

Temporal Constraints and Their Interpretations in Natural Language

Hsiu-Hui Lee, I-Peng Lin, and Chien-Ping Wu

Graduate Institute of Computer Science and Information Engineering
National Taiwan University
Taipei, Taiwan 10764, R.O.C.
hh_lee@csman.csie.ntu.edu.tw

Abstract

This paper concerns temporal interpretation in natural language sentences. In general, the Vendlerian classes of verbs may affect the acceptability of tense combination. We present a series of extensions of tense theory of atomic events to accommodate durative events. Then the interaction of tenses with time adverbials is discussed and a constraint for tense-adverb agreement is proposed. Sentences containing clauses connected by a temporal connective such as "when", "before", "after", etc. may have different aspect interpretations depending on the situation types and verb forms involved. Especially, "before" and "after" are not always inverse of each other. We can also adopt the similar mechanism to take account of this kind of sentences. Their temporal constraints are described and their temporal interpretations can also be obtained accurately.

1. Introduction

This paper concerns temporal interpretation in natural language. In general, the Vendlerian classes of verbs may affect the acceptability of tense combination [2]. In simple sentences of normal contexts, there exists some restrictions on the verb forms and the co-occurred time adverbials.

- (1) John leaves tomorrow.
- (2) John is leaving now/tomorrow.
- (3) * John is leaving yesterday.
- (4) * John has a dog tomorrow.

(1)-(3) show that the verb form with simple present or present progressive can not be modified by the adverbs of past, but can be modified by the adverbs of present or future, but . In addition, this reason is not suitable to explain the unacceptability of (4). It seems that the lexical nature of verb (or the so called Aktionsart) may affect the meaning of tense. This requires a more rigorous rule in a theory of tense.

On the other hand, those sentences containing clauses connected by *when* are always interpreted as simultaneity. But Hinrichs provides a counter-argument against this in [6]. He says that if two events are connected by *when*,

they can have any temporal order with respect to each other. Compare (5)-(7):

- (5) John broke his arm when he wrecked the Pinto.
- (6) The Smiths threw a party when they moved in.
- (7) The Smiths invited all their old friends when they threw a party.

In (5), the events are understood as happening simultaneously; in (6) the event in the matrix clause is perceived as following the event of the *when*-clause, while (7) is a mirror-image of (6). And Yip also notes that sentences containing *when* have different aspect interpretations depending on the situation types and verb forms involved [13]. For example,

- (8) John came in when I was watching TV.
- (9) John was reading when I was watching TV.

Obviously, in (8) John's coming time of John marks a subinterval of my TV-watching time, and in (9) John's reading time will temporally overlap my TV-watching time described in the adjunct clause.

In general, the temporal connective *before* indicates that the situation in the matrix clause occurred earlier than the situation in the adjunct clause and *after* has the opposite meaning [11]. For example,

- (10) He shaved before he went to the party.
- (11) He went to the party after he shaved.

(10) and (11) mean the same. But it is contrary to what might imagine that *before* and *after* are not strict converses of each other [5]. For example,

- (12) John met Mary before she was a student.
- (13) Mary was a student after John met her.

Since (13) allows the possibility that Mary was a student even before John met her, (12) and (13) would not have the same meaning. It is noted that *before* and *after* are only true converses when the clauses they link report the occurrence of instantaneous (or non-durative) events.

In this paper, we are trying to deal with the simple sentences and those sentences with temporal connectives. This paper is organized as follows. Section 2 briefly describes the time model and the situation types. Section 3 presents a theory of tense and aspect. Section 4 discusses the interaction of tense with time adverbials.

As for sentences containing clauses connected by *when*, *before* and *after*, the temporal semantics of each connectives and their interpretations are given in Section 5 and Section 6 is the concluding remarks.

