K. Hornsby and M. Egenhofer (1999) Shifts in Detail through Temporal Zooming. In: A. Tjoa, A. Cammelli, and R. Wagner (Eds.), *Tenth International Workshop on Database and Expert Systems Applications*, Florence, Italy, IEEE Computer Society. pp. 487-491.

Shifts in Detail Through Temporal Zooming*

Kathleen Hornsby and Max J. Egenhofer
National Center for Geographic Information and Analysis
and
Department of Spatial Information Science and Engineering
University of Maine, Orono, ME 04469-5711 USA
{khornsby, max}@spatial.maine.edu

Abstract

Spatio-temporal knowledge representation often requires shifting from one level of detail to another so that users can carry out a desired task. Geographic information systems typically treat such alterations in detail with respect to the geometric properties of objects. In this paper, we extend the theories based on geometrical considerations only to an approach that focuses on shifts between levels of temporal detail. The approach is based on a model of change to identifiable objects and describes temporal zooming that involves expanding or collapsing the transitions between identity states of objects. This work offers promising new directions for spatio-temporal query languages.

1. Introduction

People view the world at different levels of detail, abstracting from the world only those things that serve their present interests [1-4]. These changes in detail enable people to translate the complexities of the real world into simpler representations. With geographic information systems (GISs), abstraction methods have typically been applied to the geometric properties of objects. For instance, GISs offer users tools for spatial or *geographic zooming* on the geometry of objects [5-7]. In this paper, we extend the theories of zooming in GISs based on geometrical considerations only to temporal zooms—operations that support shifts among levels of temporal detail, generating different views of objects over time. Temporal abstractions have been studied for certain domains including clinical settings [9] and traffic-control studies [10] where methods for abstracting high-level concepts and patterns from time-stamped data have been explored.

Shifting between levels of detail is a necessary routine for the domain scientist. The formalization of such shifts for implementation in a GIS, however, is more complex. This paper presents a new set of operations to support shifts in levels of detail over time. The approach is based on a model of change for identifiable objects. An object refers to the representation of a real world phenomenon in an information system that exists as a physical entity, such as a building, or something conceptual, such as a county or state. Objects are associated with certain identity states. Identity conveys the uniqueness and individuality of an object [11, 12] and has been used in models of change to track objects over time [13, 14].

In this paper, we draw on the cognitive aspects relating to the different perceptions of levels of details of objects that change over time, rather than the actual measure at which objects become discernible from each other (resolution). The notion of thinking about the world at different grain sizes fits well with our conceptualization of how people shift between different levels of temporal detail of objects. We use *detail* in this paper to refer to these concepts.

The remainder of the paper is organized as follows: Section 2 describes how shifts can occur between levels of temporal detail. Section 3 summarizes the identity-based Change Description Language that is used to express various operations on object identities. This visual language is applied in Section 4 to model different levels of temporal detail. Section 5 presents new temporal zoom operations. Section 6 concludes the paper.

---

* Max Egenhofer's research is supported through NSF grants IRI-9613646, SBR-9700465, BDI-9723873, and IIS-9970123; grants from the National Imagery and Mapping Agency under grant number NMA202-97-1-1023; the Air Force Research Laboratory under grant number F30602-95-1-0042; the National Institute of Environmental Health Sciences under grant number 1 R 01 ES09816-01, and Bangor Hydro-Electric Co.; and a Massive Digital Data Systems contract sponsored by the Advanced Research and Development Committee of the Community Managment Staff.

2. Shifting Between Different Levels of Temporal Detail

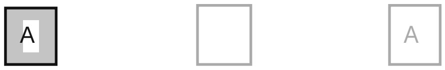
Geographic entities can be perceived according to different levels of temporal detail. The building of a new public library in a town, for instance, can be perceived and modeled as one step or from a different perspective, multiple steps, where each of the separate tasks—forming a building committee, selecting a site, hiring an architect, hiring a contractor, building the library—that contribute over time to the creation of the building are relevant. This refinement of detail over time brings forward additional information that at the coarser level has been abstracted away. The selection of the site for the library by the building committee and the hiring of the contractor, for example, were not relevant at the coarser level of detail. Conversely, coarsening the level of temporal detail collapses the sequence of facts about the process into fewer details.

