An Approach to the Semantics of some English Temporal Constructions

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Abstract

This paper outlines a general framework for giving the meanings of temporal prepositions (and some related adverbials) in English. The framework takes the form of a method for translating English sentences involving these adverbials into an expressively limited temporal logic, whose operators permit only restricted quantification over subintervals of a given interval. We illustrate our approach with reference to the temporal adverbials *one Monday, every Monday, on Monday, in July, for five minutes* and *in two hours*. We pay special attention to sentences containing multiple temporal adverbials. In particular, we show how some of our linguistic intuitions concerning the acceptability of combinations of temporal adverbials prevent us from entertaining sentences that are either logical falsehoods or logically equivalent to simpler sentences.

Introduction

This paper outlines a general framework for giving the meanings of temporal prepositions (and some related adverbials) in English. We cannot set out the theory in its entirity here; instead, we illustrate the main features of our approach by discussing the semantics of the temporal adverbials *one Monday, every Monday, on Monday, in July, for five minutes* and *in two hours*.

We shall be paying particular attention to sentences which combine several temporal adverbials. Examples of such sentences are:

(1) John was in the office for three hours every Thursday

(2) Kwiksave will be open for 6 hours every Sunday until 23rd May.

Certain combinations, however, produce peculiar-sounding sentences. For example,

(3) * Mary worked on the paper one day within two days

(4) * John drove to Aberdeen for 30 minutes for 2 hours

would count as nonsense for most native English speakers. Our approach to the semantics of temporal prepositions aims to explain why some combinations of these temporal adverbials are acceptable whereas others are not.

A temporal logic based on sub-intervals

Consider the sentence

(5) John drove to Aberdeen one Monday.

Three temporally significant components can be identified in this sentence: (i) the tense and aspect of the verb, (ii) the temporal adverbial *one Monday*, and (iii) the underlying tenseless sentence, *John drive to Aberdeen*. The function of verb-tense and -aspect is a vast and still imperfectly understood topic, which we cannot address in this paper. We content ourselves with the observation that one part of that function is to constrain the general segment of time under discussion by locating it relative to the time of utterance or time of reference. We shall call this segment of time the *interval of interest*, and denote it by I_0; we have nothing more to say on how it is determined. The function of the temporal adverbial *one Monday* is to locate the reported event more precisely in time; we will concern ourselves with this function in some detail below. To this end we employ a predicate $[Monday](I)$, which we take to be true of all and only those intervals which coincide exactly with Mondays (starting at 00:00 hours and ending at 24:00 hours). Finally, the function of the underlying tenseless sentence is to describe the type of event or state located in time by the other components. Again, we shall assume that $[John\ drive\ to\ Aberdeen](J)$ is a predicate true of all and only those intervals over which John drives to Aberdeen (starting when John sets off and ending when he arrives).

Sentence (5) states that, at some time in the interval of interest, there is a Monday such that, sometime within that Monday, John drives to Aberdeen. That is:

(6) $\exists I(I \subset I_0 \,\&\, [Monday](I) \,\&\, \exists J(J \subset I \,\&\, [John\ drive\ to\ Aberdeen](J)))$.[1]

For convenience, we distinguish between predicates such as $[Monday](I)$, which arise from temporal adverbials, and those such as $[John\ drive\ to\ Aberdeen](J)$, which arise from the underlying tenseless sentence. We call the former *temporal restrictions* and the latter *atomic formulae*; however, both are in reality just predicates of intervals.

We can reformulate the truth-conditions in (6) more elegantly using a temporal logic by means of two familiar notational conventions. First, if ϕ is an atomic formula, then,

rather than writing $\phi(J)$, we instead write $\models_J \phi$. Secondly, we introduce a temporal operator $\diamond$ with the semantics:

(7) Let ϕ be a formula and $\tau(J)$ a temporal restriction. Then $\models_I \diamond(\tau, \phi)$ if there exists a $J \subset I$ such that $\tau(J)$ and $\models_J \phi$.

