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AN APPROACH FOR SPATIAL PATTERN MATCHING IN SIMULATION TRAJECTORIES

Tom Warnke, Adelinde Uhrmacher

Institute of Computer Science
University of Rostock
Albert-Einstein-Straße 22
18059 Rostock, GERMANY

ABSTRACT

For models that include spatial aspects, the description and recognition of spatio-temporal patterns is an important building block for the analysis of simulation trajectories. We propose an approach that makes use of user-definable qualitative spatial relations between moving entities to represent simulation trajectories as directed labeled graph. In this graph, spatio-temporal patterns can be found through a graph pattern matching algorithm. We implemented the approach using the graph database Neo4j and successfully tested it on movement data from the Robocup Soccer Simulation as well as spatial cell biological simulations.

1 INTRODUCTION

In many application fields, spatial aspects play an increasing role in model behavior. The simultaneous movement of entities during simulation runs gives rise to spatio-temporal patterns. The description and recognition of such patterns facilitates the analysis of spatial simulation experiment results and could also be used as target function in simulation-based optimization. Several approaches exist for qualitative reasoning about spatio-temporal properties as well as finding pattern occurrences in given data. However, none of these approaches deals with both the description and recognition of spatio-temporal patterns for a broad set of applications. Consider, for example, a match in the Robocup 2D Soccer Simulation League (Noda et al. 1997). As a multi-agent system with 22 players and one ball, a simulated match results in a set of movement trajectories. To formally describe interesting sequences of the match, e.g., a certain attack play, a spatio-temporal pattern specification is needed. Based on such a specification, match records can be searched for occurrences of the pattern. Similarly, spatio-temporal patterns are relevant for research questions about spatial cell biology models. For example, the movement of proteins on the cell membrane can give clues about their interaction and function for intercellular signaling pathways (Bittig et al. 2011). Specifying and searching for movement patterns is a crucial step in analyzing spatial simulation trajectories.

2 OUR APPROACH

We propose a graph-based technique for the representation and discovery of spatio-temporal patterns in simulation trajectories. The procedure to find occurrences of a spatio-temporal pattern in a simulation trajectory can be organized into the following steps:

1. A set of qualitative spatial relations between two entities, based on their relative positions, is defined (e.g., by distinguishing between direction and distance: "A is northwest and far from B" (Frank 1992)). The relations are chosen to fit the analysis task at hand and also to be jointly exhaustive and pairwise disjoint (JEPD (Düntsch 2005)).
2. At each time point of the trajectory, for each pair of entities the qualitative relation between the entities is determined from their relative positioning.

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3. A labeled directed graph representing the simulation trajectory is constructed. It contains time points, an ordering of the time points and the determined relations between all pairs of entities at every time point. We refer to this graph as the *data graph*.
4. Similar to the construction of the data graph, a *pattern graph* is constructed. It also makes use of the defined qualitative spatial relations.
5. Using a graph pattern matching algorithm, all occurrences of the pattern graph in the data graph are determined.

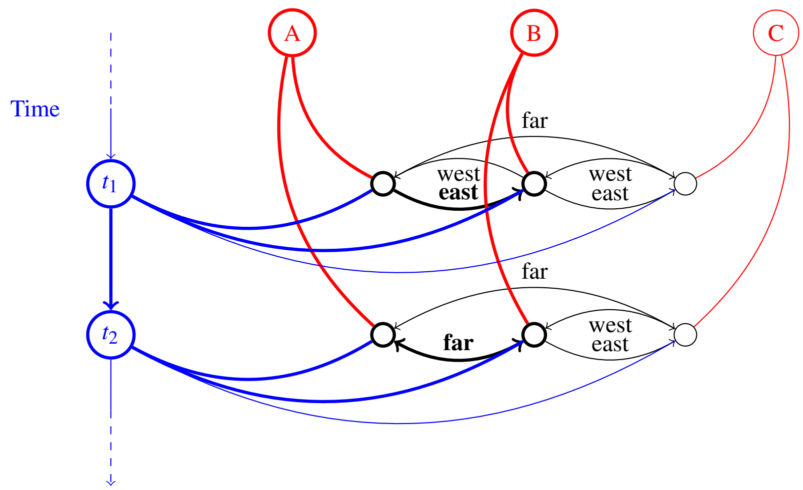

Figure 1: A snippet from a data graph representing two time points t_1, t_2 (blue) and three entities A, B and C (red) as well as the six resulting positions (black), related by undirected edges. Spatial relations are "east" with its counterpart "west" as well as the symmetric relation "far". Printed bold is an occurrence of the pattern graph "an entity is east of another, and at the next time point far away from it" (corr. $east(x,y) \wedge X(far(x,y))$, true with $\theta = [x/_A, y/_B]$ at time point t_1).

While the construction of the data graph is straightforward, the pattern graph can be defined in different ways. We implemented the algorithm above using the Graph Database Neo4j[1] for data graph construction and its powerful query language *Cypher* for pattern specification. It currently allows specifying complex patterns and finding their occurrences in reasonable time. The implementation has successfully been tested for the analysis of simulated soccer matches as well as spatial cell biology models. The current approach is focusing on points in time and space. Future work will be directed towards developing and evaluating domain specific languages for including also *nonpointlike* constructs in spatio-temporal patterns.

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[1] http://www.neo4j.org/