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Temporal Reasoning in a Hybrid System

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Abstract

Temporal aspects of knowledge are receiving increasing attention for their importance both in organizing knowledge bases and in natural language understanding. Most of the current proposals follow a purely logical approach without taking advantage of the possibilities offered by the integration of a logical (assertional) language and a terminological one. A proposal for such an integration is presented. The assertional language we propose avoids reification and includes a rich set of denotational entities. Our system is shown to be able to handle complex phenomena like periodic events.

1 Introduction.

The development of a system able to engage in a dialog with a user involves considering several representational problems. Representing time is one of these problems, because time permeates our view of reality.

In a financial domain, for example, like that of the consultation system we are developing (the WISBER system, [Bergmann, Gerlach 1987b]) notions like that of duration of an investment or of date, and the associated reasoning processes, are absolutely crucial. The ability to represent and use time is therefore necessary to properly organize both the expert knowledge and the knowledge acquired during the dialog

Being able to store temporal information offers also advantages from the point of view of the organization of the knowledge base. If, for example, the

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system is able to associate an interval of validity to the facts that it knows, instead of just deleting the previous data when new information is acquired, the expert knowledge about previous situations can be used and, at the same time, kept separate from the knowledge about the current situation, avoiding at the same time the problems with deletion in predicate calculus.

Temporal reasoning is also the basis for handling *tense*, which aspect is crucial for properly understanding and generating natural language utterances. A sentence in which tense restrictions are violated, like "I will buy a bond YESTERDAY", strikes much more than a sentence in which *selectional* restrictions are violated, like "I spilled a bond yesterday". This seems to suggest that tense plays in semantics a role at least as important as that of semantic categories. In addition, tenses are heavily used to implicitly convey information. The implications of the sentence "I bought a house six years ago", for instance, are quite different from those of "I will buy a house next week"; and especially so if the hearer is a system which wants to know approximately the amount of money that the speaker (the user) currently owns. Since tenses introduce temporal relations between the utterance event and other events (the time of the event and a time of reference: see, e.g., [Yip 1985]), it is hard to imagine how to handle them without some form of temporal reasoning ability.

It should not be surprising therefore that in recent years the interest in time has grown considerably both in the AI and in the DB community, as certified both by the number of talks on this topic which have recently been presented on conferences ([Ladkin 1986, 1987], [Leban et al. 1986], [Vilain, Kautz 1986]) and by a recent bibliography ([McKenzie 1986]). The work done in AI has mainly focused on the development of appropriate *temporal logics* ([Mays 1983], [McDermott 1982], [Allen 1983, 1984], [Allen, Hayes 1985], [Shoham 1987], [Reichgelt 1987]). These temporal logics are now being used more and more as a basis for work on *temporal inferencing*, where the term temporal inferencing indicates both the processes which exploit the temporal inferences and the organization of the knowledge base which supports these inferences. Research on temporal inferencing within the formal framework provided by an existing temporal logic is being carried on, among others, by Allen ([Allen, Frisch 1982]), by Vilain and Ladkin on Allen's logic ([Vilain 1982], [Vilain, Kautz 1986], [Ladkin 1986, 1987]), and by Kowalsky [1986].

In this paper I will describe the methods used to represent and use time in WISBER. The emphasis will be on the representation, rather than on the actual inference procedures. The most significant difference between our work and the work described above is, in fact, our adoption of a *hybrid* style of representation à la KRYPTON ([Brachman et al. 1985]); and, consequently, our attempt to integrate the representation of time with the *epistemological*

style of organizing the knowledge base typical of systems like KL-ONE ([Brachman, Schmolze 1985]).

General justifications for the choice of an hybrid style of representation are presented in the literature ([Brachman et al. 1985]). A specific motivation for the representation of time is that most of the existing temporal logics are *sorted* logics; a component to define the types is therefore necessary. Using a KL-ONE-like language for this purpose offers several advantages. For example, if we use the T-BOX to define generic concepts like EVENT or TIME-INTERVAL, those axioms of [Allen 1984] or [Kowalski, Sergot 1986] which are just a reformulation of the axiom schemata formalizing inheritance (e.g., the axioms concerning the existence of role fillers) are no longer necessary since they can be inferred at no additional cost from the standard interpretation of the T-BOX (e.g., that of [Schmolze, Israel 1983]).

The idea of just using one of the currently available temporal logics as a basis for the A-BOX and (the interpretation of) the T-BOX engenders, however, certain difficulties. Most of these logics are based on the so-called *reification* approach. This approach has been elegantly formalized, but has some severe drawbacks, described in section 2.1.

