Spatio-Temporal Reasoning with Composite Events in Mobile Systems

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ABSTRACT

In mobile systems, the requirements on event detection are fundamentally different to those in distributed systems. Composite event detection must be driven not just by the time of occurrence of an event, but also by its location of occurrence. Hence, the theory of composite event detection, as applied in traditional DEBS, needs to be reassessed. In this short paper, we motivate the notion of spatio-temporal event detection and propose the base operators of a spatio-temporal event language.

Categories and Subject Descriptors

C.2.1 [**Network Architecture and Design**]: Wireless Communications

General Terms

Design, Algorithms

Keywords

Composite event detection, mobile systems, spatio-temporal reasoning

1. OVERVIEW

In wireless sensor networks, the affinity of space and time in the monitoring of physical phenomena and their spatio-temporal properties has been acknowledged [1]. There, Römer and Mattern propose four-dimensional spacetime (three dimensions for space and one dimension for time) to support data fusion, that is, to "assemble distributed observations into a coherent estimate of the original physical phenomenon" and discuss approaches to localisation of sensor nodes in spacetime. In [2], the same authors acknowledge the efficiency of event-based communication to transmit state changes between sensor nodes and investigate composite event detection techniques to detect real-world states in sensor networks. However, to date the spatial aspects of event detection in mobile systems have not been explored in a comprehensive manner. [3] and [4] consider location in publish/subscribe middleware. In [3], Chen et al. define the notion of spatial event and enable a spatial subscription model. In [4], Cugola and Munoz de Cote develop a distributed publish/subscribe middleware where spatial restrictions can be issued by publishers and subscribers. The work does not however consider location in the syntax and semantics of composite event languages.

Consider the ZebraNet project at Princeton University[1] ZebraNet uses wireless sensor technology to "perform novel studies of animal migrations and inter-species interactions". In such an environment, a composite event could state "notify me if a zebra and an antelope graze at the same location within a one-hour time period" or "notify me if the calf is more than 100m away from its mother". Today, such "spatial" occurrences cannot be expressed in a composite event language.

Traditional composite event languages (e.g. Snoop [5] or SAMOS [6]) allow for the temporal reasoning of event occurrences in distributed systems. Nodes are fixed, that is, the location of occurrence of an event is implicit and spatial reasoning is "hard-wired" into the application. This is not the case in mobile networks where nodes experience different degrees of mobility and the location of occurrence is linked to node location at the time of occurrence.

In traditional composite event languages, the event operators "sequence" (;), also called "happened-before", and "concurrency" (||) enable temporal reasoning over event occurrences. Other event operators, such as conjunction and disjunction, are irrelevant to temporal reasoning. Due to the lack of a global clock in distributed systems, times of occurrence are inaccurate and depend on the time synchronisation model. An interval-based timestamp, as suggested by Liebig et al. [7], captures clock uncertainty for each node of a distributed system. Point-based semantics, where events are regarded as instantaneous, and interval-based semantics, where events are regarded as durative, are used for the correlation of events.

In this short paper, we develop a simple model for spatio-temporal event detection. We present space in 1D. This eases comprehension and illustrates the main results. Applying the results to 2D and 3D is straightforward and will be presented in future work.

