Toward a formal ontology of time and aspect

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Abstract
We present a work in the scope of formal ontologies, notion taken from the knowledge representation community. What we study is the concept of time and aspect described and conceptualized from linguistics. Our aim is thus to propose a formal ontology of time and aspect considering temporal concepts introduced in a formal way.

Introduction
Our aim is to precise some concepts and properties of time for building ontologies where temporal notions are essential when we take into account the evolution of objects trough time. This approach is in the scope of formal ontologies researches as developed for instance by N. Guarino’s or B. Smith. Different articles introduced temporal concepts in ontologies (i.e. GFO reusing the notions endurant and perdurant objects...), however our approach is founded on a theory of aspectuality and temporality in natural language. The basic concept of state, event and process and related concepts like sequence of events, enunciative process, continuity between resultative state and event, temporal reference systems... are useful to propose a formal ontology of time. This paper is a part of a program aimed at relating linguistic descriptions from a theoretical point of view and ontologies.

The methodology
The general methodology adopted in the frame of this work starts from a linguistic problem to go to a systematic analysis. The linguistic notions that we investigate are that of time and aspect. Those notions are first mathematically conceptualized (for instance topological intervals). It enables thus to visually represent them and secondly to build by abstraction a formal language (for us, an applicative system of aspeuctal operators and temporal relations) which expresses aspeectual and temporal operations identified in language. To summarize this general framework, we give the following diagram:

![Diagram of methodology](image)

Formal framework
We first introduce the formal notions we use to work out the problem of time and aspectuality analysis aiming at the conceptualization and formalization of an ontology of time captured by categories of tenses and aspect in natural languages.

Historically the applicative formalisms have been studied through combinatory logic, developed by Curry who introduced a logic of abstract operators and composition of them using a fundamental operation called application. The notion of functional types introduced by Church is incorporated in the applicative formalism giving the combinatory logic with types. The basic structure is thus an operator applying to an operand to build a result. However the expressivity of such formalism can be restrict by using types. Hence, the application of an operator is allowed only if takes as argument an operand with a specific type. This notion of type is introduced to characterize different classes of objects (absolute operands) and operators. We give then the explicit construction rule of functional types:

[T] (1) Primitive types are Types
(2) If α and β are Types, then Fαβ is a Type

F is the functional type constructor. Now we introduce a typed applicative system. In such system, operators, operands and results are typed.

The meaning of the type Fαβ is the following: it is a type of an operator which can be applied to an operand with the type α and the result of this application is with the type β. The application rule is given as follow:

[APPt] [X: Fαβ] [Y: α] [XY : β]

We give an illustration of the formal language established to describe the time and aspect theory as presented in [Des94]. From this theoretical point of view, we assume that an utterance is the result of temporal, aspectual and
modal operations applying to a predicative relation written \( \Lambda \). For instance the predicative relation presented in its applicative form ((eat (apple)) John) can be specified by a specific aspectual operator returning for instance the processual value “John is eating an apple” or with another aspectual operator returning the value event “John ate an apple”.

The general form underlying an utterance is given by the following applicative expression:

\[ \text{Utterance} \leq \text{ASP-TMP(\Lambda)} \]

where ASP-TMP is a « complex » operator composed by operators corresponding to temporal situation (regarding the enunciation time), aspectual classifications (process, state, event) and semantico-cognitive categorization of lexical predicates. Actually, all these operators deal with the same aspectual concepts which are “event”, “state” and “process” [Des94, Des05]. Indeed, the enunciation is conceptualized as a process expressing a speaker while he is speaking. The lexical predicate is considered as well to have intrinsic aspectual value related to cognitive categorization (i.e. stable, kinematic or dynamic situations).

The set of topological intervals is the interpretation domain (in a model in Tarski sense) of the language of operators and consists in a part of its semantics. Consequently a predicative structure having an aspectual and temporal specification is said to be true onto a topological interval. For instance, an utterance with the aspectual value of a process is true onto a half-opened interval.

More generally, the mathematical notions which are involved in the conceptualization of aspectual values are intervals of instants (being real numbers). Thus, we consider topological intervals having boundaries so it is possible to conceptualize the value of process with a half-opened interval, the value of state with an opened interval and the value of event with a closed interval. The notion of contiguity is introduced as well to express dependencies between aspectual values. For instance the value of ‘resulting state’ comes straight after an event which is a cause, so contiguous to it.

The general network of dependencies between aspectual values is introduced by the following diagram.

The properties and specifications of “state”, “event” and “process” as well as some formal relations between them are presented for instance in [Des94, Des05]. In this network we have different kinds of arrows: (i) “is a sort of”; (ii) “implies”; (iii) “contains”. For instance a descriptive state (i.e. the sky is blue) is a sort of a state. The resulting state (i.e. John has bought a new car) is a sort of state and it implies an occurrence of one event, the occurrence being before and contiguous to the state. The activity state (i.e. the plane is in fly ) is associated to a progressive process (i.e. the plane is flying) but the temporal area are not the same since the interval of validity (an opened interval) is included in the validity interval of the underlying process. In our conceptualization (Descleès, Guenchtéva 1995) the aspectual notions especially activity, state, event and process are defined in a different way from Vendler.