Then (6) can be re-written as the following assertion in temporal logic:

(8) $\models_{I_0} \diamond([Monday],$
$\diamond(\texttt{true}, ([John\ drive\ to\ Aberdeen])).$

where `true` is the *trivial temporal restriction* satisfied by every interval. In this paper we show how to translate English sentences involving a variety of temporal adverbials into assertions in this temporal logic.[2]

Now consider the sentences

(9) John drove to Aberdeen every Monday.

(10) John drove to Aberdeen on Monday.

Sentence (9) states that, for every Monday in the interval of interest, sometime within that Monday, John drives to Aberdeen. Sentence (10), by contrast, can be taken to assert that there is a unique Monday in the interval of interest, and that, sometime within that Monday, John drives to Aberdeen.[3] We can formalize these truth-conditions by introducing two further operators into our temporal logic:

(11) Let ϕ be a formula and τ a temporal restriction. Then $\models_I \square(\tau, \phi)$ if, for all $J \subset I$ such that $\tau(J)$, $\models_J \phi$.

(12) Let ϕ be a formula and τ a temporal restriction. Then $\models_I \bullet(\tau, \phi)$ if there is a unique $J \subset I$ such that $\tau(J)$, and there is a $J \subset I$ such that $\tau(J)$ and $\models_J \phi$.

[2] Abandoning the predicate calculus in favour of variable-free languages (in our case, a temporal logic), in order to provide a more natural treatment of the truth-conditions of English sentences, is not a new strategy. See, for example, Suppes (1976). Like many other authors who have discussed temporal adverbials in English (e.g. Richards *al.* 1989), we have concentrated on truth-conditional aspects of meaning. We do not intend to dismiss accounts of other dimensions of cognitive function, or to play down non-truth-conditional phenomena such as polysemy (Lakoff 1987), (Herskovits 1986) (Rice 1992). We just intend to concentrate on truth-conditions. A rather different formal approach to temporal aspects of English is taken by Hwang and Schubert (1992), who use their own representation language, based on structures called tense-trees. Our approach, by contrast, avoids such complex representations, restricting itself instead to standard constructions in modal logic. We claim that our approach has the advantages of accessibility, clarity, and amenability to standard techniques of formal analysis. In fairness, however, it should be noted that Hwang and Schubert are concerned to model aspects of discourse structure which we have deliberately overlooked.

[3] This is not entirely proper, since it is plausible to take the existence of a unique Monday in the interval of interest to be *presupposed* rather than asserted. Since, however, we are not concerned with presupposition in this paper, we shall take a small liberty here and ignore the difference. This simplification will clarify the explanation of important phenomena regarding the iteration of temporal prepositions, and its removal is routine.

The truth-conditions of (9) and (10) are then, respectively:

(13) $\models_{I_0} \square([Monday],$
$\diamond(\text{true}, ([John\ drive\ to\ Aberdeen])).$

(14) $\models_{I_0} \bullet([Monday],$
$\diamond(\text{true}, ([John\ drive\ to\ Aberdeen])).$

The operators $\diamond$, $\square$ and $\bullet$ are the only ones we shall be concerned with in this paper. In order to give the semantics of prepositions such as *before*, *after*, *by*, *until*, and *since* (which all concern the *direction* of time), additional operators are needed. These words lie beyond the scope of the present paper; but they do not affect the central features of our approach. One of these features is that our temporal logic only permits (restricted) quantification over sub-intervals of a given interval, a feature which limits its expressive power.[4]

Assembling the pieces

In the previous section, we gave the truth-conditions of English sentences by translating them into a temporal logic. In this section, we describe how such translations can be produced systematically. A computer implementation of this translation process (for the full range of English temporal prepositions) exists, and all of the translations from English to our temporal logic given in this paper are transcriptions of program output.[5]

Recall sentence (5) and its truth-conditions (8). We can generate the formula in (8) from (5) by means of the following process:

Translation step 1: Decompose the original sentence (5) into the underlying tenseless sentence *John drive to Aberdeen* and the temporal adverbial *one Monday*. (Remember, we are ignoring verb-tense and -aspect in this paper.)

