

ON THE COMPLEXITY OF TEMPORAL INDICES
IN AN ADEQUATE MODEL-THEORETIC TREATMENT OF TENSE

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In model-theoretic semantics indices are elements with respect to which well-formed formulas are assigned truth values. The original model-theoretic semantics based on predicate calculus have no indices, for truth values in such a system are assigned to formulas absolutely. In the possible-world semantics of Montague as first set forth in Montague 1970, henceforth PTQ, truth values are assigned to sentences with respect to a pair of indices, (i, j) , where i is a choice of world and j is an element of a linearly ordered set of "moments." In such a system the temporal index, j , represents the "moment of speech" and a sentence like

(1) John is sick

can be true relative to certain choices of temporal index and false relative to others. This enhancement of traditional model-theoretic semantics with a temporal index representing the moment of speech results in a system which obviously conforms more closely to our intuitions about natural language.

We can think of indices as devices in the formal system which correspond to elements of the context of utterance which play a role in the interpretation of the utterance. These elements may be linguistic or non-linguistic and, thus broadly defined, the notion of temporal indexicality ignores the distinction that is sometimes made between deictic and anaphoric temporal reference.

The tense logic of PTQ also employs existential tense operators H and W which are precisely the Priorian operators P and F . In particular, if f is a formula and t_s represents the moment of speech, Pf is true relative to t_s if and only if f is true relative to t for some t prior to t_s and Ff is true relative to t_s if and only if f is true relative to some t that is subsequent to t_s . Let us say that a sentence is "indexical at t ", where t is a moment, if an acceptable formulation of a truth condition for the sentence has the form:

There exists a moment, t' , standing in such-and-such a relation to t (i.e., one of " t' is prior to t ", " $t' = t$ ", or " t is prior to t' ") such that such-and-such is true at t' .

Then in a system like that of PTQ we can provide intuitively

adequate interpretations for sentences which are indexical at the moment of speech. The sentences (1) and

(2) John has smoked dope

are more or less adequately interpreted by "There exists $t = t_s$ such that John is sick at t ." and "There exists t prior to t_s such that John smoked dope at t .", respectively.

But a moment's reflection convinces us that sentences may involve indexicality at moments other than the moment of speech. It is clear, for example, that the sentence

(3) It was raining

is not adequately interpreted by "There exists t prior to t_s such that it was raining at t ." (consider negation). Rather, we interpret sentences like (3) and

(4) John had smoked dope

relative to a contextually provided moment of reference, t_r , prior to t_s . Specifically, (3) is true relative to a pair of moments (t_s, t_r) , where t_r is prior to t_s , if it was raining at t_r , and (4) is true relative to (t_s, t_r) , where t_r is prior to t_s , if there exists a moment t prior to t_r such that John smoked dope at t .

We face a choice at this point as to how best to introduce the reference moments, t_r , into the formal apparatus. In systems in which such moments of reference are supplied by existential temporal operators, and in which the truth conditions for sentences such as (3) and (4) consequently involve the assertion of the existence of the moments of reference, a great many problems with the relative scope of quantifiers and temporal operators arise which are avoided in a system in which the reference moments are temporal indices, i.e., part of the index complexes relative to which the sentences are interpreted. (See Bryan 1980 for a discussion of such scope problems.) But I think a better argument for a formal system in which such moments of reference are included in index complexes is that such a system more closely models the way humans process natural language. We simply have such moments at hand when we interpret sentences like (3) and (4). It is true that we may not know the exact location of the reference moment, and indeed that the reference "moment" may in fact have some duration. But formal devices are always abstractions, and I do not think these difficulties need force us to adopt a system in which the assertion of the existence of reference moments is part of the interpretation of a sentence.

If we must have a reference moment t_r prior to t_s to interpret sentences like (3) and (4), we must have two reference moments, t_{r1} prior to t_{r2} prior to t_s , for sentences like

(5) John didn't know that it had been raining (when Mary arrived)

or (6) John was looking for the girl who had been singing.

In fact, it is clear that we can construct grammatical English sentences whose interpretations require n reference moments for any positive integer n , although actual performance contexts would rarely involve more than three. (A "limiting proof" to this effect is the point of Saarinen, 1976.)

A fully explicit, Montague-based system is set forth in Bryan 1980 in which temporal indices are elements of the cartesian product $J \times R$, where J is an ordered set of "moments" and R is the set of finite sequences over J . Given $(j,r) \in J \times R$, r is a sequence of "reference moments." A sentence, S , in the fragment of English generated by the syntactic component of the system is interpreted relative to an element in the set of "suitable temporal contexts" for S . The set of suitable temporal contexts for S is a subset of $J \times R$ which is defined in terms of the syntactic rules which apply in the generation of S . It is defined by specifying both the number of reference moments in the sequence r and the precedence relations which must hold between pairs of moments in the set $\{j, r(1), r(2), \dots, r(n)\}$.

This system provides satisfactory interpretations for the sentences generated by its syntactic component. But a fully adequate model-theoretic accounting of tense in English would require a further enhancement of the complexes of temporal indices. In particular, index complexes would have to reflect the notions of "reference from a point of view" and "accessibility of moments as reference moments."

We can see this by considering again sentence (6). (6) has both a de re reading, on which John was looking, at reference moment t_r prior to t_s , for a particular girl who was singing at t'_r prior to t_r , and a de dicto reading, on which John was looking, at t_r prior to t_s , for any girl with the property that she was singing at t'_r prior to t_s . If suitable temporal contexts are elements of $J \times R$, there is no difference between the configuration of events and reference moments for the de re reading and that for the de dicto reading. And yet intuitively there is a difference. For the de re reading the reference moment t'_r is in the past of t_r from the point of view of the speaker/hearer. John need not have access to the moment t'_r and indeed may not know that the girl he seeks has ever

sung. For the de dicto reading t_r' is in the past of t_r from the point of view of John. This difference can be diagrammed schematically as shown in figure 1.

