

A COMPUTATIONAL MODEL OF THE SEMANTICS OF TENSE AND ASPECT

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The PUNDIT natural-language system processes references to situations and the intervals over which they hold using an algorithm that integrates the analysis of tense and aspect. For each tensed clause, PUNDIT processes the main verb and its grammatical categories of tense, perfect, and progressive in order to extract three complementary pieces of temporal information. The first is whether a situation has *actual* time associated with it. Secondly, for each situation that is presumed to take place in actual time, PUNDIT represents its *temporal structure* as one of three situation types: a state, process, or transition event. The temporal structures of each of these situation types consist of one or more intervals. The intervals are characterized by two features: kinesis, which pertains to their internal structure, and boundedness, which constrains the manner in which they get located in time. Thirdly, the computation of *temporal location* exploits the three temporal indices proposed in Reichenbach 1947: *event time*, *speech time*, and *reference time*. Here, however, event time is formulated as a single component of the full temporal structure of a situation in order to provide an integrated treatment of tense and aspect.

1 INTRODUCTION

The PUNDIT text-processing system extracts temporal information about real-world situations from short message texts.² This involves three complementary analyses. First, PUNDIT determines whether a situation has **actual time** associated with it. A reference to a possible or potential situation, for example, would need a different treatment. Second, it determines the **temporal structure** of the predicated situation, or the manner in which it evolves through time. Finally, it analyzes the **temporal location** of the actual situations with respect to the time of text production or to the times of other situations. These three pieces of information are derived from the lexical head of a predication (verbal, adjectival, or nominal), its grammatical inflections (tense, progressive, perfect), and finally, temporal adverbs such as *before*, *after*, and *when*. Each of these components of temporal meaning is assigned a context-dependent compositional semantics. A fundamental premise of this approach is that the several sentence elements contributing temporal information can and should be analyzed in tandem (Mourelatos 1981, Dowty 1986) in order to determine the times for which predications are asserted to hold. This is accomplished by means of a model of the semantics of time that incorporates both aspect and a Reichenbachian treatment of tense (Reichenbach 1947).

The temporal analysis component described here

was originally designed to handle PUNDIT's first text domain, CASREP messages, which are reports describing equipment failures on navy ships.³ This domain was a particularly appropriate one for implementing a component to analyze the time information contained explicitly within the individual sentences of a text. CASREPs are diagnostic reports consisting of simple declarative sentences. They present a cumulative description of the current status of a particular piece of equipment rather than narrating a sequence of events. Within one sentence, several different situations may be mentioned, linked together by explicit temporal connectives such as *before* and *after*. It is thus possible to extract a good deal of the important temporal information from these texts without handling intersentential temporal relations. However, the implementation of the temporal semantic component described here lays the necessary groundwork for eventually computing intersentential relations along lines proposed in Webber 1987 and this volume.⁴ The capacity to process intersentential temporal relations is, of course, essential for adequately handling narrative data.

2 TEMPORAL INFORMATION

The premise of the present work is that accurate computation of the temporal semantics of the verb and its grammatical categories of tense, perfect, and progressive provide a foundation for computing other kinds of

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temporal information, including the interpretation of temporal adverbials.⁵ However, the task of modeling the semantic contribution of the verb and its categories is a complex one because temporal information is distributed across several nonunivocal lexical and grammatical elements. As the extensive linguistic and philosophical literature on tense and aspect demonstrates, the precise temporal contribution of any one surface category of the verb is contingent upon co-occurring verbal categories, as well as upon the inherent meaning of the verb, and even the nature of the verb's arguments (Comrie 1976, Dowty 1979, Mourelatos 1981, Vlach 1981, Vendler 1967). Hence, even a preliminary solution to the computational problems of interpreting temporal information in natural language requires recognizing the relevant semantic interdependencies. This paper proposes a solution to the computational task of extracting temporal information from simple declarative sentences based on separating temporal analysis into distinct tasks, each of which has access to a selected portion of the temporal input. The ultimate goal is to represent temporal information as explicitly as possible at each stage of analysis in order to provide the appropriate information for the next stage. Because the representations are constructed incrementally, it is important that they should be explicit about what has been derived so far, yet sufficiently noncommittal to avoid conflicting with subsequent processing.

