Handling Temporal Data Imperfections in OWL 2 - Application to Collective Memory Data Entries

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Abstract. Dealing with imperfect temporal data entries in the context of Collective and Personal Memory applications is an imperative matter. Data are structured semantically using an ontology called "Collective Memo Onto". In this paper, we propose an approach that handles temporal data imperfections in OWL 2. We reduce to four types of imperfection defined in our typology of temporal data imperfections which are imprecision, uncertainty, simultaneously uncertainty and imprecision and conflict. The approach consists of representing imperfect quantitative and qualitative time intervals and time points by extending the 4D-fluents approach and defining new components, as well as reasoning about the handled data by extending the Allen's Interval algebra. Based on both extensions, we propose an OWL 2 ontology named "TimeOntoImperfection". The proposed qualitative temporal relations are inferred via a set of 924 SWRL rules. We validate our work by implementing a prototype based on the proposed ontology and we apply it in the context of the Collective Memory Temporal Data.

Keywords: Temporal data imperfection · Imprecision · Uncertainty · Both imprecision and uncertainty · Conflict · OWL 2 · 4D-fluents approach · Allen's interval algebra · Collective Memory Temporal Data

1 Introduction

Temporal Collective and Personal Memory Data may be affected by many types of imperfection [15]. In fact, Collective Memory is dedicated to relate historical facts like National Movement and Festivals and to describe remarkable passages from the lives of famous personalities. For instance, "Marilyn Monroe died on the night of August 4 to 5, 1962. Nearly five hours passed between the estimated time of death, around 9:30 p.m. and 10 p.m.". In this example, the imprecision is expressed in "the night of August 4 to 5, 1962" and "around 9:30 p.m. and 10 p.m.".

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Many other kinds of imperfections that may affect temporal data are distinguished in our proposed typology [5] and the typology of Collective Memory Data imperfection proposed in [15]. Representing and reasoning about imperfect temporal data in the context of Collective Memory Model, based on an ontology named "CollectiveMemoOnto", is what we specifically addressed in this work. We reduce to four types of imperfection defined in our typology which are imprecision, uncertainty, both uncertainty and imprecision and conflict.

In the semantic web field, several approaches have been proposed to deal with perfect temporal data. However, to the best of our knowledge there is no works that deal with many temporal data imperfections at the same time.

In this paper, we propose an approach for representing and reasoning about imperfect temporal data in terms of both qualitative relations (e.g., "before") and quantitative ones (time intervals and points). It consists of: *(1)* Representing imperfect temporal data in OWL2. We extend the 4D-fluents approach [23] with new ontological components to represent: *(1.1)* imperfect quantitative temporal data, and *(1.2)* qualitative temporal relations between time intervals and points. Certainty degrees related to each kind of imperfection are calculated using possibility and evidence theories. *(2)* Reasoning about imperfect temporal data by extending the Allen's interval algebra [6]. It proposes qualitative relations only between time intervals. It is not devoted to handle imperfect time intervals. Furthermore, it is not intended to relate a time interval and a time point or two time points. We extend it by proposing qualitative temporal relations between imperfect time intervals. They preserve important properties of the original algebra. We adapt the resulting interval relations to propose temporal relations between a time interval and a time point, and two time points. *(3)* Proposing an OWL 2 ontology called "TimeOntoImperfection". It may be integrated in other ontologies to handle imperfect temporal data such as "CollectiveMemoOnto". It is implemented based on our extensions. Inferences are done using SWRL rules.

The structure of this paper is as follows. Preliminary concepts and related work in the fields of temporal data representation and reasoning in the Semantic Web are reviewed in Sect. 2. Section 3 introduce our proposed 4D-fluents approach extension. Section 4 introduce our proposed Allen's Interval Algebra extension. Section 5 presents our OWL 2 "TimeOntoImperfection" ontology. In Sect. 6, we present a validation in the context of Collective Memory Data.

2 Preliminaries and Related Work: Handling Temporal Data in Semantic Web

Imperfect temporal data are characterized using quantitative or qualitative terms. Imperfect quantitative temporal data means imperfect time intervals and points.

2.1 Temporal Data Representation and Reasoning About

Current technologies for the Semantic Web suffer from its lack to represent and reason about temporal data. Ontology languages such as OWL provide only binary relations and forsaken temporal data, which presents a major weakness. This explains the emergence of many researches in this context.