3. Identity-based Change Description Language

Geographic entities can be modeled as objects. A *Change Description Language* [14] has been developed that is based upon a classification of alterations to discrete objects through tracking changes to *object identity*. Object identity provides a way to represent the individuality or uniqueness of an object, independent of its attributes and values.

The Change Description Language uses symbols to convey the basic elements of the model as well as combinations of these elements. The elements or *primitives* are based on identity states of objects and are founded on the notion of existence. Existence, in this paper, refers to the physical presence or occurrence of an object or, for conceptual objects, the belief in or perception of an object. The State of Maine, for example, can be modeled as an existing object. This object is not a physically existing object, but rather an object that has been created by human decree. Existence is different from the notion of appearance, a similar concept in the visual domain. Although an object's identity is immutable, the state of an identity may change, for example, from existing to non-existing.

The primitives arise from the fact that an object can be in one of two identity states: either existing, describing the case where an identifiable object is present, conceptually or physically (Figure 1a), or non-existing. We further refine non-existence to differentiate between non-existing identity states: non-existing without history and non-existing with history. The first case describes the situation in which no object with identity is existing or has existed previously (Figure 1b). The term *without history* means that no previous object with that identity has existed. This case is contrasted with the second one, which represents a non-existing object *with history* (Figure 1c). In this case, an object with identity previously existed but has been eliminated and no longer exists. The Soviet Union, for example, no longer exists in 1999. Objects have been given a label to aid identification. These symbols illustrate states in which objects reside at different times.



(a) (b) (c)

Figure 1: Basic symbols used for (a) an existing object, (b) non-existing object without history, and (c) non-existing object with history.

Temporal change is modeled in a qualitative fashion based on the order of events [15]. The change from one identity state to another is captured through an arrow and is referred to as a *transition* (Figure 2). Scenarios reflecting changes to object identity are developed from the left of the transition arrow to the right, where left corresponds to *before* and right to *after*. Transitions are assumed to be direct, with no intermediate states being portrayed. The Change Description Language conveys only qualitative aspects of change, for example, no information on the duration of the length of time of a transition is portrayed.

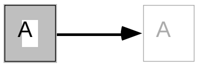


Figure 2: A transition between two identity states of an object.

A set of basic identity-based change operations is derived through systematic combinations of the primitives, capturing the semantics of a `create` operation (Figure 3a), the operation `continue existence` that reflects a transition between two states of an existing object (Figure 3b), the operation `eliminate` (Figure 3c), the operation `destroy` that reflects the permanent removal of an existing object resulting in a non-existing object without history (Figure 3d), and the transition from a non-existing object with history to an existing object captures the semantics of a `reincarnate` (Figure 3e), describing the fact that the same identity has existed previously.

The remaining four are combinations of non-existing identity states: `continue non-existence with history` (Figure 3f), a `forget` operation (Figure 3g), the transition from a non-existing object without history to a non-existing object with history describes a `recall` operation (Figure 3h), and the operation `continue non-existence without history` of an object (Figure 5i).

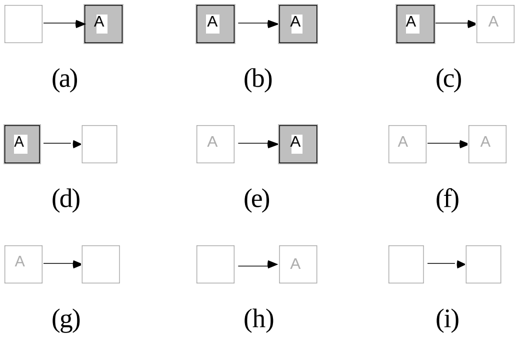


Figure 3: Operations on single objects.

Temporal co-occurrence of transitions affecting different objects is conveyed through aligning identity states vertically. A set of transitions belongs to a *scenario of change*. A scenario reflects a conceptualization of change, namely the set of objects with identities involved in transitions relating to the task at hand.

