On Temporal Cardinality in the Context of the tOWL Language

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Outline

- The tOWL Language – Overview
- A Discussion on Temporal Cardinality
- Conclusions

The tOWL Language

- For the current purpose, a clear definition of time is required.
- We distinguish between:
  - Temporal 'infrastructure' (timepoints & intervals);
  - Change.
- Providing support for the representation of these aspects of time in a Semantic Web context is the general goal of the tOWL language.

The tOWL Language

Temporal infrastructure

- Describes the quantitative aspect of time
- Provides a basic texture for complex temporal representations
- Common example: intervals + Allen's relations
- Very concrete
- Requirements:
  - Rely on standards (we are extending a standard!)
  - Represent timepoints and intervals
  - Represent temporal constraints
  - Level of granularity

The tOWL Language (Change)

Change

- Most entities change some of their traits in time

- Think of:
  - Changing height of a person, from child- to adulthood
  - Changes in the price of a company’s share
  - Changes in variables (fundamental & technical indicators, etc.)

- Representing change = enabling context-awareness

- Context-awareness → better decision-making (though not invariably)

- Think of reasoning over several versions of an OWL-DL ontology (snapshots). In the same time!

The tOWL Language

Change as complex process

- Many phenomena can be described as processes
- Think of:
  - Obtaining a driver's license
  - Drug trials
  - Leveraged Buy Outs
- A process is described by its states (phases)
- Each process has certain 'transition rules' (axioms)
- A proper representation of processes and their associated axioms enables automated reasoning

The tOWL Language

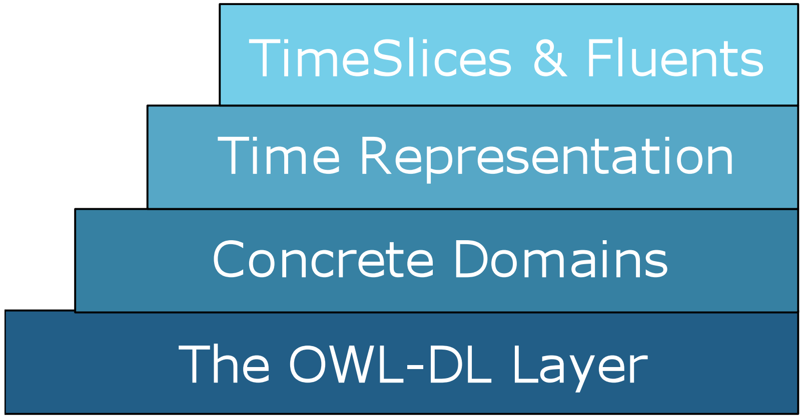
Until now:

- Time is a relevant dimension of knowledge on the Semantic Web
- Two state-of-the-art Semantic Web languages have currently been standardized: RDF & OWL
- Although a (somewhat limited) temporal extension exists for RDF, none has been yet devised for OWL
- We seek to:
  - Extend OWL-DL into a temporal dimension;
  - Enable the representation of quantitative time, as well as change.

The tOWL Language

The tOWL Layer Cake

- Layered approach for the design of the tOWL language;
- The extensions are built on top of the OWL-DL layer;
- Concrete domains enable a meaningful time representation (intervals & Allen's interval relations);
- The timeslices & fluents approach employs the time representation for the semantics of change.