We classify them into two categories: *(1)* approaches that extend OWL or RDF syntax by defining new OWL or RDF operators and semantics to incorporate temporal data, which are Temporal Description Logics [7], Concrete Domains [17] and Temporal RDF [12]. *(2)* approaches that are implemented directly using OWL or RDF to represent temporal data without extending their syntax, which are Versioning [16], Reification [9], N-ary Relations [18], 4D-Fluents and Named Graphs [22]. They offer reasoning support and they can be combined with existing tools [11].

Most of these approaches handle only perfect temporal data and neglect imperfect ones and few approaches treat only some imperfections but not many imperfections at the same time. They are not intended to handle time points and qualitative temporal relations between a time interval and a time point or even two time points. Our approach should be based on existing OWL constructs. We choose to extend the 4D-fluents approach to represent imperfect quantitative temporal data and associated qualitative temporal relations since it minimizes data redundancy as the changes occur on the temporal parts and keep the static part unchanged. It maintains a full OWL expressiveness [8,13,20,24] and [14]. In 4D-fluents approach presents two classes, named "TimeSlice" and "TimeInterval". Four certain properties, named "tsTimeSliceOf", "tsTimeIntervalOf" "HasBeginnig" and "HasEnd"are introduced.

2.2 Temporal Data Reasoning: Allen's Interval Algebra

Allen proposed 13 qualitative temporal relations between perfect time intervals. He defined them in terms of the ordering of the beginning and ending bounds of the corresponding intervals. A particularity that the Allen's algebra holds, is that we can deduce new relations through the composition of other ones (e.g., "Before (A, B)" and "Equals (B, C)" give "Before (A, C)". Allen's interval algebra is not dedicated to handle uncertain time intervals and it does not relate a time point and a time interval, nor two time points. A number approaches have been extended this algebra such as [1,8,21] and [19]. These extensions are based on theories related to imprecise temporal data or uncertain temporal data. Furthermore, most of these extensions do not preserve all the properties of the original Allen's algebra. For instance, in [18], the relation "Equals" is not reflexive. However, the compositions of the resulting relations are not studied by the authors. For example, in [10], the authors do not propose the composition table of the proposed temporal relations. Most of the proposed approaches that represent and reason about imperfect temporal data, mainly deal with only imprecise temporal data or only uncertain temporal data and use fuzzy and probability theories. However, to the best of our knowledge there is no approach to deal, at the same time, with several types of imperfections in ontology.

3 Representing Temporal Data Imperfection in OWL 2

We extend the 4D-fluents approach with new ontological components and components based on OWL-Time[1] ontology to represent imperfect quantitative temporal data and associated qualitative temporal relations in OWL2. We reduce to imprecision, uncertainty, both uncertainty and imprecision at the same time and conflict as kinds of temporal data imperfections.

"TimeSlice" is the class domain for entities representing temporal parts. "time:TimeInterval" and "time:TimeInstant" are respectively the classes representing intervals and time points. "time:DateTimeDescription" is the class representing dates and time clocks. We propose an approach to deal with imprecise temporal data, specifically dates and time clocks in OWL 2 with a crisp view. We represent precise time points (dates and time clocks). For the dates, let D, Mo and Y be, respectively, precise day, month and year. We use three datatype properties from OWL-Time named "time:day", "time:month" and "time:year" to relate, respectively, "time:DateTimeDescription" and D, Mo and Y. Similarly, we represent the time clocks. We represent imprecise time points (dates and time clocks). For the dates, let D, Mo and Y be, respectively, imprecise day, month and year. We represent them by disjunctive ascending sets $\{D^{(1)}...D^{(d)}\}$, $\{Mo^{(1)}...Mo(mo)\}$ and $\{Y^{(1)}...Y^{(y)}\}$. We define for each of D, Mo and Y, respectively, two datatype properties: "HasDayFrom" and "HasDayTo", "HasMonthFrom" and "HasMonthTo", "HasYearFrom" and "HasYearTo". They are all connected to the "time:DateTimeDescription" class. Similarly, we represent the time clocks. We also represent the other types of imperfections (i.e., uncertainty, both uncertainty and imprecision, and conflict). A detailed description of this part is available in an appendix.[2]

4 Reasoning About Uncertain Temporal Data: Extending Allen's Interval Algebra

We extend the Allen's algebra to: *(1)* reason about imperfect quantitative temporal data to infer qualitative temporal relations and *(2)* to reason about the qualitative temporal relations to infer new ones.

