Multi-Phase Reasoning Model for Temporal Semantic Knowledgebase

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Abstract. The increased awareness of the advantages of semantic technologies and their improved toolability are encouraging more users and organizations to publically publish semantically tagged information. A large proportion of this information is time-critical, either because of the temporal state inherent in dynamic application domains such as media and news, or because of the proliferated use of nomadic smart devices that are capable of recording real-time user context. Hence, the ability to represent and interlink time-critical multi-domain and location-aware information plays an important role in enabling the integration and exploration of such data. However, the semantic modelling of real-time dynamic applications has proven to be challenging; primarily due to the overhead of parsing the semantic metadata and the subsequent inference performed by the reasoning engine at compute time. Despite valuable work aspiring to standardise the representation of temporal information in the semantic space, technological restrictions such as the standard binary representation of semantic reasoning language constitutes limitations in representing/modelling of temporal and dynamic events. This work contributes to that body of research by proposing a more specialised semantic tools and methodology that is capable of handling and exploring temporal attributes of real-time (dynamic) contexts that requires real-time supplementary reasoning. We define a novel Multi-phase Reasoning Model (MPRM), which can be used to construct augmented classifications for temporal events requiring supplementary reasoning. Our approach is based on arresting dynamic entities at the modelling phase in preparation for more efficient handling of their temporal state outside the semantic repository.

Keywords

Semantic knowledgebase, Supplementary Reasoning, Temporal knowledge, Dynamic Application Domain, Location-Aware Access.

1. INTRODUCTION

As technology advances, real-time access to dynamically evolving knowledge sources has become an important component of service delivery for various business, medical, and engineering applications. Several organizations now rely on publically publish information in the delivery of services. Thus, tools and methodologies of representing and interlinking time-critical information are crucial for enabling the integration and exploration of such information has attracted research efforts in various fields including Database Systems, Artificial Intelligence, and the Semantic Web [1]. Consider a Context-Aware System (CAS) that uses the information obtained from several public knowledgebase such as Geonames and locally sourced event information in order to enrich the contextual data on offer to its users. For instance, recommending near-by entertainment events to a tourist requires a multi-phase reasoning of semantically tagged information. At one level, reasoning has to be performed to infer the appropriate entertainment services using the event-host-location (Geonames) and event related information (publicly sourced). At the next level, further reasoning has to be performed to match the inferred event information to the dynamic user context, i.e. time of the day, user's specific interest, and user's location etc. Challenges of such scenario include the execution of subsequent reasoning phases are inter-dependent on the outcome of the previous, which is further complicated by the temporal parameter within each phase. In addition, the validity of publicly sourced information, as well as the time-frame in which user can benefit from such inference are crucial.

Semantic web technologies are best placed to implement Complex Event Systems and Context-Aware Systems amongst others due to their capability of modelling data that represents multiple information domains, and reasoning on the modelled knowledge to interrelate it to a specific context. However, the semantic modelling of temporal events using the current standardized semantic web languages represents a major challenge. For instance, representing a person's location in OWL can be depicted as *haslocation*(PersonA, locationA), but in the view of temporal modelling, the time at which PersonA is at locationA holds the validity of such statement, as nomadic person can only at a location temporarily. Modelling such scenario will entail such statement to be represented as *haslocation*(PersonA, 17, t1, t2) where t1 and t2 are start-time and end-time respectively. An important factor to consider when modelling entities with temporal states is defining the relationship between times, i.e. the declaration of relationship between t1 and t2 from the above illustration, in order to identify event as continuous or instantaneous. For example, an event where t1 meets t2 can be denoted as tm(t1, t2) i.e. the system has information of such person being at locationA before locationA is within a specific time. Therefore; the above statement, ideally, can then be written as *haslocation*(PersonA, LocationA, tmA) in order to suggest adequate service in the clause of context awareness.

Moreover, the utilization of binary predicate by semantic technology tools such as RDF and OWL does not allow such above representation to model temporal events, due to its provision of only first order semantic syntax [2]. In this paper, we introduced a novel approach to efficiently model temporal contextual information in a Complex Events scenario by isolating the temporal attributes of these events. These isolated attributes are then further classified through intelligent extraction of temporal classification-dependent events requiring supplementary reasoning, semantic reasoning of the extracted characters, alignment and matchmaking of new knowledge with the extracted attributes accordingly. The purpose of this model is to help construct a multi-phase framework that will efficiently support semantic repositories in providing the necessary supplementary reasoning when handling of temporal complex events.

The rest of this paper is organized as follows: section 2 examines the state of art in modelling temporal events, section 3 describes our approach of modelling temporal event for supplementary reasoning with logical notations, and section 4 presents our concluding remarks and further work.