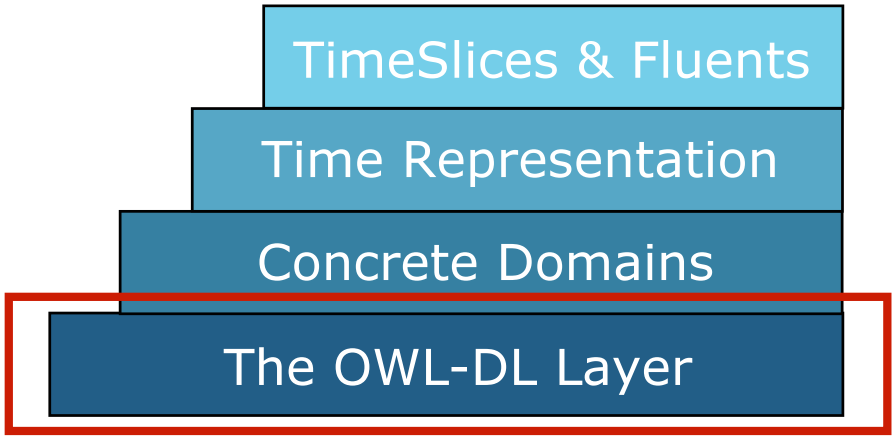


The TOWL Layer Cake

The tOWL Language

The OWL-DL Layer

- Based on Description Logics (DL)
- OWL-DL offers the means to:
  - formalize a domain by defining classes and properties of those classes,
  - define individuals and assert properties about them, and
  - reason about these classes and individuals to the degree permitted by the formal semantics of the OWL language.
- Tools & Reasoners: Protégé, Pellet, Racer, FaCT++



The TOWL Layer Cake

The tOWL Language

The Concrete Domains Layer

- OWL-DL has only limited support for concrete domains
- We seek to:
  - Enable feature chains
  - Enable complex temporal restrictions based on the concrete domain (binary predicates)
- Temporal concrete domain = constraint system
  - Intervals and Allen's 13 interval relations

The TOWL Layer Cake

StockGoodDay ≡ (priceBegin, priceEnd).<

The tOWL Language

The Time Representation Layer

- Constraint system based on intervals and Allen's 13 interval relations
- We define intervals in terms of their endpoints (*start* & *end*)

  Interval = (start,end).<

- The endpoints are defined by relying on XML Schema dateTime

The TOWL Layer Cake

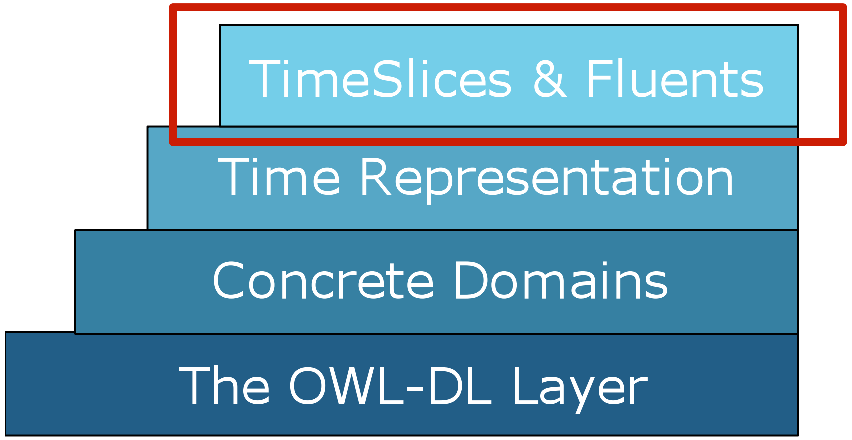
Example: In an LBO process, the early stage (may) be followed by the abort stage; in case this happens, the two stages follow each other immediately.

$$\exists(\texttt{earlyStage} \circ \texttt{time}, \texttt{abort} \circ \texttt{time}).\texttt{meets}$$

The tOWL Language

The TimeSlices & Fluents Layer

- Represent temporal aspects of entities other than timespan
- This layer regards change and state transitions
- TimeSlice = temporal part of an individual
- Fluent = indicates the changing attribute value
- Two types of fluents:
  - fluentObjectProperty
  - fluentDatatypeProperty