We extend the Allen's interval algebra to reason about imperfect time intervals. When considering perfect time intervals, our approach reduces to Allen's interval algebra. We redefine the 13 Allen's relations to propose temporal relations between imperfect time intervals. For example, for uncertain time intervals, let $A = [A^-_{ca-}, A^+_{ca+}]$ and $B = [B^-_{cb-}, B^+_{cb+}]$ be two uncertain time intervals. For instance, we redefine the relation "$Before(A, B)$" as: "$Before_c(A, B)$"; where "c" is the certainty degree associated to the relation "Before" between A and B. This means that the uncertain ending bound of the interval A is less than

[1] https://www.w3.org/TR/owl-time/.

[2] https://cnam-my.sharepoint.com/:b:/g/personal/nassira_achich_auditeur_lecnam_net/EUCb9oFijgpJgjXEjCZmtUcBtTXfAr_t57p9YsCBnQEMtw?e=YsgVUc.

the uncertain beginning bound of B. Table 1 presents Allen's relations between uncertain intervals.

$$Before_c(A,B) \Rightarrow A^{+}_{ca-} < B^{-}_{cb+} \quad (1)$$

Table 1. Temporal relations between two uncertain time intervals A and B.

Relation(A,B)	Relations between interval bounds	Inverse(B,A)
Before$_c$(A,B)	$A^{+}_{ca+} < B^{-}_{cb-}$	After$_c$(B,A)
Meets$_c$(A,B)	$A^{+}_{ca+} = B^{-}_{cb-}$	Met-by$_c$(B,A)
Overlaps$_c$(A,B)	$(A^{-}_{ca-} < B^{-}_{cb-}) \wedge (A^{+}_{ca+} > B^{-}_{cb-}) \wedge (A^{+}_{ca+} < B^{+}_{cb+})$	Overlapped-by$_c$(B,A)
Starts$_c$(A,B)	$(A^{-}_{ca-} = B^{-}_{cb-}) \wedge (A^{+}_{ca+} < B^{+}_{cb+})$	Started-by$_c$(B,A)
During$_c$(A,B)	$(B^{-}_{cb-} < A^{-}_{ca-}) \wedge (A^{+}_{ca+} < B^{+}_{cb+})$	Contains$_c$(B,A)
Ends$_c$(A,B)	$(B^{-}_{cb-} < A^{-}_{ca-}) \wedge (A^{+}_{ca+} = B^{+}_{cb+})$	Ended-by$_c$(B,A)
Equals$_c$(A,B)	$(A^{-}_{ca-} = B^{-}_{cb-}) \wedge (A^{+}_{ca+} = B^{+}_{cb+})$	Equals$_c$(B,A)

The certainty degree "c" is inferred from the certainty degrees "c_{a+}" and "c_{b-}" using a Bayesian Network [2].

All the other tables presenting Allen's relation between imperfect time intervals of the other imperfections (imprecision, simultaneously uncertainty and imprecision, and conflict) are presented in the appendix.[3]

We adapt the qualitative temporal relations between time intervals to propose relations between a time interval and a time point as shown in Table 2 which also represents uncertainty like the last subsection. The qualitative temporal relations between time intervals are adapted to propose relations between time points, as shown in Table 3.

5 "TimeOntoImperfection": The Proposed Ontology

The temporal data imperfection ontology, named "TimeOntoImperfection".[4] it is a top-level ontology, which can be merged with other ontologies of domain that must be extended to represent and reason about imperfect temporal data. It is based on the extension of the 4D-fluent approach with predefined elements of the OWL-Time ontology, elements that we have defined to represent the targeted imperfections, and the extension of Allen's interval algebra to reason about imperfect temporal data. We create our "TimeOntoImperfection" ontology using the Protégé ontology editor. In the literature, there is not, to our knowledge, an ontology temporal data imperfection. The temporal data imperfection ontology contains 5 classes, 201 object properties and 44 data type properties that represent time interval bounds, time points, dates, and time clocks as well as all

3 https://cnam-my.sharepoint.com/:b:/g/personal/nassira_achich_auditeur_lecnam_net/EeIhjd586WxGmeA_HI5OCgQBNtW1ie2ODZONZ0T0fX5oKQ?e=o7n0LQ.