2. RELATED WORK

Various approaches have been described by several researchers for the implementation of temporal event systems; most of these approaches are designed to suit a specific class of applications. A common class of temporal applications is the area of Context-Aware Systems, which is the focus of our research. Adopting Dey and Abowd's definition of context - "*information used to characterize the situation of entities that are considered relevant to the interaction between a user and an application*"- further justifies that semantic web tools are well-suited for the development of Context-Aware systems due to their ability to consume interlinked data, i.e. the consumption of contextual data, and further reason on these data for subsequent classification. However, a limitation of representing temporal contextual information using semantic web tools is its inefficiency in handling time-critical dynamic applications where information changes spontaneously over time. The work in [3] attempts to tackle the limitation of semantic representation of temporal data by using OWL ontology to represent entities and it relations. The author proposed modeling temporal entities using a four–dimensionalist (pendurantist) ontology, employing OWL abstract syntax to represent synchronic relationships where variation of time is considered. The authors used 4D approach of modeling temporal entity in OWL, by integrating the 4D fluent ontology to OWL-Time ontology. This approach utilizes pedurantism (an approach for ontology in analytical metaphysics) by attempting to treat temporal entities in a domain as four dimensional with the temporal aspect that participate in the relation. For instance, in our case, Complex event A (compA) and complex event B (compB) can only be related via any object relationship through their temporal parts i.e. compA@t1 and compB@t1 respectively, such that compA@t1 and compB@t1 are subclasses of the 'Temporal Part' concept. The TemporalPart concepts then relate to their corresponding events using *temporalPartOf relationship*, meaning compA@t1 relates compA via temporalPartOf object *temporalPartOf(compA, compA@t1).* The TemporalPart concepts further relate the Time concept (a component of OWL-Time ontology) via a relationship *temporalExtent.* Although the approach does permit some aspects of OWL binary representation of application with temporal states, the limitation of object proliferation arising from a temporal relation generating double objects eventually leads object redundancy. This limitation ultimately makes this approach imperfect for our situation where exploration and reasoning is required on enormous amount of already store datasets with newly collected ones. Other disadvantages in our case may include OWL reasoning limitation and ontology conflicts.

Few other approaches include the combination or extension of two or more previous works on temporal events. Temporal Description Logics (TDL) [4] proposed the extension of Description logics (DL) in combination with temporal logics (interval-based and point based) to semantic web tool, OWL. It represents information that relates a particular instant of time, which requires the support of concrete domains. In, [5] Concrete domains present additional operator and datatypes to the underlying domains. While TOWL [6] came up with the approach of unifying the 4D Fluents (discussed above) and concrete domain approach. Versioning [7] on the other hand proposed the creation of newer version of ontology whenever changes occur. The authors of [8] introduce an approach of handling temporal information using OWL and_SWRL then, using SPARQL-based queries to express temporal queries. The above proposals are not ideal for our situation for the following reasons; TOWL lack the support of standard reasoning tools(JENA, PELLET etc.) and querying tools

(SPARQL, RDQL etc), and also, there can be limitation of information redundancy, and identification complications of temporal events in cases of multiple version of ontology and finally no provision for classification-dependency reasoning.

Similar to 4D-fluents, the N-ary relations and Reification approach [9] depicts n-ary relations in a binary format using OWL. This approach does not permit the extensive utilization of OWL reasoning capability due to shortcomings that include the adjustment of domain and the range properties of n-ary relationships, i.e. intermediate object-property now represents the temporal classes' relationships. This limitation demonstrates the non-suitability of this approach for our work as concept's domains and ranges are imperative for context (information characterizing an entity) classification. For example, in the clause of person's location, *hasLocation* predicate will no longer have instance of *Person* and *Location* as subject- object relationship, rather, instance of a *Person* will have subject-object relationship with *TemporalLocation* via the *hasLocation* predicate, incurring inconsistency effect when the *Location* predicate requires further or dependency classification.

Although, our work focuses on achieving supplementary reasoning of temporal contextual information, we equally figured adopting an appropriate modelling approach that eschew the identified limitations such as object redundancy, ontology conflicts amongst others.

3. OUR APPROACH ON HANDLING TEMPORAL KNOWLEGDE FOR SUPPLEMENTARY REASONING

The modelling of contextual information with temporal states can be extremely challenging due to the dynamic evolvement of such information. Since contextual information (information used to characterize an entity) is obviously useful in several ways such as for performing sentiment analysis in [10], for prediction of diffused information in [11] and for user profiling etc., the efficient handling of such information is critical. Although semantic web technology facilitates the congregation and filtering of information from multiple domains based on define set of rules, the technical limitations of semantic modeling languages such as OWL not allowing the combination of asymmetry and transitive axiom on a single property (just to avoid the lack of decidability in the OWL _DL reasoning) amongst others, made its suitability questionable for temporal context applications such as ours as an object carrying temporal characteristics in most cases may require the combination of both properties.