2. Time Model and Situation Types

2.1 Time Model

The time model that we choose is based on Allen's results [1]. There are thirteen mutually exclusive temporal relations. However, we think that they are too primitive for our representation of tenses since the relations suggested in English are usually vague [12]. We combine Allen's thirteen relations into the following seven:

earlier (\ll) later (\gg) include (\supset)
 include_by (\subset) overlap (o) overlap_by (oi)
 equal ($=$)

where "earlier(A, B)" summarizes the relationships in which one interval A precedes B and "later(A, B)" is the inverse; "include(A, B)" that summarizes the relationships in which one interval A wholly contains B and "include_by(A, B)" is the inverse; and the definitions of "equal(A, B)", "overlap(A, B)" and "overlap_by(A, B)" remain the same as Allen's. These seven relationships also mutually exclusive. In addition, two other relations are introduced for convenience: "include_eq(A, B)" marks the interval B is a subinterval of A or B equals to A , and "include_eq_by(A, B)" is the inverse.

The transitive closure of the temporal relations can be obtained by computing the possible relations between any two time intervals. For example,

earlier(A, B) & earlier(B, C) \Rightarrow earlier(A, C)
 include_by(A, B) & overlap(B, C) \Rightarrow
 earlier(A, C) \vee include_by(A, C) \vee
 overlap(A, C)

2.2 Situation Types

As discussed earlier, the lexical nature of verb may affect the meaning of the tense. For example, the English present tense can have different meanings.

(14) I leave the office at 5:00.

(15) I have a dog.

(14) can be valid in the future or be a habitual present action and (15) is only valid in the present. Therefore, the classification of the **situation type** is necessary [10, 12]. Situation types should be viewed as corresponding to the core verb phrases rather than simply to the verbs. Below are our classification of the situation type and some examples:

states: e.g. *know the answer, like somebody.*

activities: e.g. *read, play, sing songs*

protracted events: e.g. *walk to the store, sing a song*

momentaneous events: e.g. *die, graduate, arrive, leave*

This classification is based on the relations between time periods in which the proposition is valid and on its duration. A detailed account on the distinction between these four types of situation is presented in [8].

3. A Theory of Tense and Aspect

Most of the work on time relations of tenses [2, 7, 13] is based on Reichenbach's notions of three times: speech time (S), event time (E), and reference time (R). The speech time S is the time that the sentence is uttered; the event time E named by the verb is the interval for which a basic tenseless proposition is said to be true; and the reference time R is the time with respect to which the event is being considered. They all treat the situations as instantaneous events and do not consider that those events may have some duration. As a result, the inter-relationships among S , R and E are restricted to be precedence or simultaneity only.

Now, by considering the following two sentences:

(16) John built this house last year.

(17) John was building this house last year.

The same time adverbial *last year* appears and plays different roles. In the former, *last year* is the whole time of house-building; while in the latter, *last year* was just a part of time of house-building. This is because the above two sentences have the different **aspect** notions. Aspect serves to distinguish such things as whether the beginning, middle, or end of an event is being referred, and whether the event is completed or possibly left incomplete [3, 9]. Therefore, it is seems to reasonable to expand the traditional theory of tense by considering aspect together. We generalize the tense structure of atomic events to durative events. As a result, the reference time and event time may be an extended period and its inter-relationship is not longer to be precedence or simultaneity only.

We following Eynde [4], assume that basic tense structures are not primitive but rather are themselves composed of an RS relation and an ER relation. These relations can be the temporal relations discussed in our time model. The tense meaning (TSM) will be defined as relations between the time of reference and the time of Speech: Rel(R, S). The number of possible relations between R and S can be reduced to the following three:

anterior Rel(R, S) = (\ll)
 simultaneous Rel(R, S) = (\supset)
 posterior Rel(R, S) = (\gg)

On the other hand, the aspect meaning (APM) is defined as a set of temporal relations between the time of event and the time of reference: Rel(E, R). According to [4], the following values can occur:

perfective Rel(E, R) = (\subseteq)
 durative Rel(E, R) = (\supset)
 inchoative Rel(E, R) = (oi)
 terminative Rel(E, R) = (o)

retrospective Rel(E, R) = («)
 prospective Rel(E, R) = (»)

