different forms of abstractions of reality; in GIS they are represented by vector and raster models, respectively. Their investigation is from uttermost importance because they represent the basic entities that move in space and time. Galton (2001) has criticized the lack of a clear and sound formal mathematical model of these conceptualizations. His developed model, however, does not incorporate time directly, but defines objects and fields in the spatial domain only. Goodchild, Yuan and Cova (2007) saw the need for a single framework to cope with dynamic geographic phenomena that have both field and object characteristics. They have developed an atomic form of geographic information from which both representations can be derived; an important step towards a general theory on the notion of geographic entities.

Static representations, such as fields and objects need an extension to allow temporal variation. Semantics for different kinds of change and a classification of operations on objects were developed by Hornsby and Egenhofer (1997). Similar work, adding restrictions based on ontological classes, has been done by Medak (2001).

It was noted that both objects and events are equally needed to model dynamic processes. Several approaches toward a definition and formalization of events exist. Yuan (2001) defined events as spatio-temporal aggregate of one or several processes. Galton and Worboys (2005) argued that processes undergo change while events do not. Worboys (2005) approach was to embed computational processes in space and time to be able to model real-world events. The idea was to describe spatial and temporal reference frames as processes (everything is a process). Other, partially diverging definitions and approaches exist, for example the SPAN and SNAP ontology defined by Grenon and Smith (2004).

3 Status Quo And The Underlying Problem

A plethora of research has been carried out to define and formalize notions of spatial (objects, fields) and spatio-temporal (process, event, action, state) concepts. Current approaches, however, suffer from an ambiguity in terms. Their slightly different meanings and shadings make a mutual consent on a framework difficult. It should be noted, however, that these differences may have its roots in the underlying applications the authors had in mind. Also, many implementations build on the definition of previously defined terms and seem to partially contradict each other. Also, models to represent change have been developed across many disciplines but the vast number of different approaches make the definition of a common ground difficult (Craglia and Goodchild, 2008). What is needed, in the long term, is a generic approach that works independently of a specific implementation.

4 Requirements And One Possible Solution

Several key points need to be considered “en route” to achieve the vision of dynamic GIS. This section discusses some of the requirements that are likely to play a role in a successful integration of dynamic aspects.

(1) Change needs to be modeled on a generic and abstract level, i.e., independent of actual implementations. Operations must work on all different kinds of objects and processes, not just in a specific domain. This also ensures that the process model can be used across various disciplines and is not limited to a particular application.

(2) The universal elements that form the basis for this approach need to consider both event- and object-oriented representations. Dynamic real-world phenomena often consist of object-based change in relation to events. i.e., they are hybrid.

(3) Both granularity (Level of detail) and topological aspects are crucial in developing dynamic GIS. The manipulation of process models must preserve topology even over multiple granularities.

(4) Many processes are likely to take place concurrently and possibly in relation to other processes. Real-world phenomena are not linear but consist of multiple interleaved events.

(5) Basic process models require the capabilities to be scaled-up to real-world problems (Worboys, 2005). Is seems natural to first build a system made of simple parts. These can then combined to form a more complex system whenever scaling required (building blocks).

It seems that Algebra-based tools can help to achieve the long term goal of a universal description of change as it seems to fit the above discussed requirements. An Algebra consists of a class of objects and a set of potentially dynamic operations (2) and axioms that describe the properties of these operations .

Frank (1998) acknowledged the usefulness of Algebras when discussing change. The complete abstraction from an implementation (1) and their combinational capabilities (Frank 1999) make them a very attractive tool for building a process model. The combination of Algebras may account for both the granularity (3) and the building blocks (5) part. Timpf et al. (1992) have successfully demonstrated how algebraic specifications can be used to build a model over multiple levels of granularity. (4) seems to be a challenging task because the concurrency of processes and their consequences make models increasingly complex and difficult to decipher. This may work out for small-scale problems but a model quickly becomes unusable in more complex situations.

The points mentioned here are by no means meant to be comprehensive or complete. The authors are also aware that each of the examples noted offers enough material to do extensive research on its own. It is believed, however, that the requirements presented here can help to agree on a common ground for future dynamic GIS.

References

CHRISMAN, N. R. (1997), Beyond the snapshot: changing the approach to change, error, and process, In M. Egenhofer and R. Golledge (eds), Spatial and Temporal Reasoning in Geographic Information Systems, New York, NY, Oxford University Press: 87-95

CHRISTAKOS, G., BOGAERT, P. & SERRE, M. (2002), Temporal GIS. Springer Verlag

CRAGLIA, M., GOODCHILD, M.F., ANNONI, A. & et al. (2008), Next-Generation Digital Earth, A position paper from the Vespucci Initiative for the Advancement of Geographic Information Science, International Journal of Spatial Data Infrastructures Research 3:146-167

GOODCHILD, M.F., YUAN, M., COVA, T.J. (2007), Towards a general theory of geographic representation in GIS, International Journal for GI Science, 21:239-260

GRENON, P., Smith, B. (2004), SNAP and SPAN: Towards Dynamic Spatial Ontology, in Spatial Cognition & Computation: An Interdisciplinary Journal, Vol. 4, No. 1. (2004), pp. 69-104.

FRANK, A. U. (1998), “GIS for Politics.” Paper presented at the GIS Planet '98, Lisbon, Portugal (9 – 11 Sept. 1998)

FRANK, A. U. (1999), One Step up the Abstraction Ladder. In Proceedings of the International Conference on Spatial Information Theory, COSIT 1999:95-107

FRANK, A. U. (2001), Socio/Economic Units: Their life and Motion, in Life and Motion of Socio-Economic Units, J.-P. Cheylan, A.U. Frank, J. Raper, eds, Taylor and Francis

GALTON, A. (2001), A formal theory of objects and fields, In Proceedings of the International Conference on Spatial Information Theory: Foundations of Geographic Information Science, COSIT 2001:458-473

GALTON, A. (2004), Fields and objects in space, time, and space-time, Spatial Cognition and Computation, 1:39-68

GALTON, A., WORBOYS (2005), M., Processes and Events in Dynamic Geo-Networks, Geospatial Semantics:45-59

HORNSBY, K., EGENHOFER, M.J. (1997), Qualitative representation of change, In Proceedings of the International Conference on Spatial Information Theory: A Theoretical Basis for GIS:15-33

LANGRAN, G., CHRISMAN, N.R. (1988), A framework for temporal geographic information, Cartographica, (3) 25:1-14

MEDAK, D. (2001), Lifestyles, in Life and Motion of Socio-Economic Units, J.-P. Cheylan, A.U. Frank, J. Raper, eds, Taylor and Francis: London

TIMPF, S., VOLTA, G.S., POLLOCK, D.W. (1992) A conceptual model of wayfinding using multiple levels of abstraction. LNCS (639):348-367

WORBOYS, M. (2005), Event-oriented approaches to geographic phenomena. International Journal of Geographical Information Science, 19:1-28

YUAN, M. (2001), Representing complex geographic phenomena in GIS, Cartography and Geographic Information Science, (28) 14:83-96