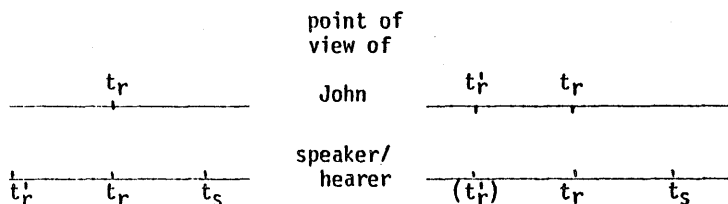


Figure 1

To take another example of a sentence that illustrates the notion of accessibility of moments as reference moments and the need for different "levels of accessibility" or "points of view," consider the sentences

(7) John wanted to meet a girl who had shaken hands with E.T.

and (8) John wanted to meet a girl who has shaken hands with E.T..

Whereas (7) exhibits the de re/de dicto ambiguity we would expect with the intensional verb want, (8) has only the de re reading. A natural way to explain this difference would be to reflect in the formal apparatus the fact that, whereas the reference moment t_r prior to t_s at which John wanted is accessible as a reference moment both from the point of view of John and from the point of view of the speaker/hearer, t_s is accessible as a reference moment only from the point of view of the speaker/hearer. Index complexes with the desired two levels of accessibility are pictured in figure 2 on the next page. Since had shaken means "in the past of a prior reference moment" and since such a prior reference moment, t_r , is accessible from the point of view of both John and the speaker/hearer, we get both (7)-de re, in which the hand shaking took place in the past of t_r from the point of view of the speaker/hearer, and (7)-de dicto, in which it was to have taken place in the past of t_r from the point of view of John. The meaning of the present perfect, on the other hand, is "in the past of the present moment, t_s ," and this moment is accessible as a reference moment only from the point of view of the speaker/hearer, allowing the de re reading of (8). Given the multi-level configuration of indices as shown in figure 2,

there is no "in the past of t_s from the point of view of John," which would be contained in the meaning of (8)-de dicto.

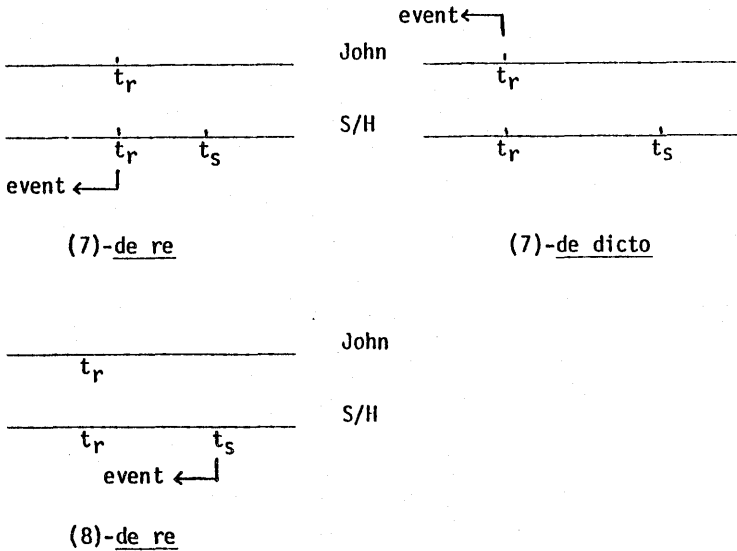


Figure 2

These and similar considerations lead to a revised definition of the set of possible temporal index complexes. Suppose that J is a non-empty set of "moments" and that \leq is an order on J with the properties of "less than or equal to" on the reals. Then we may take temporal index complexes to be elements of the set of configurations of the form

$$\langle t_s, \langle v_i \rangle_{0 \leq i \leq n}, \langle r_{v_i(j)} \rangle_{0 \leq i \leq n, 0 \leq j \leq m_i} \rangle, \text{ where}$$

- i) t_s is a moment (the "moment of speech")
- ii) $\langle v_i \rangle_{0 \leq i \leq n} = v_0, v_1, \dots, v_n$ is a finite sequence of moments such that $v_0 = t_s$. The $v_i, 0 \leq i \leq n$, are "points of view."
- iii) $\langle r_{v_i(j)} \rangle_{0 \leq i \leq n, 0 \leq j \leq m_i}$ is a sequence of length n of

finite sequences of moments such that

- a) $r_{v_i}(0) = v_i$ for $0 \leq i \leq n$
 and b) if $j_0 \in J$ and $j_0 = r_{v_k}(q)$ for some $0 \leq k \leq n$
 and $0 \leq q \leq m_k$, then $j_0 = r_{v_{k-1}}(s)$ for some $0 \leq s \leq m_{k-1}$.

The moments $r_{v_i}(0), r_{v_i}(1), \dots, r_{v_i}(m_i)$ are "moments of reference from the point of view v_i ."

Temporal index complexes, so defined, can be of arbitrary complexity with any number of reference moments and any number of levels of accessibility, although, as noted, these numbers would be small in actual performance contexts. They allow for reference from a point of view as shown schematically above and are so defined that a reference point at any level of accessibility is also accessible at any "lower" level. The best arguments for index complexes such as these are formal ones, having to do with the fact that they allow a more intuitive, less ad hoc formal treatment of the "meaning" of tenses.

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