[1] http://www.princeton.edu/~mrm/zebranet.html

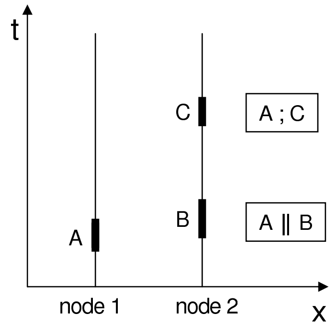

Figure 1: DEBS view of composite events

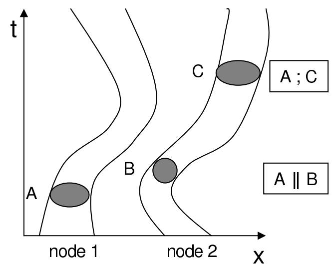

Figure 2: Mobile systems view of composite events

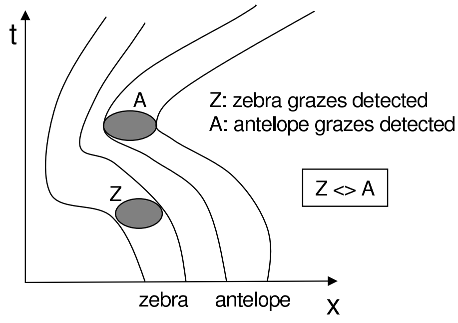

Figure 3: Example of "same location" operator

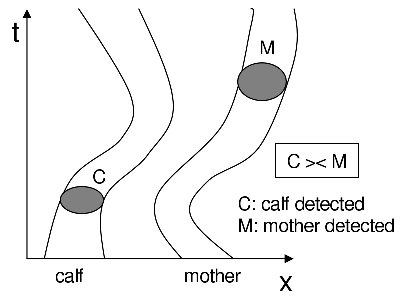

Figure 4: Example of "remote" operator

Figure 1 illustrates the time reasoning applied in traditional distributed systems. 1D space is presented on the x-axis, time is presented on the t-axis. Subevents occur on two nodes which are fixed and are therefore presented as straight lines on the x-axis. Clock uncertainty at time of occurrence is presented in the form of intervals along the t-axis. Two composite events are illustrated, $A \| B$ and $A; C$. The analogue case in a mobile system is presented in figure 2. Due to the problem of localisation in space and time, uncertainty exists along both the x- and the t-axis. Since frequent resynchronisation reduces the location and clock uncertainties, the uncertainty area grows and shrinks periodically.

Consider the example above. The subevents of "notify me if a zebra and an antelope graze at the same location within a one-hour time period" are presented in figure 3. We need an instance of "zebra grazes detected" and "antelope grazes detected" at the same location to detect the full composite event. "Notify me if the calf is more than 100m away from its mother" is illustrated in figure 4, where "calf detected" and "mother detected" are primitive events C and M. We ignore the temporal restriction "within a one-hour time period" and the spatial restriction "more than 100m away" for the time being.

By analogy to temporal reasoning, we introduce two base operators for spatial reasoning, "same location" (<>) and "remote" (><). Hence, in both dimensions, x (for 1D space) and t (for time), we are now able to detect overlaps of uncertainty areas (in form of "concurrency" and "same location") and disconnections (in form of "sequence" and "remote") and have therefore achieved consistent semantics. Note that the spatial operators apply immediately in 2D/3D.

Although our base event operators for temporal and spatial reasoning provide for fundamental reasoning on event occurrences in mobile systems, their expressiveness is limited. Hence, we propose temporal and spatial restrictions over time and location of occurrences of events to improve expressiveness. In [8], a spatial restriction (event occurs at a specific location or in a group) and a temporal restriction (event occurs in a time interval) are introduced for event correlation in hybrid network environments. More recently, Qiao et al. presented "temporal events", where events are composed using temporal event operators [9]. The first approach is very limited and the latter covers temporal reasoning (in interval-based semantics) only.

A temporal restriction of an event A is defined as $A_{(T-res)}$ where *T-res* represents a time interval. A temporal restriction of a composite event $A\ op\ B$ is defined as $(A\ op\ B)_{(T-res)}$ where *T-res* represents a time interval (A and B lie within "time interval") or a time difference (A and B are "time difference" apart). A spatial restriction of an event A is defined a $A_{(S-res)}$ where *S-res* represents a region. A spatial restriction of a composite event $A\ op\ B$ is defined as $(A\ op\ B)_{(S-res)}$ where *S-res* represents a region (A and B lie with "region"), a distance (A and B are "distance" apart), or a direction (B lies in a given direction of A)[2].

Using the language outlined above, our examples are presented as follows:

1. $(\textit{zebra grazes detected} <> \textit{antelope grazes detected})_{(\subseteq 1h)}$
2. $(\textit{calf detected} >< \textit{mother detected})_{(\geq 100m)}$

Our temporal and spatial restrictions are defined for a point-based semantics. Interval-based semantics will be considered

[2]Note that there is no analogue of "direction" in the temporal domain since it is implicit in the event operator "sequence".

in future work. There, the location of occurrence denotes a region, and spatial reasoning needs to address questions such as, does the location of occurrence of one event lie within the location of occurrence of another event?

Note that time and location of occurrence are ordinary event parameters that drive composite event detection in mobile systems, for example when detecting a "sequence" of two events. Temporal and spatial restrictions allow for refined reasoning on those event parameters. In the strict sense, temporal and spatial restrictions are conditions and could be dealt with in the C-part of ECA rules. However, besides limiting the expressiveness of the composite event language, this would lead to the detection of composite events that are later filtered out in the condition-part. Temporal and spatial restrictions enable composite event detection to be localised in space and time and hence, save indispensable resources

Currently, we study (qualitative and quantitative approaches) to spatio-temporal reasoning in AI with the aim to define an interval/region-based semantics of our model (see e.g. [10]) and Geographic Information Systems (GIS) to refine temporal and spatial restrictions (see e.g. [11], [12]).

2. CONCLUSIONS

In further work, we will extend our 1D model to 2D/3D and develop models for both point- and interval-based semantics. Moreover, we will present temporal and spatial restrictions as well-defined expressions over time and location of occurrence parameters.

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