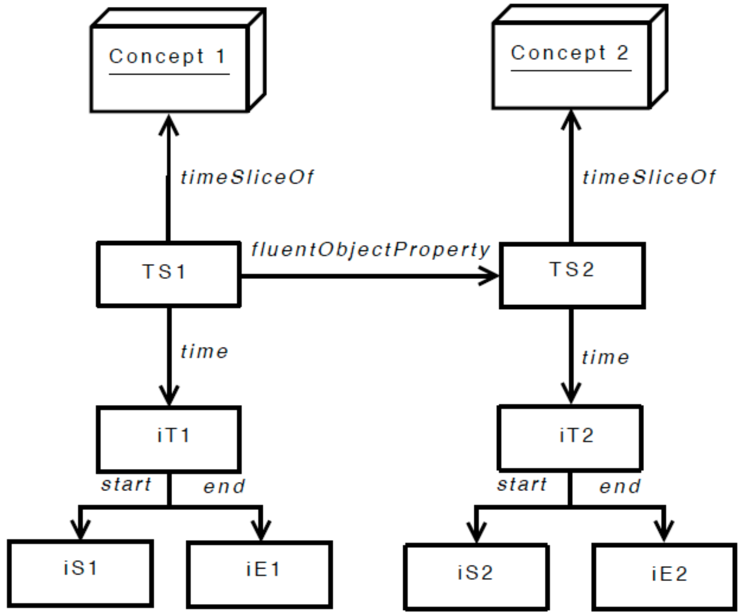
The TOWL Layer Cake

Timeslice Equality & Representation

- Two timeslices are equal (identical) if the following holds:

$$(TS_1, TS_2).\mathtt{eq}_{\mathtt{TS}} \equiv (TS_1.\mathtt{time}, TS_2.\mathtt{time}).\mathtt{equal} \wedge \\ \wedge (TS_1.\mathtt{timeSliceOf}, TS_2.\mathtt{timeSliceOf}).\mathtt{sameAs}$$

- Timeslice representation:



How does a temporal setting influence the OWL-DL constructs?

Cardinality

- OWL-DL implements three constructs for cardinality:
  - minCardinality
  - maxCardinality
  - cardinality

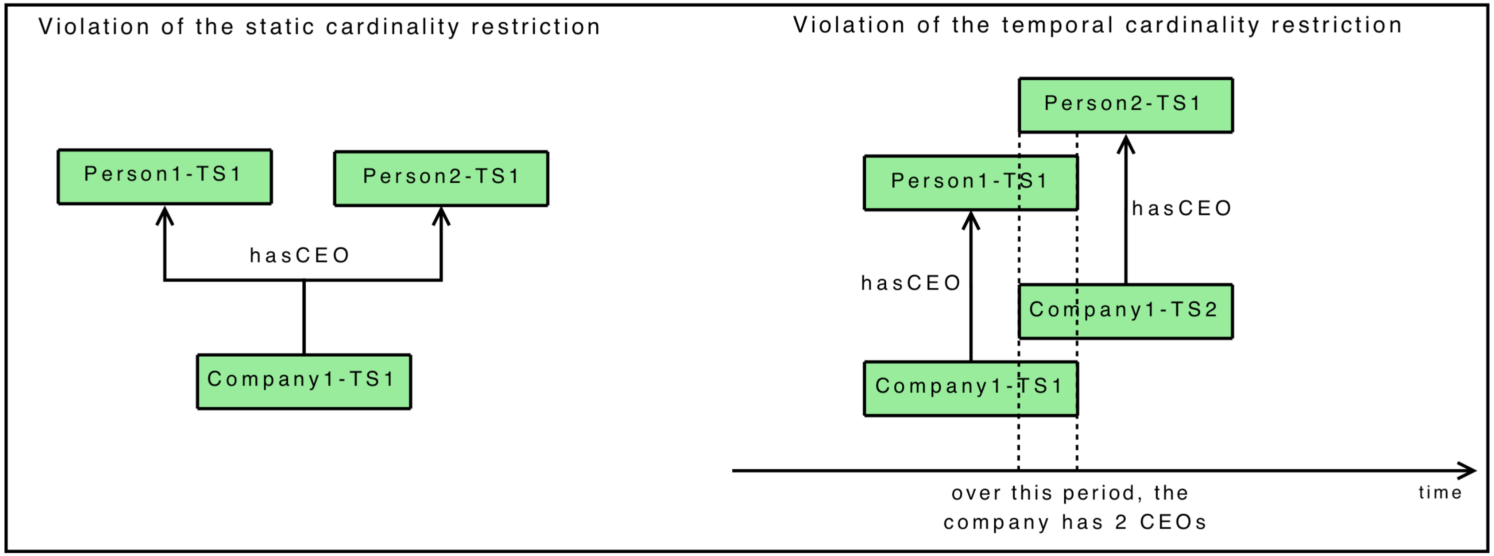
- If stated to have the value ***a*** on a property ***P***, with respect to a class **C**, then any instance of **C** will be related through ***P*** to at least/at most/exactly ***a*** individuals (of which the type may further be restricted by the range of **P**).

