A Formal Model for the Representation of Processes having an Internal Structure

Eleni Galiotou
Department of Informatics
TEI of Athens
and, Department of Informatics and Telecommunications,
University of Athens
e-mail: <egali@di.uoa.gr>
&
Gérard Ligozat
LIMSI-CNRS,
Paris-Sud University, France
e-mail: <ligozat@limsi.fr>

Abstract
In this paper, we propose a formalization of relations between processes having an internal structure using the formalism of generalized intervals [Bestougeff and Ligozat (1992), Ligozat (1991), Ligozat (1996)]. The main temporal object of this formalism is an increasing sequence of typed boundaries called a "poly-typed" string and is used for the representation of a complex event or state. The typing of the boundaries allows reasoning over the degree of completion of actions.
In particular, we deal with the relations of causation and enablement grouped under the notion of consequentiality [Moens (1987)], which constitutes the cognitive basis of the tripartite ontology of events [Moens and Steedman (1988)]. We propose a formalization of this notion of consequentiality that proves to be indispensable to artificial intelligence tasks involving temporal and causal relations in natural language.

Keywords:
knowledge based systems, artificial intelligence, cognitive science

1. Introduction

In Artificial Intelligence tasks, one cannot take into account causality without considering its temporal aspect. For example, the prediction or explanation of system functioning implies necessarily a description of their evolution in time. In addition, in everyday reasoning, the world is conceived as a series of interrelated events in such a way that an event causes or allows the emergence of another. Yet, not every temporal succession implies the existence of a causal link. According to [Bunge (1979)], changes of states but not states themselves can be produced and sometimes linked, in a causal way. Nevertheless, in modern philosophy it widely accepted that causality is a relation between events. According to [Davidson (1980)] we cannot give a convincing account of explanation or causality if we do not consider events as individuals. As a matter of fact, the need to consider events as a fundamental ontological category is put forward not only in Artificial Intelligence but in Linguistics and Philosophy as well. For instance, in [Kamp (1980)], H. Kamp suggests the construction of temporal structures of points and intervals based on events. In Artificial Intelligence a number of approaches have been proposed such as Allen's theory of action and time where an ontology of properties, events and processes is associated to temporal intervals [Allen (1984)]. The ontology is used in the processing of action, planning and causality. Nevertheless, this theory of action and time proves to be inadequate for Natural Language Processing tasks since only a limited number of linguistic phenomena can be represented. In fact, in order to take into account temporal reference or the internal structure of events we need a more complex ontology and representation language. An ontology that meets the abovementioned requirements is the tripartite ontology of events [Moens (1987), Moens and Steedman (1988)]. A central notion in this approach is that of an *event nucleus* which is composed of a *preparatory process* leading to *culmination point* which is followed by a *consequent state*. Reference to specific parts of the nucleus determine the type of the corresponding temporal entity. A *culminated process* corresponds to an entire nucleus, and a *culmination* is constituted by a *culmination point* followed by a consequent state. A *process* is determined by reference to the preparatory process part of the nucleus while a *state* refers to its consequent state. A *point* is an atomic event with no consequent state. Thus, we can explain why the same event can be used by reference to its preparatory process, to its culmination point or its consequent state. This proposal for an ontological change has as starting point the study of internal structure of events and the way language can be used in order to describe parts of this structure. This classification is not an objective classification of events and states but it rather corresponds to a mental structuring of the world. Moreover, it does not rely on the relation of temporal precedence alone but also on the cognitive basis of the relation of consequentiality. In section 2, we propose a representation of the tripartite ontology of events using the generalized interval formalism and in section 3 we propose a formalization of this notion of consequentiality and we discuss the use of this notion in a reformulation of the causal interpretation principle.

2. Temporal knowledge in the generalized interval framework

2.1 The generalized interval formalism

The richness and the complexity of linguistic knowledge implies that well known formalisms such as Allen's interval based framework [Allen (1984), Allen (1983)] are inadequate for the representation of knowledge which is not limited to events and the relation of temporal precedence. In particular, the representation of the tripartite ontology of events requires a formalism allowing a direct representation of the internal structure of temporal entities. We claim that the generalized interval formalism [Ligozat (1997), Ligozat (1996), Ligozat (1991), Bestougeff and Ligozat (1992)] is such a formalism, since it allows the direct representation of qualitative processes having an internal structure. In addition, from the point of view of its implementation, this formalism has properties that generalize the properties of Allen's formalism. A generalized interval containing n points is called an *n-interval*. Therefore, an "ordinary" interval according to Allen's model is a 2-interval. The relation between a p-interval and a q-interval is called a (p,q)-relation:

Definition Let T be a linear order. An n-interval in T is an increasing sequence of elements of T: $(t_1, \dots, t_n)$ where $t_1 < \dots < t_n$

Let $x=(x_1, \dots, x_p)$ be a p-interval and $y=(y_1, \dots, y_q)$ be a q-interval in a linear order T. The points y1, …, yq define a partition of T into 2q+1 zones numbered from 0 to 2q:

zone 0 : $\{t \in T \mid t < y_1\}$;
zone 1 : y_1 ;
zone 2 : $\{t \in T \mid y_1 < t < y_2\}$;
…
zone 2q : $\{t \in T \mid t > y_q\}$.