In addition, OWL provides support for only first-order semantics as it uses binary predicates for relationship representation, therefore it does not provide for reasoning beyond the first layer relationship. These factors have led to a major challenge in the modelling of temporal knowledge [12] as contextual information because classification of these temporal events as contextual information can necessitate multiple reasoning-dependencies, which thus calls for a multi-phase reasoning of temporal-state objects in order to achieve robustness in the computation of newly collected knowledge with the already stored ones.

We anticipate the need to transparently identify objects with temporal attributes that requires supplementary reasoning in the associated domains. This process can further enhance the efficient handling of this identified temporal knowledge outside the semantic knowledgebase, thus reducing the maintenance overhead such as information conflicts at the reasoning layer of semantic knowledgebase. Furthermore, we can overcome limitations of knowledgebase reasoners such as lack of ability to reason beyond the capacity of first order semantics, which may only be achievable with OWL_Full sublanguage (the most expressive level of web ontology language). However, the lack of extensive support for OWL_Full level of reasoning and expressiveness by the current semantic reasoning engines has made it presently unachievable. We adopted a novel approach as described below to efficiently handle semantic temporal knowledge in overcoming the aforementioned problems such as representation, consistency, and reasoning limitations as follows.

Derivation of logical notation for Temporal Contextual Knowledge

Since our aim is to represent context from several temporal Complex Events retrieved from external source in relation to the explored already stored knowledge for further evaluations and decision making. We consider in our approach a dynamic complex event data that requires supplementary context classification by adopting the widely acceptable definition of context [9] as information used to characterise entity

We further extend contexts (information for characterization) into static context *(S)* and temporal contexts *(T)*. We declare start-time (t_s) and end-time (t_e) **ε** time *(t)*. Therefore, in a universe discourse of domain *(D)* that consists of concepts *(X)* can be written as follows: $X \rightarrow D(X)$

Using the notation Validity *(V)* as attributes for validating temporal concepts, we arrested the dynamic context using the Validity *(V)* concept, which can either be instantaneous I_s or interval I_n as **ε** time *(t)*.

Thereby, Validity concept is represented in the domain of discourse as follows:

$(V) \rightarrow (I_s \vee I_n) \mid I_s \rightarrow e(t_s,t_e)$ and $I_n \rightarrow l(t_s,t_e), \mid el(t_s,t_e), V \, \mathcal{E} \, X$ where *e* and *l* are denoted equal (=) and less-than (<) respectively.

Taking that, concepts *(X)* within the domain *(D)* can only be temporal through the possession of temporal attribute Validity *(V)*.

Consequently, temporal concept *(T)* in the domain *(D)* is defined as:

$$T \rightarrow X \, V(X)$$

and Static concept as: $S \rightarrow X \neg V(X).$

Since Entity *(E)* within the domain *(D)* is characterised by Context *(C)* and all annotations are element of concepts X

$$C \rightarrow (E\ (X)) \mid C, E \, \mathcal{E} \, X,$$

Apart from Validity *(V)* concept being a unique identifier for distinguishing the contextual entities with temporal state, it further, shows the current state of the identified temporal context in time granularity, which can be specified by knowledge engineer. Therefore;

Temporal Context (C_T): $C_T \rightarrow T(C)\ X\ (V(X)\ (E\ (X)\ )\ X(V,E)$

Or

Static Context (C_S): $C_S \rightarrow S(C)\ X\ (\neg V(X)\ (E\ (X))\ \neg X\ (V, E)$

Domain *(D)* comprising of contexts can now be taken as follows:

$$D \rightarrow (X\ (V\ E)\ v\ \neg X\ (V\ E))$$

Hence; in a universe discourse of *concept X*, *Entity E* and all existential of *Validity V* can be written as follows:

$$\text{D} \rightarrow \text{E VX ((V E) v} \neg \text{X(V E))}$$

The above notation indicates how temporal contexts that require further reasoning are isolated to prepare further processing through distinctive knowledge extraction and alignment. Temporal knowledge that further requires classification is then asserted at the semantic modelling stage by categorization through semantic object property so as to permit reasoning of this temporal knowledge at distinct phases.

4. CONCLUSION AND FUTHERWORK

The intelligent exploration of time-critical information necessitates the adoption of new modelling techniques to overcome the limitations of semantic technologies in modelling temporal information, in particular the requirement of real-time reasoning on inferred knowledge at multiple inter-dependent stages. To address these shortcomings, we proposed a multi-phase model that isolates the temporal information in preparation for supplementary reasoning, through definition of logical notation, which segregates temporal objects using a defined validity object. The isolated temporal objects can further be extracted for adequate reasoning through sequential extraction, alignment and matchmaking. Our subsequent work involves the construction of a multi-phase framework that will utilise the proposed model to automate the processes of extraction, alignment and matchmaking, reasoning, and insertion of the isolated temporal information in achieving real-time supplementary reasoning in conjunction with the current semantic repository reasoning layer. In addition, an important issue such as scalability when reasoning on real-time inferred temporal information is aimed to be addressed by the framework.

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