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A MODELLING METHOD FOR ONTOLOGIES CONTAINING TIME-DEPENDENT KNOWLEDGE

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Abstract: *Knowledge representation is an important part of Artificial Intelligence. Well known formalisms such as First Order Predicate Logic (FOPL), Modal Logics or Description Logics (DL) manage to represent knowledge in a static way, producing snapshots of the described domain. Nonetheless, the real world is dynamic, subject to permanent change. Our ability to capture the changing features of our world depends on a proper representation of time. Both FOPL, DL and their temporal extensions allow for such representations, but they are cumbersome, and eventually lead to intractability. As an alternative, we introduce a cognitive model for representing time. Its features are inspired from human representation of time as well as concepts from functional and associative programming.*
Key words: *cognitive systems, ontologies, modeling, knowledge*

1. INTRODUCTION

In our world, knowledge and information are permanently changing. Properties such as the shape of a mountain, or the brightness of a star, apparently constant, are actually variable with respect to bigger time intervals.

In Artificial Intelligence, formalisms such as First Order Predicate Logics (FOPL) and Description Logics (DL) have not been designed for explicit temporal representation and reasoning (Artale & Franconi, 2000). Time can be described in both FOPL and DL, but the resulting models are complicated and difficult to use.

As a result, several temporal extensions of both FOPL and DL have been designed. Such temporal models have decidability problems: the most general interval-based temporal extension of DL is undecidable (Artale & Franconi, 2000). First Order Temporal Predicate Logics (FOTPL) is also undecidable (Hodkinson et al., 2000). Reducing FOTPL to decidable (monodic) fragments yields models where inference is often intractable (Hodkinson et al., 2000).

As an alternative to such complex and cumbersome formalisms, we propose a cognitive approach for time-dependent representation of knowledge.

Our model is designed for temporal reasoning and disambiguation of a story written in natural language. It is inspired from human cognitive processes that involve time (Evans, 2005). Such processes are described in Section 2. The model uses a simple, lightweight, ontological formalism proposed in (Giumale & Negreanu, 2009), and briefly described in Section 3. Time-dependent information is represented using a temporal graph. The structure of the graph and the operations on it are described in Section 4. In Section 5, we describe our conclusions and future work.

2. HUMAN COGNITIVE PROCESSES

Human cognition doesn't have dedicated structures designed for holding temporal information. (Evans, 2005) Unlike vision, sound, smell or touch, time isn't perceived directly. The perception of time is built by abstracting on other sensory information, especially motion and tridimensional space. Evidence can be found by examining vocabularies of many languages. In formulations such as:

"Time passes. The time for a decision has come"

the concept of time is connected to that of motion.

The basic form of abstraction that produces temporality is a form of ordering over visually perceived data. Nevertheless, human minds do not rely solely on chronological information for that ordering. It is common for a human to remember his day of graduation not by the actual date, but by the event that occured in that day. In a similar fashion, our model builds a representation of time by ordering time-dependent properties. Instead of using intervals of validity, like most temporal DL extensions, we introduce symbolic moments of time. They allow us to define durations in terms similar to human cognition.

3. ONTOLOGY

The four main ontological categories used in our model are inspired from (Giumale & Negreanu, 2009): individuals, qualities and relations, actions.

3.1 Individuals, Qualities and Relations

An individual is an atomic category that posesses no structure and which doesn't change in time.

Qualities and relations are used for describing properties and connections between individuals. We distinguish between qualities, relations and their associated instances. Suppose we define an ontology that contains the quality *male*. In the following discourse:

"John is male. Phil is also male."

the quality *male* is instantiated two times. Instances connect individuals with qualities and relations specified by the domain ontology. Furthermore, instances are time-dependent. They allow specification of more elaborate, time-dependent concepts such as: *"married twice"*. An individual satisfying this description would have two *married* quality instances, one of them ending in the past.

Both qualities and relations define roles. When an instance of a quality or relation is created, the individuals are bound to their proper roles. The following relation instance:

"John and Mary are married."

could be described in the following declarative fashion:

marriage(husband:John,wife:Mary).

where *husband* and *wife* are the roles of the *marriage* relation. To keep the representation uncluttered, we will sometimes omit the roles (especially for qualities).

3.2. Actions

Since quality and relation instances are time-dependent, they define time durations equivalent to their lifespan. On the other hand, action instances define instantaneous events that change the "state of the world", by either creating new quality and relation instances, or by ending the lifespan of existing ones. In the example: "*John marries Mary.*", the execution of such an action instance would terminate the lifespan of prior quality instances: *Single(John)*, and *Single(Mary)*, and would introduce a new relation instance: *Married(John, Mary)*.

