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Toward a Formal Ontology of Time from Aspects

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Abstract

We present a work in the field 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

The general goal of this work is to lay out a formal ontology of time and aspect conceptualized from a systematic analysis of natural languages semantics. To reach that, we first build a model within which general properties of time and aspect will be made explicit. We need these temporal properties when we take into account the evolution of objects trough time. Considering the definition of the model of time we use, even if there is some common features we don't follow the modal logic approach (Tense logic by Prior, US operators from Kamp) for several reasons, notably because we need notions such as enunciative process (for instance to treat the problems of temporal deixis), continuity and aspectual values (e.g. state, event and process and related notion like sequence of events or resultative[1] state) which are not taken into account within modal logics. Once the theory of time and aspect is established we introduce the general methodology we work with, we then give the formal framework we use and finally we make the connection with actual works in formal ontologies (see Guarino, Smith…). In that respect we define a formal ontology of "linguistic time" which is time and aspect analysed from natural languages. This treatment of time in ontologies is different from that of endurant and perdurant objects that are proposed in some articles of the formal ontologies community. This paper is a part of a program aimed at relating linguistic descriptions from a theoretical point of view to ontologies.

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Aspectual and temporal concepts

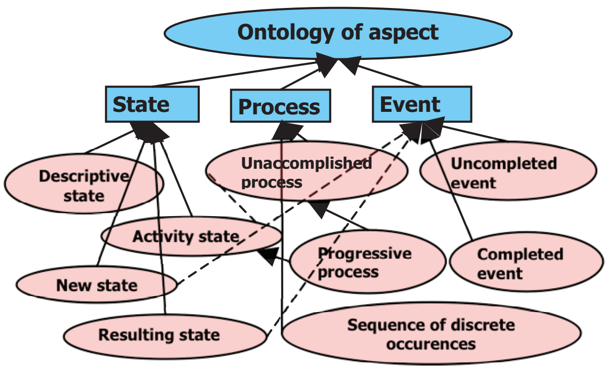
We now introduce the concepts we work with to build the model we talked which lead to a theory of time and aspect.

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 "past". There is no symmetry between past and future: the time conceptualized from natural languages is not structured by a linear order. 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 actualized inside the enunciative referential then the second occurrence must be realized inside the same referential. Thus, the notion of referential is useful to represent temporal relations between situations expressed by texts.

We make the hypothesis that linguistic time is a set of temporal referential structured by three relations: identification or concomitance, differentiation for "before" and "after" relations and breaking (in French "rupture") between two referentials; each temporal referential is a continuous set of instants. Thus each interval of instants is a topological interval (open, closed…)

From our point of view, the basic concepts of aspect are that of "state", "event" and "process". A state expresses a situation without any changes; when the state is bounded the events of change are outside of the state. An event corresponds to a modification of a situation. It is bounded by two states. A process expresses an ongoing situation without a last instant. More generally, the mathematical notions which are involved in the realization of aspectual values are intervals of instants. 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 continuous contiguity is introduced as well to express dependencies between aspectual values. For instance, the value of 'resulting state' comes directly after an event which is a cause of it.

Moreover, we identify some dependencies between aspectual values which lead to a general network of aspectual concepts that we call a linguistic ontology of aspect (see Fig 1). We are going to develop further this



notion later in this article.

The properties and specifications of "state", "event" and "process" as well as some formal relations between them are presented for instance in [Desclés 94, 05, 07]. 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 ter

Figure 1 - Ontology of aspect

(an opened interval) is included in the validity interval of the underlying process. In our conceptualization (Desclés, Guentchéva 95) the aspectual notions especially activity state, event and process are defined in a different way from Vendler (see Vendler 57).

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

The uttering (or enunciation) is not an instant but an unaccomplished process which is being realized on half-opened interval with the right boundary called T^0. In this case T^0 is not the last instant of the enunciative process but T^0 is the first instant of unrealized instants, it is a right opened boundary of all instants which are constituent of the enunciative process. This process introduces a temporal reference system organized by the utterer (see Fig 2). This enables for instance the treatment of deictics.

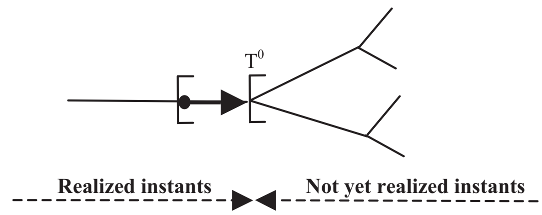


Figure 2 – Enunciation process

We recall what is a continuous cut t_c (in the sense of Dedekind) in a set E of instants linearly oriented. We suppose that E has the following conditions with two parts A_1 and A_2 of E:

(i) $A_1 \cup A_2 \supseteq E$
(ii) $A_1 \cap A_2 = \varnothing$
(iii) $A_1 < A_2$: all instants of A_1 precede all instants of A_2

t_c is continuous cut in E when one of exclusive conditions (i) or (ii) is right :

(i) $t_c \in A_1$: t_c is a right closed boundary of A_1, and
$t_c \notin A_2$: t_c is a left open boundary of A_2

(ii) $t_c \notin A_1$: t_c is a right opened boundary of A_1, and
$t_c \in A_2$: t_c is a left opened boundary of A_2.

