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MetaQ: A knowledge-driven framework for context-aware activity recognition combining SPARQL and OWL 2 activity patterns

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ABSTRACT

In this paper we describe MetaQ, an ontology-based hybrid framework for activity recognition in Ambient Assisted Living (AAL) environments that combines SPARQL queries and OWL 2 activity patterns. SPARQL is used as a standardised declarative language for aggregating, interpreting and enriching low-level contextual RDF knowledge bases with higher level derivations. The proposed SPARQL-based reasoning framework supports key inferencing tasks that are important in activity interpretation domains, but not supported by the standard semantics of OWL 2, such as temporal reasoning and dynamic assertion of structured individuals. In order to promote the extensibility and reuse of the underlying interpretation semantics, the reasoning framework is further enhanced with a conceptual layer that allows the formal representation of activity meta-knowledge by means of DOLCE+DnS Ultralite (DUL) ontology patterns. We illustrate the capabilities of the proposed framework through its deployment in a hospital for monitoring activities of Alzheimer's disease patients.

1. Introduction

The demand for *context-aware* user task support has proliferated in the recent years across a multitude of application domains, ranging from healthcare and smart spaces to transportation and energy control [1]. A key challenge in such applications is to abstract and fuse the captured *context* in order to elicit an adequate understanding of the user situation and afford services that are effectively tailored to the user needs [2].

Congruous with the open nature of context-awareness, where information at various levels of abstraction and completeness has to be integrated, ontologies have attracted growing interest as means for modelling and reasoning over contextual information and human activities in particular [3]. The OWL DL [4] and, more recently, OWL 2 [5] ontology languages have been proposed to capture the context elements of interest (e.g. persons, events, activities, locations) and their pertinent relations, and to formalise activity recognition as logical reasoning by mapping the information that is obtained directly through context detectors (e.g. video cameras, contact sensors) to respective class and property assertions.

To harvest the several benefits brought by ontologies (e.g. modelling of complex logical relations, sharing information coming from heterogeneous sources, availability of sound and complete reasoning engines [6,7]), while coping with OWL's

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inherent inability to support temporal reasoning, ontology-based frameworks adopt either an a-temporal approach to activity modelling [8–10] or combine ontologies with rules [11–14].

In the first case, the data is segmented into chunks of activities, e.g. based on predefined time windows, allowing complex activities to be derived using standard OWL reasoning for context classification. For example, the tea preparation activity in the kitchen that is inferred on the basis of heating water and using a tea bag and a cup could be modelled in OWL as[1]:

```
MakeHotTea ≡ Activity and (actor only (Person
                 and (uses some TeaBag)
                 and (uses some Cup)
                 and (uses some Kettle)
                 and (near some KitchenBench)))
```

Though relevant to applications where suitable time windows can be reliably defined, a-temporal approaches fall short when intricate activity patterns are involved, requiring, for instance, the discrimination of sequential and interleaved activities, or the modelling of dependencies among the sub-activities that go beyond the property chains expressivity provided by OWL 2. Moreover, such class descriptions can classify only existing instances, meaning that the unknown activity context must be identified and asserted beforehand, e.g. through snapshot-like definitions. For example, the `MakeHotTea` axiom above can classify only existing `Activity` instances that have been asserted as part of the "current" context.

In the second case, the combination of ontologies with rules that manage the temporal information and knowledge updates, affords far more expressive and flexible alternatives than their a-temporal counterparts. The ontology is used to represent activity-related information, whereas rules are used to further aggregate activities, describing the contextual conditions that drive the derivation of complex activities. For example, the following (pseudo) rule defines the assertion of a `MakeHotTea` activity when the person is near the kitchen bench and uses (`UseX` activities) tea-related objects.

```
UseTeaBag(?a1), UseCup(?a2), UseKettle(?a3), NearKitchenBench(?a4),
actor(?a1, ?p), actor(?a2, ?p), actor(?a3, ?p), actor(?a4, ?p),
time(?a1, ?t1), time(?a2, ?t2), time(?a3, ?t3), time(?a4, ?t4),
contains(?t4, ?t1), contains(?t4, ?t2), contains(?t4, ?t3)
→ MakeHotTea(?new), time(?new, ?t4), actor(?new, ?p)
```

However, ontologies in such approaches are essentially used solely as vocabularies for representing and sharing activity-related information. The actual interpretation of activity semantics are defined outside the ontology models, e.g. they are encapsulated in rules that are tightly-coupled with implementation frameworks, hindering interoperability and reuse. Thus, applications that share similar purposes and scope cannot directly avail of existing frameworks. Standardisation efforts for the exchange of rules on the Semantic Web, such as RIF [16], are useful to develop an interchange format between existing rule languages in a syntactic level. These standards, however, fail to capture the semantics in a conceptual level, e.g. through formal and semantically enriched models.

To promote sharing and reuse of activity descriptions, while availing of the temporal reasoning capabilities afforded by the use of rules, we propose MetaQ. MetaQ is an OWL 2 ontology-based framework for context-aware activity recognition that brings together the rigorous semantics of the DnS design pattern [17] of DOLCE + DnS Ultralite (DUL) [18] and of SPARQL [19], the standard query language for the Semantic Web. Extending the DnS design pattern and making use of the OWL 2 meta-modelling capabilities (*punning* [20]), MetaQ defines an activity pattern ontology that serves as a meta-model for the formal description of activities. The activity descriptions are in turn translated into SPARQL queries. SPARQL is an expressive standardised language, whose semantics and complexity have been studied fairly extensively, showing that SPARQL algebra has the same expressive power as relational algebra [21,22]. Moreover, SPARQL is supported by the majority of RDF-compliant frameworks, as well as triple stores and reasoners, thus further advancing the usage of standardised Semantic Web tools. As such, the contributions of the paper can be summarised in the following:

- An activity ontology pattern for the formal modelling of activity meta-knowledge, that is, contextualised relations among domain activity classes. The patterns treat domain activity classes as instances, allowing the modelling of complex class relations that go beyond tree-like dependencies and the restricted form of role chains afforded by OWL 2, such as the temporal relations among sub-activities.
- A context-aware activity recognition framework that promotes a high degree of interoperability and transparency of interpretation semantics.
- A practical framework for the combination of the standard OWL reasoning paradigm and custom activity interpretation rules in the form of SPARQL for (offline) context-based activity recognition, with well-defined semantics and high degree of interoperability.
- A proof of concept implementation and evaluation of MetaQ in a hospital for monitoring activities of people with Alzheimer's disease (AD). The system supports the dynamic translation of the activity patterns into SPARQL queries,

[1] The example follows the OWL Manchester syntax [15].