The present section of the paper provides the background needed for understanding the information that the algorithm integrating tense and aspect (presented in Section 4) is designed to compute. First, in Section 2.1, I explain what is meant by **actual time** and delimit the scope of the phenomena focused on here. Then in Section 2.2, I describe the components of temporal structure and how they are used to distinguish states, transition events, and two ways of referring to processes. Also in this section I review Dowty's (1979) aspect calculus and introduce how it is used in deriving the representation of temporal structure.

The remaining sections of the paper focus on the implementation. Section 3 describes the input to the temporal component. Section 4 presents the algorithm for computing the situation representations and their temporal location. Part of the computation of temporal location involves determining the reference time of a predication. Reference time pertains to the interpretation of relational temporal adverbials, i.e., adverbials that relate the time of a situation to another time (e.g., *The ship was refueled yesterday*, cf. Smith 1981).⁶ Temporal connectives, for example, relate the time of a syntactically subordinate predication to a superordinate one. A brief discussion of how the reference time participates in the interpretation of temporal adverbial clauses introduced by connectives such as *before*, *after*, and *when* is given in Section 5, whose more general topic is the utility of the situation representations for the interpretation of a variety of adverbial types.⁷

2.1 ACTUAL TEMPORAL REFERENCE

Actual situations are those that are asserted to have already occurred, or to be occurring at the time when a text is produced. This excludes, e.g., situations mentioned in modal, intensional, negated, or frequentative contexts.⁸ A predication denotes an actual situation when two criteria are satisfied. First, at least one of the verb's arguments must be interpreted as specific (Dowty 1979, Mourelatos 1981, Vlach 1981). For example, the simple past of *fly* denotes a specific situation in Sentence 1 but not in (2), because the subject of the verb in (2) is a nonspecific indefinite plural.

1. John flew TWA to Boston.
2. Tourists flew TWA to Boston.

This paper does not address the interaction of the nature of a verb's arguments with the specificity of references to situations.

The second criterion is that the situation must be asserted to hold in the real world for some specific time. Predications in modal contexts (including the future; cf. Sentence 3) are excluded because their truth evaluation does not involve specific real-world times, but rather, hypothetical or potential times.

3. The oil pressure should/may/will decrease. Additionally, frequency adverbials like *always* may force a temporally nonspecific reading, as in (4).

4. John always flew his own plane to Boston. PUNDIT's time component does not currently identify modal contexts, frequency adverbials, or nonspecific verb arguments. However, it does identify predications denoting situation types when the form of the verb itself provides this information.

In evaluating actual time, PUNDIT distinguishes between examples like (5) and (6) on the basis of the verb and its grammatical categories. An actual use of the sentence in (5), for example, would report that a particular pump participated in a particular event at a specific time.

5. The lube oil pump seized.
6. The lube oil pump seizes.
7. The lube oil pump seized whenever the engine jacked over.

Sentences 6 and 7, on the other hand, report on types of recurrent events. In sentence 7, it is the adverb *whenever* that indicates that the main clause refers to a recurrent type of event rather than to a specific event token situated at a particular time. In (6), it is the lexical aspect of the verb *seize* in combination with the present tense that provides that information. A further difference between the two examples is that (7) entails that on at least one past occasion the pump actually seized when the engine jacked over, while (6) does not entail that the lube oil pump ever actually seized. We will see in Section 4.1 that (6) would immediately be determined not to evoke actual time on the basis of the lexical aspect of the verb and its inflectional form. Although PUNDIT does not yet handle frequency adverbials,

Section 5 illustrates the procedure by which the main clause of (7) would be processed so that its relation to the subordinate clause event could be identified later.

Lexical aspect is the inherent semantic content of a lexical item pertaining to the temporal structure of the situation it refers to, and thus plays a major role in computing temporal information. The aspectual categories and their relevance to temporal processing are discussed in Section 2.2.

It should be noted that other semantic and pragmatic properties also affect temporal analysis. For example, there are conditions under which the present tense of a verb referring to an event, as in (6), is associated with an actual situation. Under the right conditions, first-person performatives (e.g., *I warn you not to cross me*) accomplish the named event at the moment they are uttered (Austin 1977). Even a sentence like (6) can refer to an actual event if interpreted as a report of a presently unfolding situation, as in a sportscast. Handling tense in these types of discourse would require representing pragmatic features, such as the speaker/addressee relationship, in order to handle the relation of indexicals like tense and person to the speech situation (Jakobson 1957). Section 3 briefly mentions some semantic distinctions pertaining to the verb in addition to lexical aspect, which PUNDIT does handle. Otherwise, however, this paper focuses on temporal analysis of third person descriptions containing verbs whose arguments refer to specific, concrete participants.