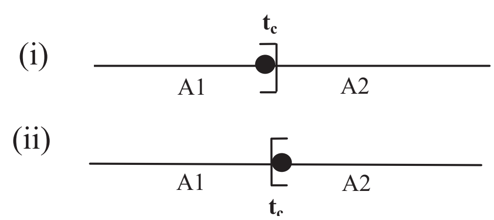
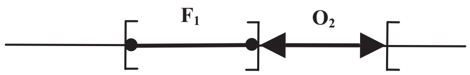


Figure 3 - The continuous cut

Thus T^0 is a continuous cut between the realized instants ("the past of the utterer") and the not yet realized instants ("the incoming instants of the utterer"). In the same way, we define the aspectual value of "perfect" (for instance the present perfect) we define this notion by the means of a continuous cut between the event and resulting state. A resultative state which is true onto an opened interval O_2, implies an occurrence of one event before the state; this event is true 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.



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 situation) is realized on discrete sequence of closed intervals. This sequence generates a discrete process with a first occurrence of the event; this discrete process is called opened when the utterer does not take into account a last occurrence of the event; the discrete process is called closed when the utterer takes into account a last occurrence. Let us take an example of an opened discrete process: "*John smokes cigarettes"* (value of generality) in opposition to "*John is smoking a cigarette*" (continuous unaccomplished process).

We assume that an utterance is the result of temporal, aspectual and uttering operations which apply to a predicative relation noted Λ. The application operation is used in a technical sense of applicative languages (Lambda-calculus, Combinatory logic and functional programming): it is an operation between operator and operand yielding to a result. For instance the predicative relation presented in its applicative form ((*eat* (*apple)) John)* can be specified by a specific aspectual operator of process returning the processual value "*John is eating an apple";* or by another aspectual operator, that of event, giving the event value "*John ate an apple*".

The general expression of aspectualization is given using a binary predicate and more elementary operator $ASP1_{I3}$, $ASP2_{I2}$ $ASP3_{I1}$, and temporal relations (REP) between intervals of realization I_1, I_2 and I_3.

$$\mathbf{PROC}_{J0}\ (\mathbf{I\_AM\_SAYING}\ (\mathbf{AND}\ (\mathbf{ASP}3_{I1}\ (\mathbf{ASP}2_{I2}\ (\mathbf{ASP}1_{I3}\ (P_2)T^2)T^1))\ ([I_1\ \text{REP}\ J_0]\ \&\ [I_2\ \text{REP}\ I_1]\ \&\ [I_3\ \text{REP}\ I_2])\ )$$

This formal expression is a scheme of different aspectual values of utterances. The symbols ASP1, ASP2, ASP3 are variables of operators with a specification: "process", "event", "state", "sequence of events", "resulting state"… The specific operators are realized on topological intervals. ASP1 is related to the meaning of the predicate according to a semantic typology of verbal meanings (see Desclés 05) (stative, kinematic or dynamic situations). ASP2 specifies relations between the predicate and a term which is completely modified or not (by spatial properties or by specific changes of states according to the meaning of predicate and terms). ASP3 is a general aspectual operator for which the predicative relation is in its scope.

Topological intervals are the interpretation domains of the formal language of operators. Consequently a predicative structure having an aspectual and temporal specification is said to be true or is realized onto a topological interval. For instance, an utterance with the aspectual value of a process is true onto a half-opened interval with a right bound T^0.

The methodology and formal framework

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 by means topological intervals). It enables thus to represent. In a second step we build by abstraction a formal language from the model. The formal language we use is an applicative one defined inside the formal and sound framework of Curry's combinatory logic with functional types.

To summarize this general approach of conceptualization and formalization from empirical data and linguistic theory (analysis of problems), we give the following diagram:

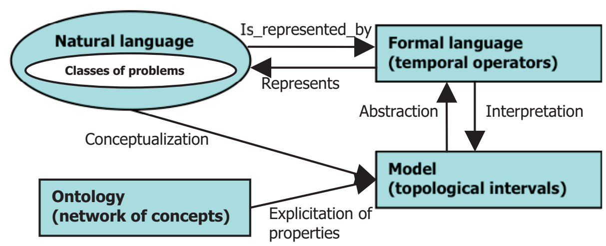


Figure 5 - General methodology

This methodology in our approach is very different from the usual studies given by logicians as Prior (see Prior 67) and modal logic or tense logic who introduces some specific operators (FPHG, US-logic) which apply to propositions and then give an interpretation of this operators in a set-based model for instance the theory of possible worlds.