4. Applying the Change Description Language to Model Shifts in Temporal Detail

Shifting the level of detail returns either a more detailed or less detailed *view*. Views are not visual representations, but rather are articulations (i.e., more detailed views) or abstractions (i.e., less detailed views) of identifiable objects and transitions.

Applying the Change Description Language to model the existence of a library, for example, illustrates how refining the level of detail over transitions between identity states of objects (Figure 4) reveals past transitions and identity states corresponding to whether the object was existing or not. It becomes possible to determine how often these states have occurred.

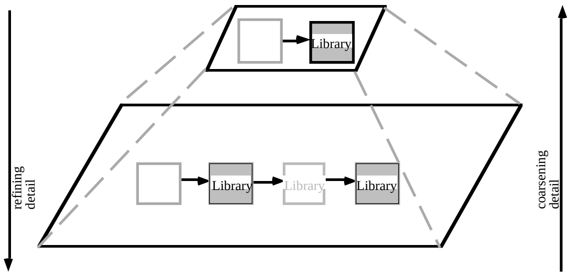


Figure 4: Transitions between objects at different levels of detail.

Conversely, coarsening the level of detail collapses the sequence of transitions into fewer transitions.

We refer to these shifts in detail over the transitions between identity states of objects as *temporal zooming*.

5. Operations to Support Temporal Zooming

The need to alter levels of detail over transitions requires a set of *temporal zoom operations* that support these shifts.

A transition linking identity states of an object over time has multiple views, each of them distinct from the others. Each view corresponds to a different way of perceiving the transitions among identity states. Views can be distinguished in two ways:

- View A has less detail with respect to identity states than View B, or
- View A cannot be compared with respect to the level of detail of View B.

Such properties lead to representations as partially-ordered sets. We choose a more restricted form of a partially ordered set, namely a lattice, because lattices capture all possible views over transitions among objects (a similar approach has been used by Stell and Worboys [8]). It arranges the views such that they correspond to a level of detail. At the highest level in the lattice, a view relates to the coarsest detail for an object (a single identity state of an object, e.g., `Library`), while at the first level of detail, more views of the object exist (Figure 5). These views include the identity states of the object at the coarsest detail as well as all first-level transitions (e.g., one transition linking two states of an object).

Two temporal zoom operations that support shifts between levels of detail are `Expand` and `Collapse` (Figure 6).

5.1 Expanding Transitions

The operation `Expand` relates two views of the same object at different levels of detail. At the coarsest level, a view is composed of an object associated with a single identity state and there will be some maximum level of detail beyond which the view does not change. At the first level of detail a view returns the state at the coarsest level plus the first-level detail.

The `Expand` operation takes a view over a sequence of identity states of an object (Figure 7a) and refining the temporal detail, returns any intermediate states of objects that are known to have occurred (Figure 7b). This distinguishes states of objects that were not apparent at a less-refined level of detail.

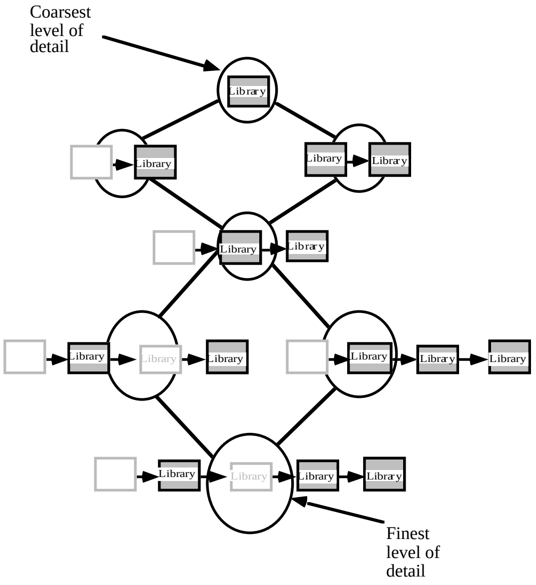


Figure 5: Detail lattice.