Our approach has been instead inspired by Hobbs' *Ontological Promiscuity* ([Hobbs 1986]). In this approach everything in the KB is an *individual*, even the assertions. In our system, accordingly, events, states and time intervals are all represented as individuals, and we use roles to represent the association between an object and a time interval. Events and states have roles describing their time (interval) of validity. The roles of time intervals describe their interrelationships, corresponding to Allen's [1983] system of relations between time intervals. We also have an individual for every (atomic) fact expressible via our assertional language. Representational problems both at the T-BOX level (the definition of intervals) and the A-BOX level (defining periodic events) are solved by introducing different kinds of individuals. We are also able to associate a time of belief to every formula.

We have developed two distinct, but interrelated, systems to support the reasoning processes of WISBER: an *assertional* component (A-BOX), called QUARK ([Poesio 1987a]), and a *terminological* component (T-BOX) called QUIRK [Bergmann, Gerlach 1987a].

2 Associating Time Intervals to Assertions.

2.1 Reification.

'Reification' means that only the relations between temporal intervals, or the association of a temporal interval with a formula, are considered predicates; while 'normal' predicates are used as functions and therefore appear in the formulas as *terms*. For instance, Shoham's representation of (1) is (2) ([Shoham 1987])

(1) HOUSE17 was red over the interval <time-point-1, time-point-2>

(2) TRUE(time-point-1, time-point-2, COLOR(HOUSE17, RED)).

where TRUE is the predicate associating a fact with the temporal interval (indicated by two time points) during which it is true.

The first problem with reification is that since non-atomic formulas are represented as functions, like in (3) or (4) (& is Shoham's function for the connective \wedge)

(3) TRUE(t_1, t_2 , COLOR(HOUSE17, RED)&HEIGHT(HOUSE17, 6meters))

(4) TRUE($t_1, t_2, \exists x$ COLOR(HOUSE17, x))

a large number of axiom schemata are needed. In the best case, as Shoham observes [1985], you have to reaxiomatize the whole FOPC - which is what Allen does in [Allen 1984]. In the worst case, you are not able to express a sentence like (4) at all - which is what happens with Shoham's proposal.

A second problem with reification is specific to the set-theoretic approach adopted by Shoham and McDermott: interpreting events as functions which denote set of time points (i.e., identifying events and time points) makes it impossible to distinguish two events which occurred in the same time interval. Using an hybrid representation the problems originated by the identification of events and time intervals become much more evident, since a concept should be defined which denotes both: what kind of event is "October 22, 1962", for instance?

The third problem of the reification approach is evidenced by observing that a system normally needs to know *both* that a certain property is valid for some time interval, *and* the time interval during which it (the system) has this belief. To represent this using reification, it is necessary to use also predicates like TRUE as functions, therefore running precisely into the kind of problems which we hoped to avoid.

The second and third problem are best illustrated by an example. Suppose that your purpose is to store in the KB a representation of the plot of Conan Doyle's *A Study in Scarlet*. First, it is necessary to represent the fact that the corpse of a man MAN1 is discovered in a room ROOM1 in a certain street in

London. This can be done by asserting that a KILL EVENT OCCURRED (or was TRUE) during a certain time interval, the AGENT being unknown.

This assertion is quite easy to represent using a role-based description of events and representing roles as two-place predicates. But things get more complicated if the event is described using a function, like KILL in

(5) $(\exists t_1)(\exists t_2)(\exists x) \text{TRUE}(t_1, t_2, \text{KILL}(x, \text{MAN1}, \text{ROOM1}))$

Let in fact say that after a while Sherlock Holmes discovers that the killing actually did not take place in ROOM1, but in ROOM2 (a quite common discovery in these stories). A formula similar to (5), but in which ROOM2 has replaced ROOM1, has to be asserted:

(6) $(\exists t_1)(\exists t_2)(\exists x) \text{TRUE}(t_1, t_2, \text{KILL}(x, \text{MAN1}, \text{ROOM2}))$

The problem now is that, you cannot simply delete (5) after discovering (6); otherwise the sequence of events would be changed. But, unless you have an enormous number of axioms or a very sophisticated equality reasoner, you are not able to conclude that $\text{KILL}(x, \text{MAN1}, \text{ROOM1})$ and $\text{KILL}(x, \text{MAN1}, \text{ROOM2})$ denote the same event if KILL denotes a constant. And making it denote a set of time points, as in McDermott's and Shoham's approach, just complicates matters, for then you are able to infer not only that these two events are identical, but also that they are identical to all those events which took place between the same points in time.