4 https://cnam-my.sharepoint.com/:u:/g/personal/nassira_achich_auditeur_lecnam_net/EWd_23zDgUVNtTUhj7uoW4QBMNh3bE3J-rt2HB60Iaa7zg?e=NKcP2z.

measures of the different types of imperfections that are the measures of certainties, the measures of possibilities, the measures of necessities and the masses of belief. We infer via a set of SWRL rules our extension of Allen's algebra.

6 Validation

In this section, we present the prototype implemented based on our ontology to explore our approach followed by a case study that we conduct in the context of the Collective Memory Data.

6.1 Prototype Implemented Based on "TimeOntoImperfection"

We propose a prototype based on our "TimeOntoImperfection" ontology to validate our work. This prototype has been implemented in Java. The main interface of the prototype allows the user to enter perfect and/or imperfect time intervals and time points and to calculate certainty degrees related to each kind of imperfection based on our proposed approach. After each new temporal data entry, the "Add Qualitative Temporal Relation" component is automatically executed to infer missing data, including associated qualitative relationships and associated metrics based on SWRL rules. Our prototype also makes it possible to perform a search on the data entered and saved by using a filter integrated in a choice bar. This is implemented with SPARQL queries.

6.2 Application to Collective Memory Data

We conduct a case study in the context of Collective Memory data whose goal is to show the interest of the current work. Collective memory data relate historical facts (e.g., "National Movement" and "Festivals") or describing remarkable passages from the lives of famous personalities (e.g., "successes", "death"). It allows the semantic representation of knowledge relating to the collective memory and individual, based on an ontology called Collective Memo Onto (CMO) that we merge with our ontology "TimeOntoIperfection" to manage the temporal dimension. Let us have the following example, "The Mona Lisa is a painting of the artist Leonardo Da Vinci. He made it between 1503 and 1506 or between 1513 and 1516, and maybe until 1519". In this example, we find two kinds of imperfections which are conflict and simultaneously uncertainty and imprecision. Let I_1 and I_2 respectively the two time intervals expressing the conflict, where $I_1 = [1503, 1506]$ and $I_2 = [1513, 1516]$. Let m_1 and m_2 the belief mass respectively associated to the I_1 and I_2. We calculate it using the evidence theory based on our approach proposed in [3]. Let P be the time point which express the uncertainty and imprecision at the same time where P = 1519. Let P_{Im} and N_{Im} the possibility and necessity degrees associated to the imprecision of P; and P_{Un} and N_{Un} the possibility and necessity degrees associated to the uncertainty of P. We calculate it using the possibility theory [4].

Table 2. Temporal relations between an uncertain time interval and an uncertain time point.

Relation(A,P)	Relations	Inverse(P,A)
Before$_c$(A,P)	$P_{cp} < A^{-}_{ca-}$	After$_c$(P,A)
Meets$_c$(A,P)	$P_{cp} = A^{+}_{ca+}$	Met-by$_c$(P,A)
Starts$_c$(A,P)	$P_{cp} = A^{-}_{ca-}$	Started-by$_c$(P,A)
During$_c$(A,P)	$(A^{-}_{ca-} < P_{cp}) \wedge (P_{cp} < A^{+}_{ca+})$	Contains$_c$(P,A)
Ends$_c$(A,P)	$(P_{cp} = A^{+}_{ca+})$	Ended-by$_c$(P,A)

Table 3. Temporal relations between two uncertain time points P and Q

Relation(P,Q)	Relations	Inverse(Q,P)
Before$_c$(P,Q)	$P_{cp} < Q_{cq}$	After$_c$(Q,P)
Equals$_c$(P,Q)	$(P_{cp} = Q_{cq})$	Equals$_c$(Q,P)

7 Conclusion

In this paper, we present an approach to handle several types of imperfection, which are imprecision, uncertainty, uncertainty and imprecision, and conflict, that can affect the temporal data in the context of Collective Memory Data. To represent this data, we extend the 4D-fluents; we used OWL-Time ontology and we define new ontological components and using theories of imperfection such as possibility and evidence theories. To reason about imperfect temporal data, we extend the Allen's interval algebra. Based on these extensions, we propose an OWL 2 ontology named "TimeOntoImperfection". Finally, we implement a prototype based on our ontology to validate our work. In the future, we plan to treat other kinds of imperfections defined in our typology such as redundancy.

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