The datAcron Ontology for Semantic Trajectories

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Abstract. Motivated by real-life emerging needs in critical domains, this paper proposes a coherent and generic ontology for the representation of semantic trajectories, in association with related events and contextual information. *The main contribution of the proposed ontology is the representation of semantic trajectories at different levels of spatio-temporal analysis.*

1 Introduction

Many critical domains w.r.t. economy and safety, such as the Maritime and the Aviation domains, where Situation Awareness (MSA) and Air Traffic Management (ATM), respectively, are of importance, require analysis of moving objects' behaviour over time: Challenges concern effective detection and forecasting of moving entities' trajectories, as well as recognition and prediction of important events by exploiting information about entities' behaviour and contextual data. Due to these needs, semantic trajectories are turned into "first-class citizens", forming a paradigm shift towards operations that are built and revolve around the notion of trajectory. Our work focuses on trajectories and aims to build solutions towards managing data that are connected via, and contribute to enriched views of trajectories: Doing so, we revisit the notion of semantic trajectory and build on it. Specifically, it is expected that we will be able to *represent, store and manipulate the wealth of information available in disparate and heterogeneous data sources, integrated in a representation where trajectories are the main entities, towards computing meaningful moving patterns so as to recognize and predict the behaviour and states of moving objects.* Therefore, motivated by real-life emerging needs in MSA and ATM domains, this paper proposes a coherent and generic ontology for the representation of semantic trajectories, in association with related events and contextual information. *The main contribution of the proposed ontology is the representation of semantic trajectories at different levels of spatio-temporal analysis: Trajectories may be seen as temporal sequences of moving objects' positions derived from raw data, of mere geometries, of temporal sequences of raw data aggregations signifying meaningful events (generalizing on the stops and moves model [8]), providing a synoptic view of raw trajectories [7], and as temporal sequences of non-overlapping meaningful trajectories segments*

(each revealing specific behaviour, event, goal, activity etc). Representations at any such level of analysis should be linked to each other, as well as to contextual information and co-occurring events: These are important features for performing informed analysis tasks at different levels of detail/analysis, consulting raw data and/or semantic information associated with it.
Existing approaches for the representation of semantic trajectories either (a) use plain textual annotations instead of semantic links to other entities [1], [2], [3], hindering the provision of a fully-fledged representation where trajectories are semantically linked with other data or with semantic resources associated with moving objects' behaviour; (b) constrain the types of events that can be used for structuring a trajectory [1], [2]; or (c) make assumptions on the constituents of trajectories [3], [6] [4] (e.g. semantic trajectories in [3] are sequences of sub-trajectories, while in [4] are sequences of episodes). To a greater extent than previous proposals, the proposed ontology *supports the representation of trajectories at multiple, interlinked levels of analysis*: For instance, although [4] provides a rich set of constructs for the representation of semantic trajectories, these are sequences of episodes, each associated with raw trajectory data, and optionally, with a spatio-temporal model of movement. However, there is no fine association between abstract models of movements and raw data. On the other hand, [3] provides a two-levels analysis where semantic trajectories are lists of semantic sub-trajectories, and each sub-trajectory in its own turn is a list of semantic points. Regarding events and episodes, these are connected to specific resources at specific levels of analysis: In [3] events -mostly related to the environment rather than to the trajectory itself- are connected to points only (something that may lead to ambiguities in some cases), while in [4] episodes concern things happening in the trajectory itself, and may be associated to specific models of movement: It is not clear how multiple models of a single trajectory -each at a different level of analysis- connected to a single episode, are associated. Finally, contextual information in [4] is related to movement models, episodes or semantic trajectories, which is quite generic, while in [3] environment attributes are associated to points only, and are assigned specific values.