2.2 TEMPORAL STRUCTURE OF ACTUAL SITUATIONS

Situations are classified on the basis of their temporal structure into three types: states, processes, and transition events. Each situation type has a distinct temporal structure comprised of one or more intervals. Two features are associated with each interval: kinesis and boundedness. Both terms will be defined more fully below, but briefly, kinesis pertains to the internal structure of an interval, or in informal terms, whether something is happening within the interval. Boundedness pertains to the way in which an interval is located in time with respect to other intervals, e.g., whether it is bounded by another interval.

This approach to the compositional semantics of temporal reference is similar in spirit to interval semantics in the attempt to account for the semantic effects of aspectual class (Dowty 1986, Dowty 1982, Dowty 1979, Taylor 1977). However, interval semantics captures the distinct temporal properties of situations by specifying a truth-conditional relation between a full sentence and a unique interval. The goal of PUNDIT's temporal analysis is not simply to sort references to situations into states, processes, and events, but more specifically to represent the differences between the three situation types *by considering in detail the characteristics of the set of temporal intervals that they hold or occur over* (Allen 1984:132). Thus, instead of specifying a single set of entailments for each of the three situation types, the

temporal semantics outlined here specifies what property of an interval is entailed by what portion of the input sentence, and then compositionally constructs a detailed representation of a state, process, or event from the intervals and their associated features. The critical difference from interval semantics is that while intervals are the fundamental unit from which situation representations are constructed, it is proposed here that intervals have properties that differentiate them from one another.

2.2.1 SITUATION TYPES AND TEMPORAL STRUCTURE

The three situation types—states, processes, and transition events—are distinguished from one another entirely on the basis of the grammatically encoded means provided by the language for talking about how and when they occur. People certainly can and do conceptualize finer differences among real-world situations and can even describe these differences, given sufficient time or space. But certain gross distinctions are unavoidably made whenever people mention things happening in the world. Here and in the next section we will examine the temporal distinctions encoded in the form of the verb, often referred to as **aspect**, which are here referred to as temporal structure. Part of the temporal structure, that which Talmy (1985) described as the **pattern of distribution of action through time**, is represented in the time arguments for the three situation types. Another part of the temporal structure, its event time, is the component of temporal structure that gets located in time by tense and the perfect. All the relevant distinctions of temporal structure are represented in terms of intervals and moments of time.

States. Very briefly, a state is a situation that holds over some interval of time, which is both stative and unbounded. A stative interval is one in which, with respect to the relevant predication, there is no change across the interval for which the situation holds. Thus stative intervals are defined here much as stative predications are defined in interval semantics:

An interval I over which some predication ψ holds is stative iff it follows from the truth of ψ over I that ψ is true at all subintervals of I (Dowty 1986:42).

Sentence 8 is an example of a typical stative predication whose verb phrase is headed by an adjective. During the interval for which the predicate *low* holds over the entity *pressure*, each subinterval is equivalent to any other subinterval with respect to the asserted situation; thus its kinesis is stative.

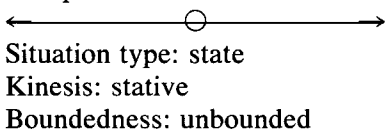
8. The pressure is low.

Some of the diagnostic tests for stative predications are that they cannot be modified by rate adverbials (**The pressure was quickly low*), nor referenced with *do it* anaphora (*The pressure was very low. *The temperature also did it/that.*) While inability to occur with the progressive suffix has often been cited as another diagnostic, it is a less reliable one. Dowty 1979 identifies a class of locative stative predications that occur in the

progressive (e.g., *The socks are lying under the bed.*) Predicates denoting cognition or behavior have often been classified as statives but may occur in the progressive with reference to a cognitive or behavioral process.⁹ Although such verbs do not appear in the current domain, they would be treated differently from pure stative verbs.

The intervals associated with states are also inherently unbounded, although a temporal bound could be provided by an appropriate temporal adverbial (e.g., *The pressure was normal until the pump seized.*)¹⁰ When an unbounded interval is located with respect to another point in time, it is assumed to extend indefinitely in both directions around that time, as with the punctual adverbial in (9). The moment within the interval that is explicitly located by tense and the punctual adverbial is the situation's event time, depicted as a circle in the middle of the interval, with arrows representing that the interval extends indefinitely into the past and toward the present.