Continuing with our story, after some time, Sherlock Holmes discovers that the AGENT of the KILL event is MAN2. The problem is that, if the system has to 'understand' the story, it is not enough for it to know that during a time interval $\langle t_1, t_2 \rangle$ a killing event took place with such and such a victim, such and such a murderer, etc. The story can only be understood when it is clear that the facts *have been discovered at different times*. But to represent this, we need to be able to express (some variation of)

(7) $\text{TRUE}(t_3, \text{NOW}, \text{TRUE}(t_1, t_2, \text{AGENT}(\text{KILL1}, \text{MAN2})))$

in which now is TRUE that is used as a function. All the advantages of interpreting predication as functions therefore disappear.

2.2 Eventualities.

The approach we have taken is to use Time Intervals - our basic means to represent time - just like any other individual of the knowledge base. We therefore use a first-order logic, in the sense that the evaluation of a formula

need not necessarily take place with respect to a specific TI, and that predication over TIs have the same status of the other predication.

In the assertional language we have developed, called IRS ([Bergmann et al. 1987]), atomic formulas can be of two kinds: **concept predicates** or **role predicates**. The effect of asserting a concept predicate is to augment the KB with a new **concept assertion**; **role assertions** are the effect of asserting role predicates. The formula (1) is represented in IRS by the role predicate

(8) (HAS-COLOR HOUSE17 RED)

(we use a lisp-like notation similar to that of [McDermott 1982]). A special KB individual is created when (8) is asserted: following Hobbs [1986], we have called these individuals **eventualities**. Instead of following Hobbs' distinction between *predicates* and *primed predicates*, however, we use the concept **EVENTUALITY** to denote all these individuals (the definition of **EVENTUALITY** is shown in Fig.1), create for every role assertion an instance of the generic concept **IROLE** (which specializes **EVENTUALITY**), and see (8) as a contraction of (9) (in which our sorted representation for the existential quantifier **EXIST** is used):

(9) ((EXIST ROLE1 (HAS-COLOR' ROLE1))
(AND (HAS-ROLE HOUSE17 ROLE1)
(ROLE-FILLER ROLE1 RED)))

(HAS-COLOR' is a specialization of **IROLE**). The predicates which relate a role assertion **R** to a time interval are therefore represented as roles of the instance of **IROLE** associated to **R**. **HAS-ROLE** and **ROLE-FILLER** in (9) are system links connecting **HOUSE17** to its role, and **ROLE1** to its role filler; the name system links is used to denote special predicates used by the KB.

Our results are, however, similar to those of Hobbs; as a matter of fact, the axiom schemata we use to relate formulas like (8) to their expanded version are a reformulation of Hobbs' axiom schemata connecting predicates with their primed versions.

Allen [1984] makes a distinction between two basic kinds of propositions: **properties** and **events** (McDermott makes a similar distinction, but uses the term **fact** instead of **property**). The relation between an event (represented as a function) and the time interval **TI1** in which it occurred is expressed by Allen using the predicate **OCCUR**:

(10) **OCCUR** (**GIVE** (**JACK1**, **MARY7**, **BALL1**), **TI1**)

while, for a property, the **HOLDS** predicate is used:

(11) **HOLDS** (**HAS-COLOR** (**CAR25**, **RED**), **TI2**)

Allen represents the difference between properties and events by giving different axiom schemata for **HOLDS** and **OCCUR**. Allen's axiom schema H.2 says that if a state **HOLDS** in **TI3**, it also **HOLDS** in all the subintervals of **TI3** (*homogeneity* property). The axiom schema O.1 says instead that if an event **OCCURS** in **TI**, it does not **OCCUR** over any subinterval of **TI2**.

We have adopted this distinction and use, therefore, two kinds of eventualities. In our hybrid approach this means that **EVENTUALITY** has two (disjoint) subconcepts, **STATE** and **EVENT**. In **STATE**, the **TIME-OF-VALIDITY** role of **EVENTUALITY** is restricted to **HOLDS**. **STATEs** correspond to Allen's properties and McDermott's facts. **EVENT** is instead defined by restricting **TIME-OF-VALIDITY** to **OCCUR**.