Temporal Cardinality

- An extension of the static concept of cardinality may be envisioned in the sense that, at any point in time, only a restricted number of timeslices may describe a concept
- In other words, temporal cardinality is meant to restrict the number of timeslices that may overlap, at any point in time for the same individual
- These restrictions should be stated on fluents, with respect to static individuals whose timeslices are described by those fluents

Temporal Cardinality in tOWL

- Example: represent the fact that, at any point in time, a company must have exactly 1 Chief Executive Officer (CEO)
- Two types of cardinality:
  - *fluent cardinality*: the (static) cardinality of the *hasCEO* fluent should be equal to 1
  - *overlapping timeslices:* the (temporal) cardinality of the *hasCEO* fluent should be equal to 1



Temporal Cardinality in tOWL

- We define the following temporal equivalents for the static OWL-DL cardinality constructs:
  - temporalMinCardinality
  - temporalMaxCardinality
  - temporalCardinality

temporalMinCardinality (definition)

Given a fluent property ***f***, a class ***C***, an individual ***i*** of type ***C*** and a value ***a*** such that ***a*** in ***N***, we represent by ***temporalMinCardinality(f; a)*** the restriction on ***f*** with respect to timeslices of ***i*** for which ***f*** is defined that, at any point in time, any timeslice of ***i*** is described by at least ***a*** timeslices through ***f***.

Temporal Cardinality in tOWL

- Define a function ***g*** that, given a fluent ***f***, a static individual ***i*** and a point in time ***t***, returns the number of timeslices of different individuals ***j*** holding at ***t***, for which ***f*** is explicitly defined and linked from a timeslice of ***i*** that also holds at ***t***

$$
\begin{aligned}
g_{(f,i,t)} = |\{ j \in C^{\mathcal{I}} \mid & \exists x, y, s, e \ \texttt{s.t.}\ x, y \in TS^{\mathcal{I}} \land (x, i) \in \texttt{timeSliceOf}^{\mathcal{I}} \land \\
& \land (y, j) \in \texttt{timeSliceOf}^{\mathcal{I}} \land (x, y) \in f^{\mathcal{I}} \land s = \texttt{start}(\texttt{time}(y)) \land \\
& \land e = \texttt{end}(\texttt{time}(y)) \land s \leq t \leq e \}|
\end{aligned}
$$

Temporal Cardinality in tOWL

- The semantics of the three constructs relating to temporal cardinality can be represented as follows, where ***a***, ***f*** and ***t*** preserve their meaning as previously, and ***C*** denotes a concept

$$(\geq_{\mathcal{T}}\ a\ f)^{\mathcal{I}} = \{x \in TS^{\mathcal{I}} \mid \forall i\ \forall t,\ i \in C^{\mathcal{I}} \wedge (x,i) \in \texttt{timeSliceOf}^{\mathcal{I}} \wedge g_{(f,i,t)} \geq a\}$$
$$(\leq_{\mathcal{T}}\ a\ f)^{\mathcal{I}} = \{x \in TS^{\mathcal{I}} \mid \forall i\ \forall t,\ i \in C^{\mathcal{I}} \wedge (x,i) \in \texttt{timeSliceOf}^{\mathcal{I}} \wedge g_{(f,i,t)} \leq a\}$$
$$(=_{\mathcal{T}}\ a\ f)^{\mathcal{I}} = (\geq_{\mathcal{T}}\ a\ f)^{\mathcal{I}} \cap (\leq_{\mathcal{T}}\ a\ f)^{\mathcal{I}}$$

Conclusions

- The tOWL language is a temporal ontology language built on top of OWL-DL
- tOWL enables the representation of different aspects of change in the language, based on a clearly defined temporal infrastructure
- Temporal cardinality in tOWL is closely related to the concept of timeslices
- In a temporal setting, we seek to represent restrictions on the number of overlapping timeslices

Questions