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ABSTRACT

In this paper, we describe the implementation of a qualitative temporal reasoning. We will discuss the challenges and benefits of using the Semantic Web and Allen's Interval Logic for such reasoning.

Categories and Subject Descriptors

D.1.6 [**Programming Techniques**]: Logic Programming

General Terms

Algorithms, Design

Keywords

Allen's Interval Logic, Semantic Web, Temporal Reasoning

1. INTRODUCTION

As our physical world appears to be based on space and time dimensions, most cyber-physical systems integrate spatial and temporal aspects.

This paper focuses on Temporal Reasoning, using Allen's Interval Logic, as it handles time intervals, that are more insightful that instants to describe a context. We implemented Allen's Interval Logic with the Semantic Web. We will therefore describe some visible conflicts in the inner philosophies of Allen's Interval Logic and the Semantic Web, and the solutions we have found to overcome it.

2. IMPLEMENTATION

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2.1 Allen's Interval Logic

Allen's Interval Logic[1] proposes a formal semantic for intervals—*ie.* for temporal intervals—and defines a complete and mutually exclusive set of *thirteen* relations between two intervals, namely *precedes* (***p***), *precededBy* (***P***), *meets* (***m***), *metBy* (***M***), *overlaps* (***o***), *overlappedBy* (***O***), *contains* (***D***), *during* (***d***), *starts* (***s***), *startedBy* (***S***), *finishes* (***f***), *finishedBy* (***F***), *equals* (***e***)[1].

It is important to notice that Allen's Interval Logic natively handles uncertainty and incomplete knowledges, through disjunctions. For instance, it is possible to declare that $a(p, m, o)b$, meaning that a either *precedes*, *meets* or *overlaps* b.

Moreover, Allen's Interval Logic defines a *composition* operation $\odot$, and provides a composition table[2], so that the composition of $a(r_1)b$ and $b(r_2)c$ will provide $a(r_3)c$, given $r_1 \odot r_2 = r_3$. However, the problem of checking consistency in Allen's Interval Logic, named *satisfaction* problem, is known to be NP-Hard [7]. We then use Path-Consistency algorithm[6] to "propagate" relations between intervals, as it provides a consistent and sound solution.

2.2 Ontologies

The Semantic Web shows its real potential through its interoperability. Thanks to its design, we can seamlessly include and reuse external statements. Thus, we rely on the OWL-Time ontology[5] about *time*, which defines the thirteen Allen's relations. We have then created rules to infer relations between intervals when their beginning and end *instants* are known (Listing 1).

Listing 1: Population of intervals, in N3 language

```
_:interval1 a time:ProperInterval ;
    time:hasBeginning _:instant_start ;
    time:hasEnd _:instant_end .
_:instant_start a time:Instant ;
    time:inXSDDateTime "2013-03-28T12:00:00+01:00"^^
        xsd:dateTime ;
```

[1] http://commons.wikimedia.org/wiki/Allen's_calculus

[2] https://commons.wikimedia.org/wiki/Allen's_calculus:composition_table

```
_:instant_end a time:Instant ;
    time:inXSDDateTime "2013-03-28T13:00:00+01:00"^^
        xsd:dateTime .
_:interval2 a time:ProperInterval .

(_:interval1 _:interval2) logic:possible (
    time:before time:intervalMeets
    time:intervalMetBy time:after) .
# ...
(t:intervalMetBy t:intervalOverlaps) a:composes (
    t:intervalDuring t:intervalFinishes
    t:intervalOverlappedBy).
# ...
```

2.3 Compositions

The second part of our implementation focuses on propagating the compositions with the Path-Consistency algorithm (Listing 2). An implementation of Allen's Interval Logic with the Semantic Web was already described by SOWL[2]. However, it does only handles atomic compositions, whereas our encoding also handles compositions with disjuncted relations.

The Semantic Web has been created under the Open World Assumption (OWA) (as opposed with Closed World Assumption (CWA)), and respects a constraint of monotonicity. In intuitive terms, this means that a statement will always be *true*, and what is not stated is *unknown*. On the other hand, Allen's Interval Logic is based on *circumscription* and uses *disjunction*, so that a statement is *possible* (but might be rejected later on), and what is not stated is known to be *false*. These assumptions do not natively fit with each other.

Hence we used Scoped Negation As Failure (SNAF)[3] to perform reasoning on disjunctions without rejecting the philosophies of the Semantic Web. Indeed, the SNAF lets us consider a subgraph of the Knowledge Base (KB) as a Closed World. SNAF has been implemented by Euler Rule Engine[3] through the built-in function *findAll*, that enables to query a subgraph from an ontology, assuming a SNAF.

Allen's Interval Logic implies to reduce the set of possible relations between two intervals at every new inference. This conflicts with the Monotonicity Constraint. An acceptable solution is to use an intermediate property: rather than a single *possible* property that will be constantly reduced, we have several *possible* properties between two events, and we eventually merge it to a property *resolvedRelations*, that will be the intersection of all *possible*.

Listing 2: Propagating possible relations between events using the Path Consistency algorithm

```
# Relations between A & C through B:
{ # R1 & R2 such as "A(R1)B & B(R2)C"
  (?A ?B) logic:possible ?R1 .
  (?B ?C) logic:possible ?R2 .
  ?A log:notEqualTo ?C .
  # findall X such as "X in R1(.)R2"
  ?SCOPE e:findall ( ?X
      { ?R1 list:member ?M1 .
        ?R2 list:member ?M2 .
        (?M1 ?M2) a:compose ?X . } ?F).
  ?F list:append ?L . # L = flatten(F)
  ?L e:distinct ?D . # D = unique(L)
} => { (?A ?C) logic:possible ?D . }.

# Intersection of sets:
{ # for one possible set Q
  (?A ?B) logic:possible ?Q.
  # find all possible sets FOOTPRINT
  ?SCOPE e:findall ( 1
      { (?A ?B) logic:possible ?X. }
      ?FOOTPRINT).
  # S = intersection of Q with FOOTPRINTs
  ?SCOPE e:findall ( ?I
      { ?Q list:member ?I.
        ?SCOPE e:findall ( 1
          { (?A ?B) logic:possible ?X.
              ?X list:member ?I. }
          ?FOOTPRINT). } ?F).
  ?F e:sort ?S.  } =>
{ (?A ?B) logic:resolvedRelations ?S. }.
```

[3] http://www.agfa.com/w3c/euler

Therefore the reasoning engine will make every possible relations emerge between intervals, including intervals whose borders are unknown, as long as these intervals have at least one known relation with another interval.

3. CONCLUSION

Through this paper, we have described the implementation of Allen's Interval Logic within the Semantic Web. Although Allen's Interval Logic is already mature and well-documented, we found no sound and complete implementation of Allen's Interval Logic within the Semantic Web, using Path-Consistency Algorithm to propagate the composition rule. Despite of the fact that the Semantic Web is based on the Open World Assumption (OWA) and the Monotonicity Constraint whereas Allen's Interval Logic requires a Circumscription, the reasoning is made possible by the existence of Scoped Negation As Failure (SNAF) functions within the Semantic Web.

One may argue that the necessity of SNAF is unnatural, and solely due to the encoding of Time Intervals. It would indeed be interesting to adapt this work, using the Semi-Intervals Algebra[4] rather than Allen's Algebra.

Our implementation may be useful to maintain a knowledge-base involving temporal informations, such as a cyber-physical systems.

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