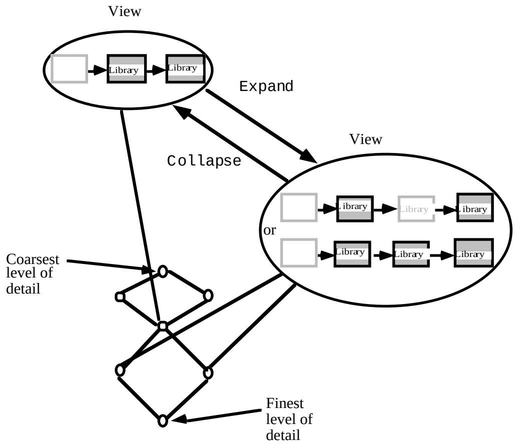


Figure 6: Temporal zoom operations: `Expand` and `Collapse`.

(a) (b)

Figure 7: `Expand` operation.

Based on a systematic application of the basic identity-based change operations, there are twenty-seven possible combinations of identity states that can be articulated through an `Expand` operation.

Certain sequences of identity states may not be valid for all domains, for example, to have a non-existing object without history followed by an existing object (other than at the beginning of a sequence of transitions between identity states) may not be plausible in some contexts.

As part of the `Expand` operation, therefore, a `Validate` operation may be desirable or necessary to check that the sequence of identity states is valid for that domain, with only valid results being returned to the user.

5.2 Collapsing Transitions

Coarsening temporal detail requires a different temporal zoom operation, the `Collapse` operation. In this case, a sequence of identity states of the same object is combined (Figure 8a) returning a new view with fewer identity states (Figure 8b). This results in a coarsening of detail over transitions between objects.

(a) (b)

Figure 8: `Collapse` operation.

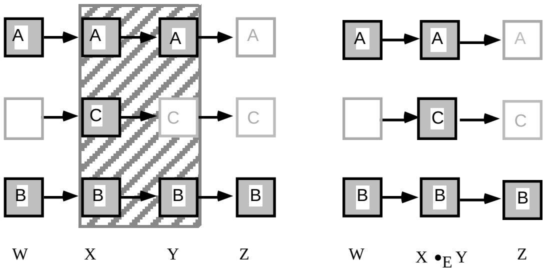
Similar to the `Expand`, the `Collapse` operation also uses certain rules that allow us to reason about combinations of identity states. These rules are similarly based on the set of valid identity-based changes to single objects.

There are different approaches one can take to determine the resulting state of an object after a `Collapse`. Depending upon the task, the priority assignments can be: existence followed by non-existing with history; non-existence; the before-transition state; or the after-transition state.

The operation `Collapse` relates two views such that one view is transformed into another view at a coarser level of detail. If the coarsest level of detail has been reached, only one state of an object exists; then the view does not change.

As an example, if objects A, B, and C exist and have a sequence of four identity states (W, X, Y, Z) (Figure 9a), we coarsen the detail by collapsing states X and Y of each object and use the reasoning that existence takes priority. The resulting view (Figure 9b) has been reduced to three states from four.

Depending on the priority scheme selected for the `Collapse` operation, the sequence of identity states returned may be meaningless or implausible for a domain. As the `Collapse` operation should return only a valid set of transitions to the user, a `Validate` operation will also be necessary as part of the `Collapse`. The `Validate` operation tests for any invalid or implausible transitions as known from the combinatorial rules and adjusts any such transitions.



(a) (b)

Figure 9: `Collapse` operation combines transitions.

The Collapse operation can be applied iteratively to obtain views at increasingly coarser levels of temporal detail. Likewise, a `Collapse` operation can be followed by an `Expand` where the result is also a view at the original level of detail. Although this is a desired outcome, it is not always guaranteed as given a lattice, the return of views at more than one level of detail is possible.