Eynde assigns the tense meaning just by its tense form and assigns the aspect meaning just by its aspect form. It is still not adequate since the situation type is not considered. One contribution of this paper is to present a more rigorous description of temporal relations by incorporating the situation type in it together. We associate each verb form with its tense meaning (TSM_v) and aspect meaning (APM_v) according its situation type. Time adverbials also contribute tense meanings (denoted by TSM_{adv}) and aspect meanings (denoted by APM_{adv}). Table 1 only lists the temporal meanings for some verb forms and some time adverbials. Detailed information can be seen in [8].

Table 1 Temporal meanings of verb forms and time adverbials

Verb Forms/ Time Adverbial	Situation Type	Tense Meaning (TSM)	Aspect Meaning (APM)
simple present	momentaneous event	{posterior}	{perfective}
	protracted event activity	{simultaneous}	{durative}
present progressive	momentaneous event	{simultaneous, posterior}	{prospective}
	protracted event activity	{simultaneous}	{durative}
present perfect	momentaneous event	{simultaneous}	{retrospective}
	protracted event activity	{simultaneous}	{retrospective, terminative}
	state	{simultaneous}	{terminative}
yesterday	-	{anterior}	-
now	-	{simultaneous}	-
tomorrow	-	{posterior}	-
for 2 hours	-	-	{perfective, durative, terminative,}

The information listed above is very useful in the determination of temporal interpretation that will be discussed in later sections.

4. Interpretation of Simple Sentences

To get the temporal interpretation of simple sentences, it is essential to check the compatibility of verb forms and its modifying temporal adverbials. Here, we propose the tense-adverb agreement constraint as follows:

Tense-adverb Agreement Constraint

The tense meaning and the aspect meaning associated with the verb form (TSM_v and APM_v) and the tense meaning and the aspect meaning associated with the time adverbial (TSM_{adv} and APM_{adv}) should be compatible respectively.

This compatibility is defined as the unification (Θ) of their corresponding temporal meanings. As a result, we can give an semantic explanation about the tense-adverb agreement. The following algorithm summarizes this:

Algorithm 1: (Computation the temporal interpretation of a simple sentence)

- Step 1: Identify the situation type of the sentence.
 Step 2: According the verb form and the situation type, get the corresponding tense meaning (TSM_v) and aspect meaning (APM_v).
 Step 3: If the time adverbial exists, then we can get the corresponding tense meaning (TSM_{adv}) and the aspect meaning (APM_{adv}).
 Step 4: Do the checking for Tense-adverb Agreement Constraint. If succeeds, the tense meaning (TSM_s) and aspect meaning (APM_s) of the whole sentence are obtained as

$$TSM_s = TSM_v \Theta TSM_{adv}$$

$$APM_s = APM_v \Theta APM_{adv}$$
 Otherwise it is semantically unacceptable.

With the above algorithm, we can explain that (1) and (2) are acceptable, but (3) and (4) are not. According to Table 1, the tense meaning of present progressive for a momentaneous event is "simultaneous" or "posterior" and the tense meaning of *yesterday* is "anterior". As a result, present progressive can not co-occur with *yesterday* in (3) but can combine with *now* or *tomorrow* in (2). As for simple present tense, on the other hand, the only tense meaning is "simultaneous" for a state; and the tense meaning is "posterior" for a momentaneous event. Therefore, (4) can not combine with *tomorrow* but (1) can.

As another example, sentences with present perfect tense, like (18), our checking can also apply.

(18) * John has come home tomorrow.

According Table 1, the tense meaning of present perfect could only be "simultaneous" regardless any kind of situation type, this clearly explains why (18) modified by *tomorrow* is unacceptable. For present perfect tense, the aspect meaning could be either "retrospective" or "terminative" for activities; and the only aspect meaning is "retrospective" for momentaneous events. Therefore, in the following two sentences,

(19) He has read for 2 hours.