Translation step 2: Map the components identified in step 1 to special data-structures, which we shall call *operator-triples*. In this case, the relevant mappings are

(15) *John drive to Aberdeen* $\mapsto$
$\langle \diamond, \text{true}, [John\ drive\ to\ Aberdeen] \rangle$

(16) *one Monday* $\mapsto \langle \diamond, [Monday], \_ \rangle$

(We shall explain these operator-triples presently.)

Translation step 3: Order the triples generated in step 2 in some way, but so that the operator triple generated by the tenseless sentence is last:

(17) $\langle \diamond, [Monday], \_ \rangle$
$\langle \diamond, \text{true}, [John\ drive\ to\ Aberdeen] \rangle$

[4] One fascinating question concerns the relationship between our temporal logic and KL-ONE-like languages (Brachman and Schmolze 1985). The idea is that temporal restrictions and formulae be regarded as concepts, and $\subset$ as the only relation. This question is, at the time of writing, unresolved. For a good survey of systems of temporal logic, see Gabbay, Hodkinson and Reynolds (1994).

[5] The program runs under LPA Prolog version 4.5, and is available on request from the first author.

(Note: in the sequel we shall introduce restrictions on the orderings of operator-triples considered here.)

Translation step 4: *Fuse* the list of operator triples to produce a formula, by matching the last operator in each triple with the first operator in the triple immediately to the right. In this case, (17) yields:

(18) $\diamond([Monday], \diamond(\mathtt{true}, [John\ drive\ to\ Aberdeen]))$

This fusion process is subject to the constraint that distinct operators cannot be matched. For example, two triples of the form $\langle \diamond, \tau_1, \Box \rangle$ and $\langle \diamond, \tau_2, \Box \rangle$ cannot fuse (in that order) because $\Box$ and $\diamond$ are distinct. (N.B. the symbol ' ' in the first triple of (17) is a 'wild-card', able to match with any operator.) This constraint is important in explaining some restrictions on the iteration of temporal prepositions.

Thus, temporal adverbials and the underlying tenseless sentence are mapped *independently* to operator triples, which are then re-ordered and fused together to produce a formula of temporal logic. This scheme allows us to give the meanings of temporal adverbials in terms of mappings to operator triples. For example, we can give the meanings of expressions of the form *one* X, *every* X, *on* X and *in* X with the mappings:

(19) *one* $X \mapsto \langle \diamond, [X], \_ \rangle$

(20) *every* $X \mapsto \langle \Box, [X], \_ \rangle$

(21) *on* $X \mapsto \langle \bullet, [X], \_ \rangle$ if X denotes a specific day

(22) *in* $X \mapsto \langle \bullet, [X], \_ \rangle$ if X denotes a day-part, month, year, century etc.[6]

The above approach works for sentences containing several temporal adverbials. Thus,

(23) John drove to Aberdeen one Monday in July

can be decomposed into the underlying tenseless sentence *John drive to Aberdeen*, together with the temporal adverbials *one Monday* and *in July*. These three components generate, by means of the mappings (15), (19) and (22), the triples

(24) $\langle \bullet, [July], \_ \rangle$
$\langle \diamond, [Monday], \_ \rangle$
$\langle \diamond, \mathtt{true}, [John\ drive\ to\ Aberdeen] \rangle$.

The triples (24) can then be fused to generate the truth-conditions

(25) $\models_{I_0} \bullet([July], \diamond([Monday], \diamond(\mathtt{true}, [John\ drive\ to\ Aberdeen])))$.

The strength of this approach emerges when we consider unacceptable sentences like:

(26) * John drove to Aberdeen on Monday one July.

Here, decomposition and mapping produce the operator triples

(27) $\langle \diamond, [July], \_ \rangle$
$\langle \bullet, [Monday], \_ \rangle$
$\langle \diamond, \mathrm{true}, [John\ drive\ to\ Aberdeen] \rangle$.