The (p,q)-relation is entirely determined by specifying for each boundary of X which zone of Y it belongs to. Furthermore, each oddly numbered zone contains one x_i at most. So, the set $\Pi(p,q)$ of (p,q)-relations is the set of non-decreasing sequences π of p integers between 0 and 2q, where each odd integer occurs at most once [Ligozat (1991)]. Each element π in $\Pi(p,q)$ is associated to a set of equations and inequations $E(\pi)$:

$$E(\pi) \begin{cases} x_i = y_{(\pi(i)+1)/2} & \text{if } \pi(i) \text{ is odd;} \\ x_i > y_{\pi(i)/2} & \text{if } \pi(i) \text{ is even, } \pi(i) < 2q \text{ ;} \\ x_i < y_{(\pi(i)+2)/2} & \text{if } \pi(i) \text{ is even, } \pi(i) > 0 \end{cases}$$

for I = 1, …, p.

The calculus of generalized intervals is presented in detail in [Ligozat (1991)], [Ligozat (1996)] and [Ligozat (1997)].

2.2 The representation of temporal knowledge

The generalized interval framework allows the association of different kinds of processes to typical schemata in terms of sequences of typed boundaries. The main object of the n-interval formalism is a "poly-typed" string (henceforth PTS) i.e. an increasing finite sequence of typed boundaries (opening, closing and undefined), which is associated to linguistic information. The typing of the boundaries allows reasoning over the completion of actions so, it proves to be adequate for the representation of grammatical aspect, also. The boundaries of a PTS define a partition into 2n+1 zones numbered from 0 to 2n and correspond to time points. Odd numbers correspond to typed boundaries and even numbers correspond to open intervals defined by these boundaries. A PTS containing n boundaries will be referred to as *n-string*. The use of this numbering allows the denotation of combinatorial possibilities between two n-strings. In the following we give a representation of the elements of the tripartite ontology of events [Moens (1987)] in the n-interval formalism [Galiotou (1999), Galiotou & Ligozat (2002)]. Temporal entities are classified into events and states. Events are in turn classified into extended events (processes and culminated processes) and punctual events (points and culminations). In the following we give the representation of temporal entities situated in the past using the generalized interval formalism.

Culminated process (Past, Perfect)

```
[---------I--------[------------------- I
O1        U3       O5                   U7
```

Here, a preparatory process is represented by the interval (1 3), the culmination point by boundary #3 and the consequent state by the interval (3 5). The time of speech is represented by boundary #7.

Process (Past, Imperfective)

```
[---------[-------------------I
O1        O3                  U5
```

Here, the process corresponds to the interval (1 3) and the time of speech to the boundary #7.

Culmination (Past, Perfective)

```
I---------[-------------------I
U1        O3                  U5
```

The culmination point is represented by boundary #1, the consequent state by the interval (1 3) and the time of speech by boundary #7.

State (Past, Imperfective)

```
]---------[-------------------I
C1        O3                  U5
```

Here, the state is represented by the interval (1 3) and the time of speech by boundary #5.

Point (Past, Perfective)

```
I-------------------I
U1                  U3
```

A point is represented by boundary #1 and the speech time by boundary #3.

In the abovementioned representations we have adopted the following notations: **[** is an **O**pening boundary, **]** is a **C**losing boundary and **U** is an **U**ndefined boundary. Typed boundaries are used to describe the degree of completion of an action and therefore the grammatical aspect.

A sequence of poly-typed strings reflecting the temporal structure of a consistent piece of discourse is called a *temporal site*. This temporal site can be represented by a temporal constraint network i.e. a graph where the edges correspond to typed n-strings and the arcs to relations between them. As [Bestougeff and Ligozat (1992)] point out, at this point we can anticipate different ways of processing such as :

- In case of an incomplete graph, calculate possible relations between two generalized intervals using the formula of composition of relations as introduced in [Ligozat (1991)]. An application of this procedure can be found in [Galiotou (1999)].
- Verify that the set of relations in the temporal constraint network is consistent.
- Verify that updating the temporal constraint network does not introduce an inconsistency.