Allen's H.2 and O.1 axioms have been incorporated into our inference procedures, as well as the additional axiom

(12) $(\forall x)(\forall t)((\text{EVENT}(x) \wedge \text{TIME-INTERVAL}(t) \wedge \text{OCCUR}(x, t)) \supset$
 $(\forall y) \text{IROLE}(y) \wedge \text{HAS-ROLE}(x, y) \supset \text{HOLDS}(y, t))$

which states that for every instance **x** of **EVENT**, if **x** **OCCURS** in a time interval **t**, then for all the roles of **x** it is true that they **HOLD** during **t**.

The concept **IROLE** mentioned before is a specialization of **STATE**. We represent therefore the fact that **ROLE1** holds during the time interval **TI1** (example (2)) as

(13) (**HOLDS** **ROLE1** **TI1**)

This way we can obviate a common problem with the definition of concepts: which states should be represented as independent concepts, and which instead as roles? We may want to introduce for states of possession a specialization of **STATE** called **OWN** - in which case the representation of "Jack has a Ferrari" becomes

(14) ((EXIST **CAR25** (AND (**CAR** **CAR25**)
(**HAS-BRAND** **CAR25** **FERRARI**)))
(EXIST **STATE27** (**OWN** **STATE27**))
(AND (**HAS-EXPERIENCER** **STATE27** **JACK17**)
(**HAS-OBJECT** **STATE27** **CAR25**))))

or to define a **HAS-CAR** role for individuals of type **PERSON**. If an instance of (a subconcept of) **STATE** is introduced for each individualized role this decision becomes a matter of convenience.

²Allen also introduces *processes*, connected to time intervals by a predicate **OCCURRING** with a different axiomatization. For the moment we have not used this further distinction.

Conjunctions are not a big problem. The contents of the assertion (15) - in Shoham's formalism - which is equivalent to (6), but in case-frame notation,

- (15) (\exists TP1) (\exists TP2)
 TRUE (TP1, TP2, KILL(KILL1)&VICTIM(KILL1, MAN1)&HAS-LOC (KILL1, ROOM1))

can easily be represented by (16) (quantification has been omitted in this and the following formulas for the sake of brevity)

- (16) (AND (KILL KILL1)
 (OCCUR KILL1 TI1)
 (VICTIM KILL1 MAN1)
 (HAS-LOC KILL1 ROOM1))

where TI1 is the time interval corresponding to \langle TP1, TP2 \rangle and in which, due to (12), it is not necessary to specify HOLDS predicates for the roles. The disjunction (in Allen's format)

- (17) OCCUR(OR(P(a,b), Q(c,d)), TI2)

(where P and Q are binary predicates) can be represented as

- (18) (OR (AND (P' e₁) (HAS-ROLE a e₁)
 (ROLE-FILLER e₁ b) (HOLDS e₁ TI2))
 (AND (Q' e₂) (HAS-ROLE c e₂)
 (ROLE-FILLER e₂ d) (HOLDS e₂ TI2)))

with OCCUR replacing HOLDS in case of events.

Eventualities are used as *handles* (using again Hobbs' terminology) to which all the information concerning atomic facts can be attached in the form of roles or system predicates. The temporal interval of validity is not in fact the only thing that we need to attach to a given assertion. Among other things, we want to know its truth value, its justifications, etc.

2.3 Periods of Belief.

Returning to *A Study in Scarlet*, to represent the fact that the system first believed that the murder had occurred in ROOM1, but then discovers that it actually occurred in ROOM2, we can define a concept BELIEF which specializes STATE (and therefore has a HOLDS role). The time interval during which the system believes something is then indicated by specifying a filler for the HOLDS role for those instances of BELIEF having as agent the individual SYSTEM. (19) makes the job:

- (19) (AND (KILL KILL1)
 (OCCUR KILL1 TI1)
 (HAS-LOC' ROLE1)
 (HAS-ROLE KILL1 ROLE1)
 (ROLE-FILLER ROLE1 ROOM1)
 (BELIEF BELIEF1)
 (HAS-EXPERIENCER BELIEF1 SYSTEM)
 (HAS-OBJECT BELIEF1 ROLE1)
 (HOLDS BELIEF1 TI2)
 (HAS-LOC' ROLE2)
 (HAS-ROLE KILL1 ROLE2)
 (ROLE-FILLER ROLE2 ROOM2)
 (BELIEF BELIEF2)
 (HAS-EXPERIENCER BELIEF2 SYSTEM)
 (HAS-OBJECT BELIEF2 ROLE2)
 (HOLDS BELIEF1 TI3)
 (BEFORE TI2 TI3)
 (DURING NOW TI3))

Three time intervals are used. The event KILL1 OCCURS in TI1, in which therefore ROLE1 and ROLE2 HOLD. TI2 is the time interval during which the system believes that the murder took place in ROOM1. TI3, which follows TI2, and includes NOW, is the TI during which it is believed that the murder took place in ROOM2.