6. Conclusions

This paper has presented a new perspective on detail, namely, *detail of transitions*. This concept involves views, which are the perception a user has of objects, their identities, and transitions. Shifting between these levels of detail is accomplished through temporal zooming. Refining the level of detail over transitions between objects results in a new, expanded view of transitions at a finer temporal resolution. In this case, more identity states and transitions of the object are shown. Coarsening the level of detail takes a view and collapses the transitions into fewer stages, abstracting away irrelevant states for the user.

Although this paper focused on effects of temporal zooming on identities, the same principals apply to spatial and thematic properties. With a higher level of detail, for example, more information on the spatial properties of objects becomes known. Apparently, such types of zoom can be combined. Zooming in over identity and spatial attributes, for example, may reveal when new objects are formed as well as when existing objects change selected spatial properties. To offer users the flexibility to explore change from different perspectives, the temporal zoom operations need to be parameterized.

As an additional perspective to this work, the `Expand` operation also reveals transitions involving additional objects with different identities that at a coarser level are abstracted away. Operations, therefore, to articulate either more or fewer objects will explored in future work.

7. References

[1] B. Tversky and K. Hemenway, "Objects, parts, and categories," *Journal of Experimental Psychology: General*, vol. 113, pp. 169-191, 1984.

[2] J. Hobbs, "Granularity," in *Readings in Qualitative Reasoning about Physical Systems*, D. Weld and J. Kleer, Eds. San Mateo, CA: Morgan Kaufmann Publishers, Inc., 1990, pp. 542-545.

[3] N. Lam and D. Quattrochi, "On the issues of scale, resolution, and fractal analysis in the mapping sciences," *Professional Geographer*, vol. 44, pp. 88-98, 1992.

[4] M. Goodchild and J. Proctor, "Scale in a digital geographic world," *Geographical and Environmental Modelling*, vol. 1, pp. 5-23, 1997.

[5] A. Frank and S. Timpf, "Multiple representations for cartographic objects in a multi-scale tree: An intelligent graphical zoom," *Computers and Graphics*, vol. 18, pp. 823-829, 1994.

[6] S. Timpf, "Cartographic objects in a multi-scale data structure," in *Geographic Information Research: Bridging the Atlantic*, M. Craglia and H. Couclelis, Eds. London, UK: Taylor & Francis, 1997, pp. 224-234.

[7] S. Timpf, "Map cube model: a model for multi-scale data," in Proceedings of *Eighth International Symposium on Spatial Data Handling*, Vancouver, Canada, pp. 190-201, 1998.

[8] J. Stell and M. Worboys, "Stratified map spaces: a formal basis for multi-resolution spatial databases," in Proceedings of *Eighth International Symposium on Spatial Data Handling*, Vancouver, Canada, pp. 180-189, 1998.

[9] Y. Shahar, "A framework for knowledge-based temporal abstraction," *Artificial Intelligence*, vol. 90, pp. 79-133, 1997.

[10] Y. Shahar and M. Molina, "Knowledge-based spatiotemporal linear abstraction," *Pattern Analysis and Applications*, vol. 1, pp. 91-104, 1998.

[11] J. Clifford and A. Croker, "Objects in Time," *Database Engineering*, vol. 7, pp. 189-196, 1988.

[12] S. Khoshafian and G. Copeland, "Object identity," *SIGPLAN Notices*, vol. 21, pp. 406-416, 1986.

[13] K. Al-Taha and R. Barrera, "Identities through time," in Proceedings of *International Workshop on Requirements for Integrated Geographic Information Systems*, New Orleans, LA, pp. 1-12, 1994.

[14] K. Hornsby and M. Egenhofer, "Qualitative Representation of Change," in *Spatial Information Theory—A Theoretical Basis for GIS, International Conference COSIT '97, Laurel Highlands, PA*, vol. 1329, *Lecture Notes in Computer Science*, S. Hirtle and A. Frank, Eds. Berlin: Springer-Verlag, 1997, pp. 15-33.

[15] A. Frank, "Qualitative temporal reasoning in GIS-ordered time scales," in Proceedings of *Sixth International Symposium on Spatial Data Handling*, Edinburgh, Scotland, pp. 410-431, 1994.