The propagation of constraints in the graph is performed using a variant of Allen's constraint propagation algorithm [Allen (1983), Allen (1984)], as it was adapted to the generalized interval framework [Ligozat (1991), Galiotou (1999)].

3. Formalizing Consequentiality

3.1 The causal interpretation principle

As it is already stated, the temporal objects in our model are n-intervals and the temporal entities associated to n-intervals are those of the tripartite ontology of events. Therefore, a study of causal phenomena consists in describing in an abstract way the linking together of these entities and consequently in the exploitation of the temporal site. In order to extract causal information from the temporal site, we follow [Nazarenko (1994)] in considering causal propensity as an interpretation principle. Contrary to [Schank and Abelson (1977)] who consider causal propensity to be the causal power of actors and allow the choice between several causal relations in the case of ambiguity, Nazarenko proposes a default rule which embodies the following principle of causal interpretation: "If there is a temporal relation between two facts A and B and there is no contrary evidence, we try to interpret A as a cause for B". In a formal manner, the causal interpretation principle will be described as:

$$\frac{A \wedge B \wedge \text{Temp-Rel}(A,B) : D}{\text{Cause}(A,B)}$$

In other words, if Rel-Temp and D represent a temporal relation and a default respectively, the abovementioned rule allows the inference Cause (A, B) from $A \wedge B \wedge$ Rel-Temp(A, B) if there is no proof that D is false. This principle relies on the human propensity to interpret sequentiality in terms of causal phenomena. In Natural Language Processing, this propensity to causal interpretation is used both in the production and in the understanding of utterances.

3.2 Consequentiality and causal interpretation

As it was already stated in the introduction, causal and temporal phenomena are intimately related but not every succession in time implies the existence of a causal relation. For instance, the temporal succession of two atomic events (punctual events without consequences) couldn't possible imply a causal link between them. Consequently, in order to process causal information on must take into account temporal ontology as well. This is line with Galton's remark that the processing of causal information must distinguish between at least states and events [Galton (1991)]. This was the main reason for our choice of a temporal ontology which is not based on temporal precedence alone but on notions like causation or enablement as well. Following [Parsons (1990)] we use the term *eventuality* in order to describe an event or state. The notion of *consequentiality between eventualities* is used in order to describe these relations of causation between events or enablement between an event and state. Therefore, a formalization of this notion of consequentiality is indispensable to causal interpretation. We propose the following:

Principle of causal relevance:
Let A={a1, a3, a5, a7} and B={b1, b3, b5, b7} be two eventualities in the form of complete nuclei. A consequentiality relation holds between these eventualities only if the culmination point of B is situated in the consequent state of A.

Notation Let E be an eventuality.
culm(E) is the culmination point of E and,
cons-state(E) is the consequent state of E

So, the formal definition of the consequentiality relation is:

$$\text{Conseq}(A, B) \Rightarrow \text{culm}(B) \in \text{cons-state}(A).$$

In the generalized interval framework, this relation of consequentiality is expressed in terms of a (4,4)-relation between the boundaries of A and B:

([0,4], 4, [4,8], [4,8]).

and alternatively, in terms of equations/inequations :

$$a_3 \langle b_3 \langle a_5$$

where: $A = \{a_1, a_3, a_5, a_7\}$, $B = \{b_1, b_3, b_5, b_7\}$
a3 = culmination point of A
(a3, a5) = consequent state of A
(a1, a3) = preparatory process of A
b3 = culmination point of B
(b3, b5) = consequent state of B
(b1, b3) = preparatory process of B

Note that, in case where A is a state, the consequent state is A itself so, the consequentiality relation is reduced to the relation of enablement.
Having a formal representation of this notion of consequentiality the causal interpretation principle becomes:

Principle of causal interpretation:
“If there is a relation of consequentiality between two eventualities A and B and there is no contrary evidence, we try to interpret A as a cause for B”.

$$\frac{A \wedge B \wedge \text{Conseq}(A,B) :D}{\text{Cause}(A,B)}$$

4. Conclusion

In this paper we have presented a formal approach to the problem of representing processes having an internal structure and we have focused on temporal and causal phenomena as conveyed by natural language utterances. In particular, we have proposed a formal representation of the tripartite ontology of events which takes into account the internal structure of events and the way human language is used in order to describe parts of this structure. The causal interpretation principle was redefined in terms of the relation of consequentiality which constitutes the cognitive basis of the tripartite event ontology. To this end, we have proposed a formalization of this notion of consequentiality using the formalism of generalized intervals. We claim that this formalization is indispensable to Artificial Intelligence tasks involving temporal and causal relations in natural language.

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