If these triples are ordered as in (27), fusing would produce the formula

$\diamond([July], \bullet([Monday], \diamond(\mathtt{true}, [John\ drive\ to\ Aberdeen])))$

which will be logically false, since no July contains a unique Monday. On the other hand, if we transpose the first two triples in (27), fusing would produce the formula

$\bullet([Monday], \diamond([July], \diamond(\mathtt{true}, [John\ drive\ to\ Aberdeen])))$

which is also logically false, since no Monday contains a July as a sub-interval. Thus, in rejecting (26) as unacceptable, our linguistic intuitions are filtering out a pointless combination of adverbials.

Accordingly, we modify step 3 of the translation process so that only those orderings of operator-triples are considered that are 'sensible', given the temporal restrictions they contain. Deciding whether a particular ordering is sensible in this sense requires a certain amount of commonsense calendrical knowledge concerning the length and frequency of the various temporal restrictions. This knowledge can be efficiently stored in a semantic network in which the nodes are the various types of temporal restrictions that can arise, and the links indicate the relations of containment and unique occurrence. The program used to generate the truth-conditions given in this paper employs just such a semantic network to eliminate unwanted orderings of the operator triples, and thus to reject sentence (26) as untranslatable. The details are routine and need not be given here.

The temporal prepositions *for* and *(with)in*

Sentence (5) reports the occurrence of an *event* — that of John's driving to Aberdeen — something with a definite point of completion. We follow common practice in taking *events* to have the property:

(28) If $\models_I \phi$ and $J \subset I$ then $\not\models_J \phi$

(Remember: $\subset$ denotes *proper* subset.) By contrast, the sentence

(29) Mary worked on the program on Monday

reports the holding of a *state*: something that is true at all times throughout some interval. We follow (reasonably) common practice and say that ϕ is a state if it has the property

(30) If $\models_I \phi$ and $J \subset I$ then $\models_J \phi$.

[6] Clearly, the qualifying conditions in mappings (21) and (22) require refinement; but that is a matter of detail which we can ignore here. An extensive study of these and similar restrictions for various languages can be found in Brée and Pratt (1995).

Properties (28) and (30) are not exhaustive; however, we claim that nearly all simple English tenseless sentences (not involving quantification, negation and other logical constructs) describe either events or states, as we have defined them.[7]

A test to distinguish between states and events is provided by the temporal prepositions *for* and *within*. The former likes to combine with states, the latter, with events:

(31) Mary worked on the paper for four hours every day

(32) The ferry sank (with)in 2 minutes

(33) * The ferry sank for 2 minutes

(34) * Mary worked on the paper (with)in four hours every day.

The distinction between events and states allows us to refine the mapping of the underlying tenseless sentence. A tenseless sentence describing an event, such as *The ferry sink*, will get mapped to a triple as follows:

(35) *The ferry sink* $\mapsto \langle \diamond, \texttt{true}, [\mathit{The\ ferry\ sink}] \rangle$

However, a tenseless sentence describing a state, such as *Mary work on the paper* will get mapped to one of two triples as follows:

(36) *Mary work on the paper* $\mapsto$
$\langle \diamond, \texttt{true}, [\mathit{Mary\ work\ on\ the\ paper}] \rangle$

(37) *Mary work on the paper* $\mapsto$
$\langle \Box, \texttt{true}, [\mathit{Mary\ work\ on\ the\ paper}] \rangle$

Why the difference? Because it follows from the property (28) of events, that if ϕ is an event, the formula $\Box(\texttt{true}, \phi)$ is false at every (non-point) interval; therefore a mapping of the form $\langle \Box, \texttt{true}, \phi \rangle$ could not be used to construct any useful formula. No such restriction applies to states.

The meanings of *for* and *(with)in* can now be given by means of the mappings:

(38) *(with)in* $X \mapsto \langle \diamond, [X], \diamond \rangle$

(39) *for* $X \mapsto \langle \diamond, [X], \Box \rangle$.