3 Definition of Time Intervals.

The traditional T-BOX languages are not expressive enough for our purposes, however. Problems arise when trying to define the concept TIME-INTERVAL. An attempt of giving a 'naive' definition of the generic concept INTERVAL, which can be used to denote both the (closed) integer interval [3 .. 17] and the temporal interval [9a.m. ... 12p.m.], would produce something like the definition in Fig. 2: an INTERVAL has subintervals, a length, may be in turn a subinterval of other intervals, and ranges over entities of a certain kind: integers for [3 .. 17], and entities which we stipulate to be other time intervals for [9a.m. ... 12p.m.].

This definition is, however, incomplete. The problems are indicated by the question marks: first of all, some of the Value Restrictions (VR) should be 'parameterized'. The fillers of the HAS-SUBINTERVAL role, for instance, cannot be intervals of any kind at random. When specializing, e.g.,

INTERVAL to TIME-INTERVAL, the VR of HAS-SUBINTERVAL must also be restricted to TIME-INTERVAL. This is left to the responsibility of the implementor, in a standard T-BOX language; there is no way to guarantee, from the definition of INTERVAL alone, that this constraint will be respected, as should be the case. The same problem is met with SUBINTERVAL-OF and RANGE-OVER (with the additional difficulty, in the latter case, that some recursion is normally involved). Another problem is that of stating that every INTERVAL must be a sub-interval of itself.

This latter constraint can be expressed using an A-BOX which allows set variables (this is not always the case). Second-order logic is, however, necessary to express the other constraint. Now, on the one hand we don't want to complicate the T-BOX for 'normal' cases to handle this special one since the efficiency of the classification algorithm crucially depends on having a simple terminological language; and, for similar reasons of computational complexity, we don't want full second-order logic as an assertional language.

We have preferred to move these constraints to the *meta* language by introducing the notion of Denotational Entity (DE). A DE is a generalization of the idea of constant; intuitively speaking, it is something which can be referred to as a unit in natural language. In standard first order logic, only indivisible units (atoms), like 'Jack' or '34' can be denoted by constants. We are a little more liberal: our set of DEs include, among others, intervals. This means that intervals, like atoms, can have roles, and that the fillers of the roles of a DE can be either kind of DE.

The distinction between a DE of type atom and a DE of type interval is not put, however, in the semantics, but rather expressed by classifying them as instances of different concepts. The type hierarchy includes a generic 'system' concept ATOM and a similar concept INTERVAL. When a DE is created (e.g., an instance of NUMBER) it may be optionally classified as an instance of ATOM or as an instance of INTERVAL; a new concept is created which specializes both NUMBER and INTERVAL. This additional constraint is not necessary when a concept, like TIME-INTERVAL, is directly defined as a subconcept of INTERVAL. In this way the VR of a role can be used to specify whether the filler of a role must be an interval or an atom; and we do not need any special RANGE-OVER role. More on DEs in [Poesio 1987b].

TIME-INTERVAL has one role for each of the inter-interval relationships defined by Allen. There are 13 relationships, including seven basic relationships (DURING, STARTS, FINISHES, BEFORE, OVERLAP, MEETS, SIMULTANEOUS) and their inverses. The meaning of the names is quite intuitive. These relationships are often symbolized by the first letter of their name (e.g., DURING -> D). The inverse relationships are symbolized by

that letter followed by 'I', as in 'DI'. Of these 13 roles, DURING, STARTS, and FINISHES restrict SUBINTERVAL-OF; DURING-INVERSE, STARTS-INVERSE, and FINISHES-INVERSE restrict HAS-SUBINTERVAL. Since each of these roles has a number restriction of (1 N), the statement of Allen [1984] that, given any interval I, for each of the relationships there exists an interval I' such that I' is related to I by that relationship, is represented explicitly in the definition of TIME-INTERVAL.

4 Periodic Events.

4.1 Sequences.

Our set of DEs includes means to handle *periodic events*, like that described by the sentence

(20) The interest is paid ONCE A YEAR

which in WISBER's domain of discourse is quite common. This kind of event has not been studied very much so far (see however [McDermott 1982], [Ladkin 1986]). The problem is not just to handle it, but to do so without introducing too much complexity into the assertional language. For this purpose, we have introduced another kind of DE, the *sequence*.