(20) * He has left for 2 hours.

(20) is unacceptable since it does not meet the agreement constraint proposed above; (19) carries "terminative" aspect meaning since *for 2 hours* modifies the reading situation.

Many researchers have similar rules or constrains about this and explain this fact that the present (or present progressive) can be interpreted as referring to the future when it is adjoined to a future clause or modified by a future adverb. But for sentences like (18), Brent cannot explain them [2] and Hornstein's CDTS cannot predict their unacceptability [7]. Though Yip tries to deal with them by changing the tense structure of present perfect, he

would pay a great deal in other respects [13]. By contrast, the current paper can elegantly solve the above problem and develop a semantic explanation for tense compatibility.

5. Interpretation of Temporally Connected Sentences

5.1 Adjunct Clause Tense Constraint

In temporally connected sentences, the verb forms of the main clause restrict the verb forms of the temporal adjunct clauses. Here, we propose the following constraint to explain the acceptability of temporally connected sentences.

Adjunct Clause Tense Constraint

In a temporally connected sentences, the tense meaning (TSM_{adj}) of the adjunct clause should be the same with the tense meaning (TSM_{mat}) of the matrix clause, i.e.,

$$TSM_{adj} = TSM_{mat}$$

In posterior contexts (that is, the matrix clause with "posterior" tense meaning), the tense form of the adjunct clause is in present rather than in future though its tense meaning is "posterior" as well.

- (21) * John left when/before/after Mary comes home.
- (22) * John sings when Harry played the piano.
- (23) Rachel will leave when/after Jon arrives.
- (24) John will play well when/after he has practised.
- (25) * John has practised when/after he will play well.

(21) is unacceptable since the tense meaning of the matrix clause is "anterior" but the tense meaning of adjunct clause is not "anterior". The similar reason can apply to (22) and (25). On the other hand, (23) and (24) are acceptable though their tense forms of adjunct clauses are not in future but in simple present for the former and in present perfect for the latter. Both of their adjunct clauses have "posterior" tense meaning which is the same as that of their matrix clauses.

5.2 Semantics of Temporal Connective

In a simple sentence, the reference time could be specified by the associated time adverb. Like the time adverb, the main role of a temporal adjunct clause is to locate the reference time of the matrix clause. Here, we assign the semantics associated to each of temporal connectives as follows. For *when*-clause, the reference time (denoted by R_{adj}) of the adjunct clause specifies the reference time (denoted by R_{mat}) of the matrix clause. We assert that the relation between R_{mat} and R_{adj} is "equal" ($=$). For *before*- and *after*- clauses, we claim that

the reference time (denoted by R_{mat}) of the matrix clause is specified by the event time (denoted by E_{adj}), not the reference time, of the adjunct clause and the relation between R_{mat} and E_{adj} is "earlier" (\ll) for *before* and "later" (\gg) for *after*.

By the semantics of temporal connective, Algorithm 2 can be used to compute the temporal interpretation for a complex sentence.

Algorithm 2: (Computation the temporal interpretation of a complex sentence)

- Step 1: Use Algorithm 1 to analyze each of clauses and get their tense meanings: TSM_{mat} and TSM_{adj} .
- Step 2: Check for Adjunct Clause Tense Constraint.
- Step 3: Check for the connective.
Consider the following three connectives:
- (a) *When*. The connective is not changed.
 - (b) *Before* or *after*. If the verb form of the matrix clause or the adjunct clause is perfect or perfect progressive, then the connective is changed to *when*.
- Step 4: Get the associated temporal meaning of the connective:

Note that in Step 3 the verb form of clause is past perfect tense, we can treat *before* or *after* as *when*. The grammar book also says that the past perfect usually has the meaning of 'past-in-the-past', it can be regarded as anterior version of the present perfect or of the simple past [11]. By using this algorithm, we will discuss each kind of connectives in the following sections.