In addition, we take the temporal restriction $[\mathit{four\ hours}]$ to be true of all and only those intervals which are 4 hours long, regardless of when they start (similarly with $[\mathit{2\ minutes}]$). With the aid of these mappings, the translation process outlined in the last section can be applied to sentences (31) and (32) to give the intuitively correct truth-conditions:

(40) $\models_{I_0} \Box([\mathit{day}],$
$\diamond([\mathit{four\ hours}],$
$\Box(\texttt{true}, [\mathit{Mary\ work\ on\ the\ paper}])))$

(41) $\models_{I_0} \diamond([\mathit{2\ minutes}],$
$\diamond(\texttt{true}, [\mathit{The\ ferry\ sink}])).$

This account immediately yields the prediction that sentence (33) is unacceptable: translation step 2 would produce triples of the form $\langle \diamond, \tau, \Box \rangle$ and $\langle \diamond, \texttt{true}, \phi \rangle$, which cannot fuse because the operators clash. The unacceptability of sentence (34) also becomes clear on our account. Applying the translation process yields:

(42) $\models_{I_0} \Box([\mathit{day}],$
$\diamond([\mathit{four\ hours}],$
$\diamond(\texttt{true}, [\mathit{Mary\ work\ on\ the\ paper}])))$

But it follows from the definition of a state that (42) is logically equivalent to the simpler

(43) $\models_{I_0} \Box([\mathit{day}], \diamond(\texttt{true}, [\mathit{Mary\ work\ on\ the\ paper}]))$

so that the prepositional phrase becomes redundant. Again, we see our linguistic intuitions functioning so as to filter out logically useless combinations.

Of course, irregular sentences such as (33) can, under certain circumstances, be given sensible interpretations. The circumstances include cases where a sentence normally describing an event is re-interpreted as a process, either by cancelling the implied point of completion or by taking the event to be repeated, for example:

(44) Mary painted the house for three hours

(45) The hamster pressed the button with its snout for three hours.

In sentence (44), the implication is that Mary did not complete painting the house; in sentence (45), the implication is that the hamster repeatedly pressed the button.

This phenomenon of 'coercion' of tenseless sentences from one aspectual class to another is discussed in some detail by Moens and Steedman (1988). In this paper, we have pretended that the aspectual class of underlying tenseless sentences can be determined unambiguously and independently of tense, aspect and temporal adverbials. Of course this pretense is just that - a pretense - and has been made merely to bracket an issue which has been discussed elsewhere. If some starred sentences in this paper seems to make sense in some circumstances, that is probably because we have ignored aspectual class shifts of this kind.

It is, however, worth noting where our account parts company with that of Moens and Steedman. Moens and Steedman introduce a basically Vendlerian system of 5 aspectual classes: states, processes, culminated processes, points and culminations. They claim (*ibid.* p. 20) that *for*-adverbials can only be used with process expressions; and they point out that those

[7] This claim is controversial, and most writers on the subject of aspectual class would distinguish additional possibilities. See, e.g. Allen (1984). Most obviously, it might be objected that the state of Mary's working on the program does not hold over very short intervals or over short pauses (head scratchings, tea breaks). Our reply is that it is open to the semantic theorist to claim that tenseless sentences describing states *are* true over such intervals, a position we believe to be (surprisingly) defensible. See Herweg (1991) for an interesting discussion of states and events.

sentences such as *The ferry sink*, which cannot easily take *for*-adverbials, are precisely those that cannot easily be coerced into processes.

The basic problem in evaluating Moens and Steedman's claim is the lack of any formal definition of *process*. For example, on the face of it, the sentence

(46) They were married for four years

combines a *for*-adverbial with a state, not a process. Is a state sometimes a process? Or is it that a state is being coerced into a process? If so, what is the difference in meaning between a state and the process into which it is coerced? The account of the difference between states and events (including processes) on p.17 leaves the matter unclear.

More seriously, consider the sentences:

(47) Mary telephoned John one day

(48) Mary telephoned John every day.