A sequence represents a totally ordered collection of DEs; this collection (I am avoiding the term *set* on purpose) may be either finite or infinite. The generic concept SEQUENCE is the common supertype of all those concepts whose instances are sequences. These generic concepts can be specialized by either restricting the type of the elements, or by restricting the ordering association; again, see [Poesio 1987] for more details. Sequences with the same type of elements are organized hierarchically, allowing very fast execution of inferences concerning order and inclusion.

The definition of SEQUENCE includes the roles SUBSEQUENCE-OF, ORDERED-BY and CARDINALITY-OF. (SUBSEQUENCE-OF s_1 s_2) is TRUE if s_1 is composed by a subset of the elements of s_2 ; its inverse is HAS-SUBSEQUENCE. (ORDERED-BY s BEFORE) is TRUE if the ordering relation over s is BEFORE. (CARDINALITY-OF s n) is TRUE if s has n elements. The assertional language includes the system link IN-SEQUENCE: (IN-SEQUENCE c s) takes a constant c and a sequence s and is TRUE iff c is an element of s .

Three functions are defined on sequences. FIRST-ELEMENT-OF(s_1) returns the first element of s_1 . SUCC-IN(e s) returns the successor of e in the

sequence s (an element can be in more than one sequence!). $\text{PRED-IN}(e\ s)$ returns the predecessor of e in s .

The three-place system predicate ($\text{HOMOMORPH } s_1\ s_2\ P$) is TRUE if P is a homomorphism conserving the (respective) order relation between s_1 and s_2 , that is, if for every element e_1 in s_1 there is one element e_2 of s_2 (and only one) such that $P(e_1, e_2)$ and, additionally, $P(\text{SUCC-IN}(e_1, s_1), \text{SUCC-IN}(e_2, s_2))$.

4.2 Sequences of Events and Time Intervals.

We can now define the generic concepts $\text{TIME-INTERVAL-SEQUENCE}$, whose elements are of type TIME-INTERVAL , and BEFORE-SEQUENCE , which denotes sequences of TIs ordered by BEFORE . The representation of (20) using IRS is then

(21) ((EXIST Z (AND (YEAR-SEQUENCE Z) (ORDERED-BY Z MEETS)))
 (EXIST Y (AND (SEQUENCE Y) (GIVE Y)))
 (EXIST W (BEFORE-SEQUENCE W))
 (AND (HOMOMORPH W Z DURING)
 (HOMOMORPH Y W OCCUR)
 ((ALL I (IN-SEQUENCE I Y))
 (EXIST X (INTEREST X))
 (HAS-OBJECT I X))))

(21) says that there are three sequences, one of years, one of giving events, and one of time intervals, such that every giving event occurs during one time interval and every time interval is DURING one year; each of the GIVE events is characterized by having an interest rate as object. Nothing is said about the number of years or giving events, as in (29) (but the number of years is certainly the same of the number of giving events).

The purpose of sequences is to make certain inferences easy without requiring the explicit specification of all their elements - which would not be at all possible for infinite sequences. If, for instance, we learn that the first year of Z is 1984 and the last 1990, it is easy to infer, on the basis of the system's knowledge about years, that Z includes 7 years, and therefore there have been 7 giving events; this may be useful to compute the global gain from the investment. We simply use the axiom (22):

(22) ((ALL X (SEQUENCE X))
 (ALL Y (SEQUENCE Y))
 (ALL P (CONCEPT P))
 (ALL N (INTEGER N)))

(IMPLIES (AND (HOMOMORPH X Y P)
 (CARDINALITY-OF Y N))
 (CARDINALITY-OF X N))

Conclusions.

In this paper I have suggested that for representing temporal information we can take advantage both of the separation between an assertional component and a terminological component, and of the epistemological organization of languages like KL-ONE . I have also suggested that we can represent time without using reification, and proposed a means (the use of Denotational Entities) to make hybrid systems of this kind more useful without introducing too much complexity. I have shown that this approach is not only useful from the point of view of modeling the domain, but also for handling phenomena like periodical events. An adequately expressive assertional language has been developed for this hybrid system.

The system described has been almost completely implemented. The inference engine and the augmented set of DEs have already been experimentally tested; work is proceeding on propagating constraints using Allen's table and defining more subconcepts of TIME-INTERVAL .