5.3 When

In English, the connective *when* may combine a non-extended situation in the matrix clause with an extended one in the adjunct clause, like (8). By Algorithm 2, we can get the relation between E_{mat} and R_{mat} is "include_eq_by" (\subseteq) and the relation between E_{adj} and R_{adj} is "include" (\supseteq). Since the relation between E_{adj} and R_{adj} is "include" (\supseteq), the relation between R_{adj} and E_{adj} is the reverse, i.e., "include_by" (\subset). With these relations and the role of *when*, the following transitive closure can be computed,

$$\begin{aligned} & \text{include_eq_by}(E_{mat}, R_{mat}) \ \& \ \text{equal}(R_{mat}, R_{adj}) \ \& \\ & \text{include_by}(R_{adj}, E_{adj}) \\ \Rightarrow & \text{include_by}(E_{mat}, E_{adj}) \end{aligned}$$

The relation between E_{mat} and E_{adj} is "include_by" (\subset). That is, the matrix situation (John's coming) marks a subinterval of the adjunct situation (Mary's TV-watching). Similarly, we consider *when* combines two extended situations, like (9). We can get the relation between E_{adj} and E_{adj} can be "include_by", "include", "overlap",

"overlap_by" or "equal". This meets what we imagine that two situations temporally intersect with each other.

Nevertheless, we consider *when* combines two non-extended situations, like (26),

(26) John left when Mary arrived.
or Hinrichs's examples (5)-(7). The relation between E_{mat} and E_{adj} after the computation can be the following seven: "earlier", "later", "include_by", "include", "overlap", "overlap_by" or "equal". Because the event time of non-extended situation is point-like in nature, it could be further simplified as: "earlier", "later", or "equal". This means, these two situations can have any temporal order with respect to each other. In this case, it needs some world knowledge to determine their actual order. Though in many cases in English, like (27), *when* is often used as *after* with the events in the simple past that describe successive events.

(27) The bomb exploded when John pushed the button.

5.4 Before and After

Recall that if *when* combines two non-extended situations which are in simple past tense, their relative ordering is not easy to be determined. Many methods can be used to explicitly express their temporal ordering. One is to combine them by *before* as (10) or by *after* as (11). With the temporal semantics of *before* and *after*, the deduced relation can successfully show that the shaving event precedes the party-going event. But by our computation, the relation between E_{mat} and E_{adj} will be "earlier" (\ll) for (12), and will be "later" (\gg) or "include" (\supset) for (13). This shows (12) and (13) are not converses.

Consider the sentence (28). By algorithm 2, we treat *before* as *when*, then the relation between E_{mat} and E_{adj} will be "later" (\gg).

(28) John escaped before he had served his term.
Obviously, it violates the intuitive interpretation of *before*. This sentence is acceptable since this non-factual use of *before* receives a counter-factual interpretation. That is to say, (28) carries only the interpretation in which John does not serve out his prison term. We can also reflect this.

6. Conclusion

In this paper, a theory of temporal interpretation of natural language is developed. We present a series of extensions of tense theory of atomic events to durative events and incorporate aspectual character in it. The tense meaning and the aspect meaning for each verb form not only depend on aspectual auxiliaries (e.g. *have*, *be*, ...) but also the situation type. And other constituents, for example, time adverbials (e.g. *for two days*, *tomorrow*),

aspectual complementary verbs (e.g. *begin*, *remain*, *finish*) of the sentence also contribute to the temporal interpretation. Then by using the checking of adverb-tense agreement, we can easily test their compatibility when adjoined by time adverbials. As for complex sentences, we first make a syntactic constraint as a filter to separate large part of unacceptable sentences from others. Then, together with our temporal semantics for each connective, we could use the same mechanism to get their accurate interpretations. In this paper, we have dealt with the uses of connectives, for example, the non-factual use of *before*, the multiple use of *when* and the asymmetry of *before* and *after*.

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