Note that only the latter can be combined with a *for*-adverbial whose argument is a duration longer than a day:

(49) * Mary telephoned John one day for 2 weeks

(50) Mary telephoned John every day for 2 weeks

It would seem, then, that sentence (48) would have to report a process, and sentence (47) a non-process. More generally, one might suppose, universal quantification always (sometimes?) results in processes and existential quantification always (sometimes?) in non-processes. Is this generalization correct? We do not know, because Moens and Steedman provide only vague definitions of the aspectual classes. With such definitions, it is sometimes difficult to extract firm predictions from their approach.

Our approach, by contrast, handles sentences (49) and (50) unproblematically. Sentence (50) translates to

$$(51)\ \models_{I_0} \Diamond([two\ weeks], \Box([day], \Diamond(\mathtt{true}, [Mary\ telephone\ John])))$$

in the way described above. Sentence (49), on the other hand, cannot successfully be translated. Translation step 2 produces triples of the form $\langle \Diamond, [two\ weeks], \Box \rangle$ and $\langle \Diamond, day, \_ \rangle$, which cannot fuse (in the only sensible order) because the operators clash. Note that this explanation of the unacceptability of sentence (49) is essentially the same explanation as that given for the unacceptability of sentence (33). Thus, we do not need to worry about the definition of "process" in deciding whether *for*-adverbials can be used. The only relevant consideration is whether the sentence-fragment governed by such an adverbial can sensibly be universally quantified. If the sentence-fragment in question is an existentially quantified expression like *Mary telephone John one day*, then universal quantification is ruled out explicitly. If the sentence-fragment in question is a basic tenseless sentence reporting an event (in our sense), such as *The ferry sink*, then universal quantification is ruled out because it would automatically result in a false statement.

Similar remarks apply to the sentences

(52) * Mary telephoned John every day within two weeks

(53) * Mary telephoned John one day within two weeks

The former will be not be translated because of an operator clash; the latter would result in the translation

$$(54)\ \models_{I_0} \Diamond([two\ weeks], \Diamond([day], \Diamond(\mathtt{true}, [Mary\ telephone\ John])))$$

which can immediately be seen to be logically equivalent to the simpler sentence

$$(55)\ \models_{I_0} \Diamond([day], \Diamond(\mathtt{true}, [Mary\ telephone\ John]))).$$

Note that this explanation of the unacceptability of sentences (52) and (53) is essentially the same explanation as that given for the unacceptability of sentence (34). The only aspectual class distinction we require is between events and states as defined above.

Note, incidentally, how our account correctly handles the amusing pair of sentences

(56) Mary worked on the paper every day for four hours

(57) Mary worked on the paper every day for four months

which differ only by the substitution of *months* for *hours*. The correct translations

$$(58)\ \models_{I_0} \Box([day], \Diamond([four\ hours], \Box(\mathtt{true}, [Mary\ work\ on\ the\ paper])))$$

$$(59)\ \models_{I_0} \Diamond([four\ months], \Box([day], \Diamond(\mathtt{true}, [Mary\ work\ on\ the\ paper])))$$

are produced automatically by our scheme, because translation step 3 is now constrained to consider only 'sensible' orderings. In particular, any operator-triple containing the restriction $[four\ months]$ must be ordered to the left of any operator-triple containing the restriction $[day]$; and any operator-triple containing the restriction $[day]$ must be ordered to the left of any operator-triple containing the restriction $[four\ hours]$.

Conclusions

In this paper, we have shown how a small collection of English temporal adverbials can be systematically mapped to a restricted temporal logic. Our translation scheme specifies the contribution these adverbials make to the truth-conditions of

sentences in which they figure, and thus yields an account of their meaning. Only a small part of our translation scheme, the full version of which can deal with all English temporal prepositions, has been presented here; however, we have been able to convey two of its essential and novel features: (1) The translation process allows the iteration of temporal adverbials within a sentence, and fails (or produces easily detectable redundancies) for many sentences which sound unacceptable. This enables us to see our linguistic intuitions as performing the useful logical function of filtering out useless adverbial combinations. (2) The temporal logic used to give the truth-conditions of sentences has limited expressive power. In particular, the operators only allow quantification over subintervals of a fixed interval. This observation helps us chart the expressive power of the English temporal adverbials covered by our account.

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