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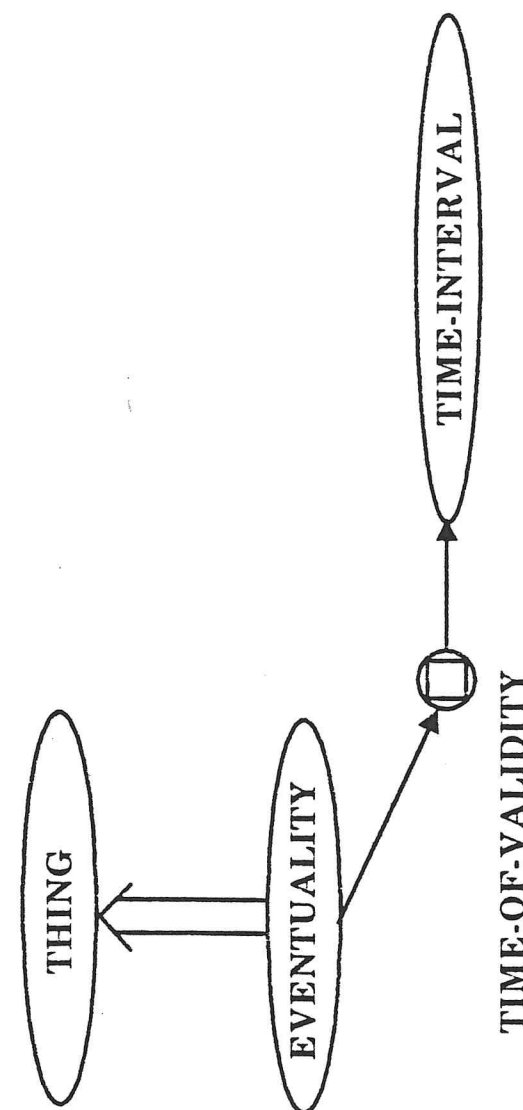