Actions are similar to CLIPS rules, and include preconditions and effects:

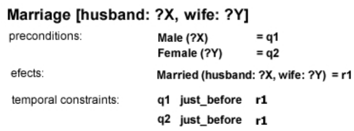

Fig. 1. Representation of an action in a domain ontology

The main difference between CLIPS rules and actions is that, upon executing an action instance, both preconditions and effects are added (if they do not exist already). This is similar to human form of deduction: in the discourse, there is no specification that *Mary* (for example) has the quality *Female*, but since she took part in *marriage* action, then she must have had such a quality.

Fig. 1 also illustrates temporal constraints introduced by the action. They are inspired from Allen's interval relations (Fisher et al., 2005). Based on constraints, the temporal graph is built. In Section 4 we describe the behaviour of only two temporal constraints: *just before* and *starts when ends*. Other constraints such as: *before, after, just after, starts simultaneously with* etc. have similar behavior.

4. TEMPORAL GRAPH

Every quality and relation instance has two symbolic moments of time associated with them. These moments do not posses actual values, i.e. they do not behave as timestamps.

In a temporal graph, such moments of time are nodes. The edges are oriented. They introduce a partial ordering over nodes. We distinguish between three types of edges (Fig. 3):

- Quality or relation edges (continuous arrows): they have a quality or relation instance attached to it, and connect the beginning and ending nodes for that specific instance.
- Future edges (dotted arrows): introduce a temporal order of two nodes, without necesarily having a quality or relation instance connecting them.
- Overlapping edges (triple lines): connect nodes that define the same moment of time.

In the initial state, before a discourse is processed, the graph contains two special nodes: *Initial* (defines an initial moment of time) and *Current* (defines the current moment of time, with respect to the discourse).

In the absence of temporal constraints, when an action introduces a new quality instance, its beginning node is connected via a future edge to *Initial*, and it's ending node is connected via an overlapping edge to *Current*. Other temporal constraints introduce or delete future and overlapping edges.

We illustrate an example of a simple domain ontology, discourse, and the evolution of the temporal graph. Assume we have a domain ontology that defines the qualities: *Single, Dead, Widower*, the relation *Marriage*, the actions *Marriage* described in (Fig. 1), and *Becomes Widower* (Fig. 2). For simplicity, we will assume that all qualities have associated actions that introduce them.

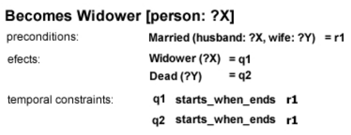

Fig. 2. Representation of action *Becomes Widower*

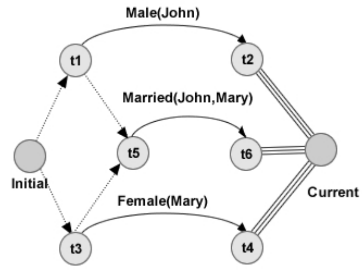

Fig. 3. The graph, after the execution of action *marry*

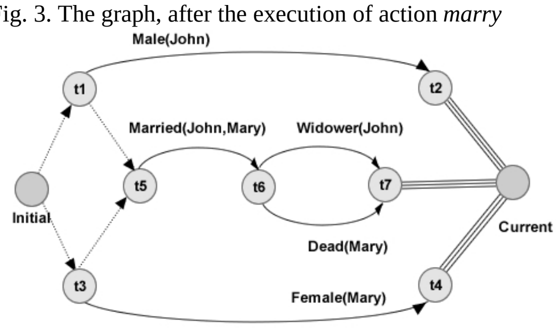

Fig. 4. The graph, after execution of action *becomes widower*

A possible discourse is: *"John is male. John marries Mary. John becomes widower"*. The first action introduces the quality *male*(*John)* (we conventionally interpret the first sentence as an action also). The *marry* action introduces the quality *female(Mary)* as a result of processing the action's preconditions. The same action introduces the relation *Married(John,Mary)*. The result is seen in Fig. 3. Notice that the qualities *Male* and *Female* should exist prior to (and during) the quality *Married*. This is reflected in the graph, where the *t*1-*t*5 and *t*3-*t*5 *future edges* correspond to the *just_before* temporal constraints in Fig. 1. When the action *becomes Widower* is executed (Fig-4), the relation *Married(John,Mary)* ends. The ending moment coincides with the appearance of two new qualities: *Widower(John)* and *Dead(Mary)*.

5. CONCLUSIONS AND FUTURE WORK

The proposed model reduces a complex temporal reasoning process to a simple graph traversal problem. Such graphs encode both static (non-temporal) and dynamic information. Further results about completeness of the model and complexity of the inference process are to be investigated. An initial version was sucessfuly implemented (in Java) and a more complex system based on temporal graphs is currently being designed.

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