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 embedded 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 restricted by using types. Hence, the

application of an operator is allowed only if it 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 F**αβ** 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 F**αβ** 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: F**αβ**] [Y: **α**]

[XY : **β**]

Formal ontology of time from aspects

Reusing the formal notions we have laid out before, we express the information which is hold in fig 1, 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 type of instant
- **Int** for the type of interval
- **Sit** for the type of situation
- **H** for the type of truth value

From these basic types are derived functional types which correspond to relations. There are different typed relations between types of the network. The relations we use in the linguistic ontology are the following:

- ε the relation whole/part (mereology in sense of Lesniewski, see Mieville 05) with type F**T** F**Int H**
- := the relation of identification with type F**T** F**T H**
- ⊆ the relation of inclusion between intervals with type F**Int** F**Int H**
- δ the relation of determination with type F **Int** F**Int H**

For instance an instant being a mereological part of an interval will be expressed by the following relation between concepts (see fig 6):

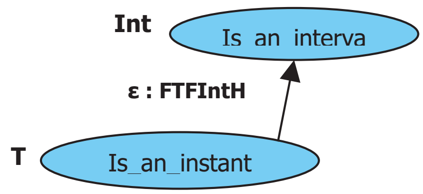


Figure 6 - An instant is a part of an interval

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 δ 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 entity with the type T" is identified with "an entity which is an instant with the type T" ("a boundary is an instant"). The relation ⊆ holds between two intervals, the first term of this relation is a subinterval of the second term.

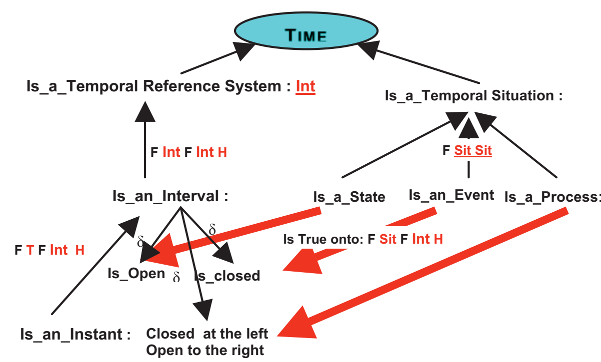


Figure 7 - Validation intervals

In this network of the figure n we introduce the basic aspects as operators building aspectual situations and relations (pictured here in bold arrows) between these basic aspects and a specific topological intervals onto which the aspectual situations are true.

A first approach of the network of concepts organizing the time conceptualized from aspect in natural languages is given by a formal and linguistic ontology by the figure 8.

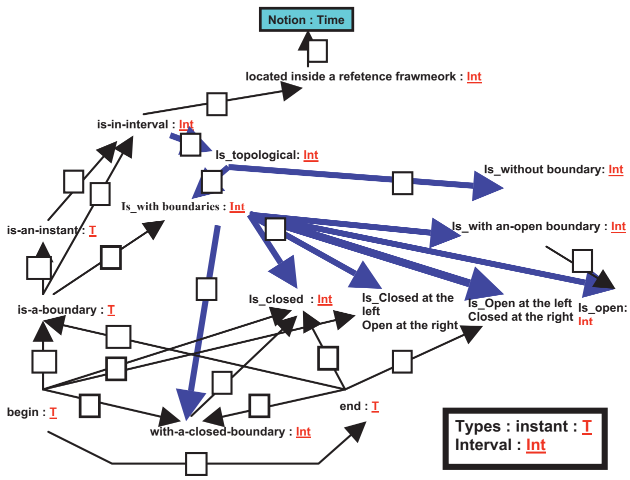


Figure 8 – Ontology of time

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

We give for instance some properties of relations:

- $X \, \varepsilon \, Y \Leftrightarrow \forall u : [X(u) \Rightarrow (Y(u)]$
  $\varepsilon : F(FXH)F(FXH) \, H$
- $X \subseteq Y \Leftrightarrow \forall u, \forall v : [X(u) \Rightarrow (Y(v) \Rightarrow u \subseteq v)]$
  $\subseteq : F(FYH)F(FXH)H$
- $X \, \delta \, Y \Leftrightarrow \forall u : [\, Y(u) \Rightarrow \exists v : [\, X(v) ;$
  $u = \delta \, (Y)(v) \,]$
  $\delta : F(FXH)F(FYH)H$

Conclusion

We have first introduced in this article an analysis of time and aspect studied from a linguistic point of view. We gave then a formal frame to express these temporal and aspectual properties. The methodology that we follow is different from that of tense logic because we start from the linguistic semantics. We make the assumption that operators such as "Since" and "Until" from Kamp can be formalized inside this formal framework. It is also possible to give a formal interpretation to operators like "still", "not yet", "already" and "no longer"

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