2 The datAcron Ontology

The datAcron ontology (`http://ai-group.ds.unipi.gr/datacron_ontology/`) was developed by group consensus over a period of 12 months following the HCOME methodology [5]. It has been designed to be used as a core ontology for the MSA and ATM domains, following a data-driven approach towards supporting analysis tasks. Its development has been driven by ontologies related to our objectives (e.g. DUL, SimpleFeature, NASA Sweet and SSN) as well as schemas and specifications regarding data sources from the different domains.
The main concepts and properties in the datAcron ontology regarding trajectories, are depicted in Figure 1. Starting from the definitions about *raw*, *structured* and *semantic trajectories* provided in [7], a *raw trajectory* is a temporal sequence of raw data specifying the moving object's spatio-temporal positions. Raw data

can be aggregated, analyzed and semantically annotated, providing multiple abstractions of a trajectory. A maximal sequence of raw data that comply with a given pattern, define an *episode*. In this work we focus on *events* as a generalisation of episodes, taking also into consideration -in conjunction to movement data- *contextual information* (i.e. any information -mostly about the environment of an object- that affects its movement). *Events* represent specific, aggregated or abstract happenings instantiating an event pattern (whose description is not part of the ontology) and are distinguished to *low-level events* regarding information about a single trajectory, isolated from its context, and *high-level events* regarding information from multiple objects' trajectories and/or contextual information. Each event is associated with one or more moving objects, and it has spatial, temporal and domain-specific properties.

A *semantic trajectory* consists of a sequence of temporally non-overlapping *trajectory parts* that can be either *semantic nodes*, *raw positions* reported from sensing devises, or *trajectory segments*. Each trajectory part may be associated to a specific *geometry*, representing a point or region of occurrence, and a *temporal entity* specifying an instant or time interval of occurrence. A *semantic node* provides a meaningful abstraction or aggregation of raw positions. E.g. a set of raw positions may signify a "turn" event: This set can be represented as a single semantic node, associated to a low-level event of type "turn". Each semantic node or trajectory segment, may be associated with any trajectory part at a finer level of analysis; e.g. with a set of raw positions representing a "turn" or the last and first point of a "gap of communication". A *trajectory segment* is a trajectory itself, part of a whole trajectory. Segmentation of trajectories can be done with different objectives depending on the application and target analysis. A *structured trajectory* is a meaningful sequence of non-overlapping semantic trajectory parts. Any trajectory part may be associated with an event that co-occurs with it spatially and/or temporally: E.g. A bad weather region may co-occur with a trajectory crossing-it (thus, related spatially) during a time period (related temporally). It must be pointed out that each trajectory part can be associated with different trajectories of the same moving object: E.g. with the planned and with the actual trajectory of that object.

According to the above specifications, and as Figure 1 shows, a trajectory -for instance- can be segmented to non-overlapping semantic trajectory segments, each corresponding to one or more semantic nodes. Each semantic node may be associated with a specific raw position or a temporally ordered sequence of raw positions of a moving object. Trajectory parts can be associated with contextual information, and they can be associated with events that happen independently from the trajectory but co-occur with the trajectory affecting the moving object's behaviour. In such a representation, one may consider a trajectory either as a list of non-overlapping trajectory segments, or as lists of semantic nodes, or even lists of raw trajectory data, or as a simple geometric object occurring in a specific time interval, also considering different mixtures of these levels of analysis, depending on analysis needs. Furthermore, it must be noticed that the notion of event comprises happenings due to the trajectory itself (e.g. a "gap

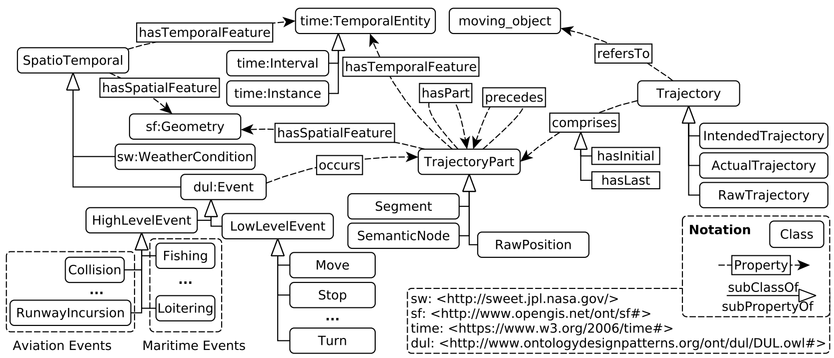

Fig. 1: The main concepts and relations of the proposed ontology.

of communication") also in conjunction to contextual information (e.g. vessel in a protected or in a bad-weather area). Such events, associated to constructs at any level of abstraction can be further inspected and justified by information at lower-levels of analysis, or be further abstracted and generalised to more abstract levels.

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