The notion of temporal referential (or temporal reference system) is essential to understand the semantics of tenses and aspects in natural languages. Different publications have shown the necessity of this notion. For instance, the uttering process defines an enunciative referential where the structure of “future” is not the same as the structure of the past. But in a lot of narrations events can’t be related to the uttering process since they belong to another referential. When an utterance uses the marker if, it introduces a new referential, a referential of possible situations; for instance the sequence “if it is raining, then it is wet outside” is true not in the enunciative referential but it defines a necessity between two occurrences of possible situations and when the first occurrence is realized inside the enunciative referential then the second occurrence must be realized inside the same referential as well. Thus, the notion of referential is useful to represent temporal relations between situations expressed by texts.

This network is a part of a more general ontology of time and aspect. We introduce the relation between different topological intervals and constitutive parts of different concepts leading to a time ontology.

**Formal ontology of time and aspect**

Reusing the formal notions we have laid out before, we express the information which is hold in fig 2, the dependencies between aspectual values and also the structure of the time conceptualized as topological intervals to establish a formal ontology of time and aspect.

Let’s consider first the time structure. The basic concepts which are involved are considered as primitive types of a typed applicative system. Those primitive types are the following:

- \( T \) for the concept of instant
- \( \text{Int} \) for the concept of interval
- Sit for the concept of situation
- H for the concept of true value

These concepts are organized by relations to which are given functional types derived from primitive ones according to the rule given in [T]. Here are the relations we use in the ontology:

- \( \epsilon \) the relation whole/part (mereology) with type \( FT \) \( \models \) Int \( H \)
- := the relation of identification with type \( FT \) \( FT \) \( H \)
- \( \subseteq \) the relation of inclusion between intervals with type \( \text{Int} \) \( \text{Int} \) \( H \)
- \( \delta \) the relation of determination with type \( \text{Int} \) \( \text{Int} \) \( H \)

For instance an instant being a mereological part of an interval will be expressed by the following relation between concepts:

![Int](image1)

Figure 3 - An instant is a part of an interval

In this diagram we express that an instant \( t \) with the type \( T \) (“\( t \) is an instant”) is a mereological part of an interval. The relation \( \delta \) expresses a specification. For instance an interval with a closed left boundary and opened right boundary is a specification of an interval with boundaries. The relation \( := \) establishes an identification between two entities with the same type. For instance, a boundary is an instant with the type \( T \) (“a boundary is an instant”). The relation \( \subseteq \) holds between two intervals, the first term of this relation is a subinterval of the second term.

In this network we introduce a new relation (written here in bold arrows) between an aspectual situation a specific topological interval onto which this situation is true.

The general network of concepts representing the time structure is partially given by the following diagram:

![Types: instant: ](image2)

Figure 4 – Ontology of time

The semantics of the relations between concepts is given by two features; the former is the functional type giving the type of concepts a relation can be applied to, and the latter is the algebraic properties. For instance, the mereological relation is transitive, antisymmetric and reflexive. According to these properties it is thus possible to make inferences.

Let’s introduce now two important concepts to understand aspectuality and temporality conceptualized by language, the notion of continuous cut and that of sequence of events.

\( T_0 \) is a continuous cut between past instants (time of the memory of the utteror) and future instants (time of the incoming instants). In the same way, when we define the aspectual value of “perfect” (for instance the present perfect) we must use this notion of continuous cut.

A cut (in the sense of Dedekind) is defined as follow:

Let’s consider a set (of instants) linearly oriented \( E \). We introduce a partition of \( E \) between \( A_1 \) and \( A_2 \) with the following properties:

(i) \( A_1 \prec A_2 \) : all instants of \( A_1 \) precede all instants of \( A_2 \)
(ii) \( A_1 \cup A_2 \supseteq E \)
(iii) \( A_1 \cap A_2 = \emptyset \)

A continuous cut \( t_c \) of \( E \) is an instant of \( E \) such that either:

(i) \( t_c \in A_1 \) : a right closed boundary of \( A_1 \), and
\( t_c \in A_2 \) : \( t_c \) is a left opened boundary of \( A_2 \)
or,
(ii) \( t_c \notin A_1 \) : \( t_c \) is a right opened boundary of \( A_1 \), and
\( t_c \notin A_2 \) : \( t_c \) is a left opened boundary of \( A_2 \).
Figure 6 - The continuous cut

\[ T_0 \text{ is the first instant of unrealized instants, it is a right opened boundary of all instants which are constituent of the enunciative process.} \]

Figure 7 - Enunciation process

A resultative state which is true onto an opened interval \( O_2 \), implies an occurrence of one event before the state; this event is closed onto a closed interval \( F_1 \). The boundary between the event and the resultative state, i.e. between \( F_1 \) and \( O_2 \) is a continuous cut.

Figure 8 - Resultative state

The other important concept in aspectuality is the one of “sequence of discrete occurrences”. It is defined as follow: A sequence of occurrences of the same event (or more generally same situations) generates a sequence of enumerative events. The sequence is a discrete process with a first occurrence of the event; this sequence is called opened when the utteror does not take into account a last occurrence of event; the sequence is called closed when the utteror takes into account a last occurrence. Let us take an example of an opened discrete process: “John smokes cigarettes” (value of habit) in opposition to “John is smoking a cigarette”.

References


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