Fig. 1

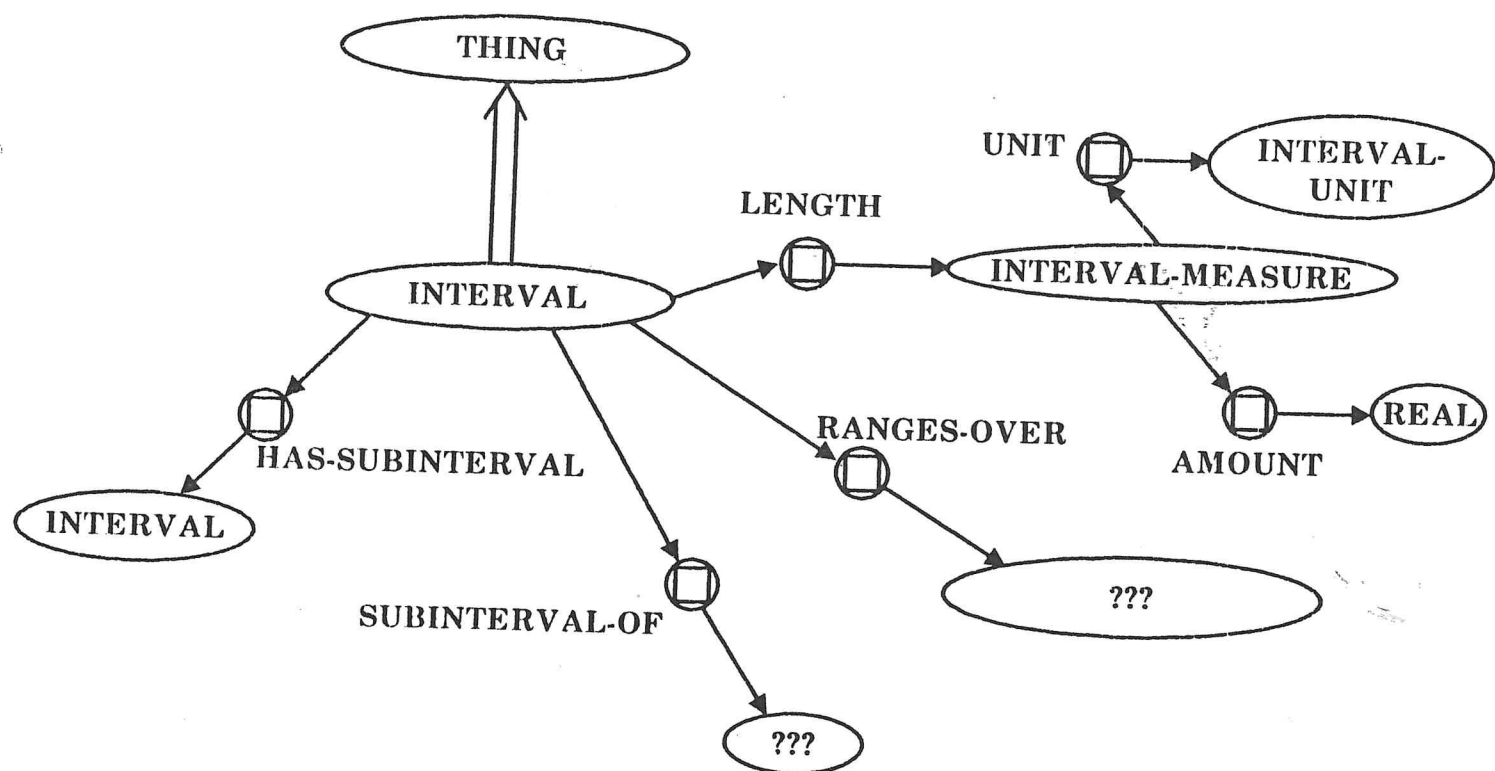


Fig. 2

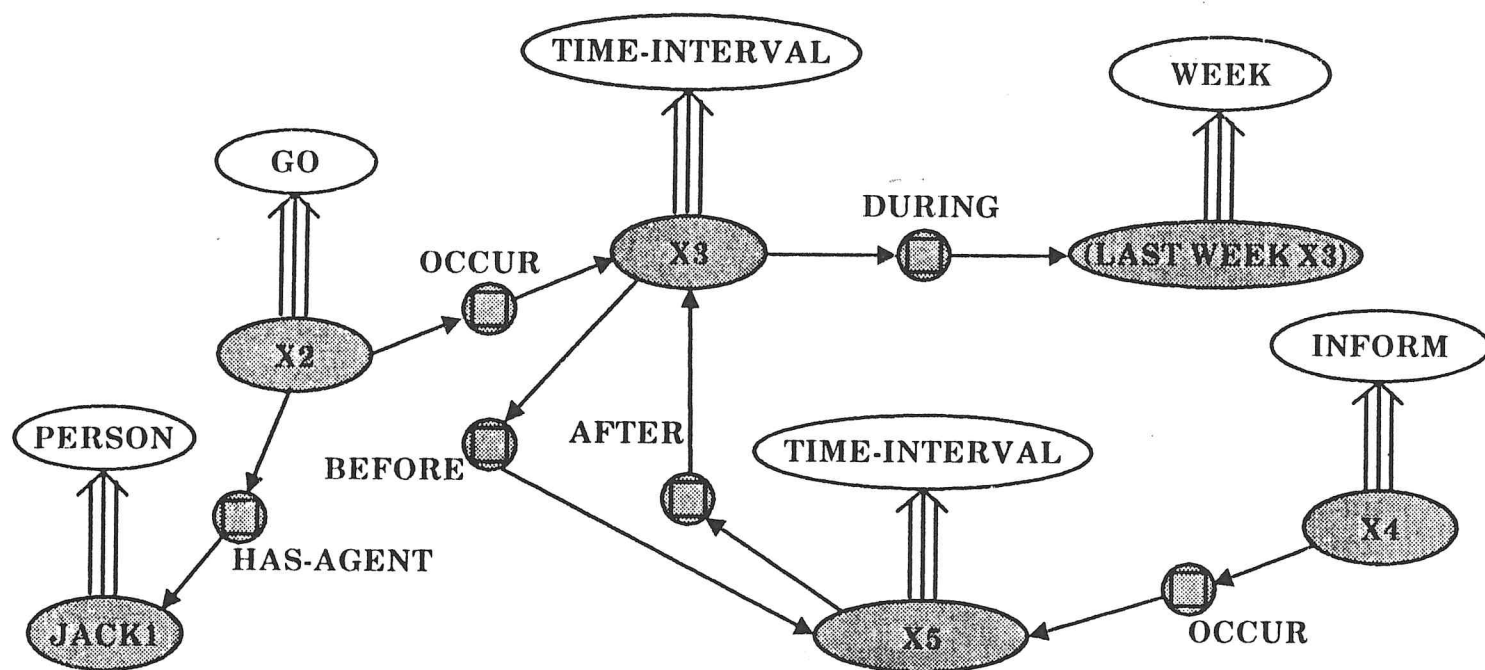


Fig. 3