9. The pressure was low at 0800.



This sentence would be true if the pressure were low for only an instant coincident with 0800, but it is not asserted to hold only for that instant; one thus assumes that it was low not only at the named time, but also prior and subsequent to it. In this sense, the interval is unbounded, as represented graphically above.

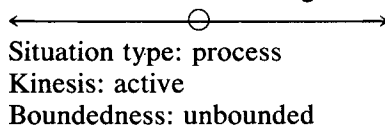
Processes. A process is a situation which holds over an active interval of time. Active intervals contrast with stative intervals in that there is change within the interval, a useful distinction for interpreting manner adverbials indicating rate of change, e.g., *slowly* and *rapidly*. Since states denote the absence of change over time, they cannot be modified by rate adverbials; processes can be.

The definition of active intervals is also adapted from the characterization of process predications in interval semantics:

An interval I over which some predication ψ holds is active iff it follows from the truth of ψ at I that ψ is true over all subintervals of I down to a certain limit in size (Dowty 1986:42).

Active intervals can be unbounded or unspecified for boundedness, depending on whether the verb is progressive. In (10), the active interval associated with the alarm sounding is unbounded and bears the same relationship to the named clock time as does the stative interval in (9) above.

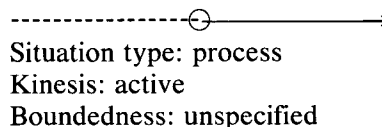
10. The alarm was sounding at 0800.



Progressive aspect has often been compared to lexical stativity.¹¹ Here the commonality among sentences like (9) and (10) is captured by associating the feature of unboundedness both with stative lexical items and with progressive aspect. The temporal structures of states and unbounded processes are thus identical with respect to boundedness. However, the distinction between the kinesis of (9) and (10) is retained by distinguishing active from stative intervals.

In (11) the interval associated with the alarm sounding is unspecified for boundedness, meaning that the clock time may occur within the interval for which the alarm sounded, or at its onset or termination.

11. The alarm sounded at 0800.



In (10), where the verb is progressive, the clock time is interpreted as falling within the unbounded interval of *sounding*, but in (11), where the verb is not progressive, the clock time can be interpreted as falling at the inception of the process or as roughly locating the entire process.¹² Nonprogressive forms of process verbs exhibit a wide variation in the interpretation of what part of the temporal structure is located by tense. The influencing factors seem to be pragmatic in nature, rather than semantic. The solution taken here is to characterize the event time of such predications as having an unspecified relation to the active interval associated with the denoted process, represented graphically above by the dashed line around the event time.

Transition Events. A transition event is a complex situation consisting of a process which culminates in a new state or process. The new state or process comes into being as a result of the initial process. Since states have no kinesis, they cannot culminate in new situations. The temporal structure of a transition event is thus an active interval followed by—and bounded by—a new active or stative interval.¹³

That there are these three distinct components of transition events can be illustrated by the following sentences in which the time adverbials modify one of the three temporally distinct parts of the predicated event.

12. It took 5 minutes for the pump to seize.
13. The pump seized precisely at 14:04:01.
14. The pump was seized for 2 hours.¹⁴

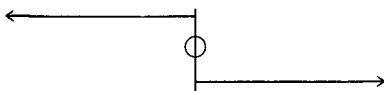
The duration *5 minutes* in (12) above applies to the interval of time during which the pump was in the process of *seizing*. The clock time in (13) corresponds to the moment when the pump is said to have made a transition to the new state of *being seized*. Finally, the measure phrase in (14) corresponds to the interval associated with the new state.

Following Dowty 1986, Vendler's (1967) two classes of achievements and accomplishments are collapsed here into the single class of transition events, and for

much the same reasons. That is, achievements differ from accomplishments in being *typically of shorter duration* and in not entailing a sequence of subevents, but they nevertheless *do in fact have some duration* (Dowty 1986:43). Even so-called punctual events (e.g., *They arrived at the station; She recognized her long-lost friend*) can be talked about as if they had duration (Talmy 1985, Jackendoff 1987), apparently depending on the granularity of time involved. It is my belief that handling granularity depends on appropriate interaction with a relatively rich model of the world and of the current discourse, but would not require new units of time; depending on the level of detail required, moments could be exploded into intervals, or intervals collapsed into moments. For these reasons, punctual events are not treated here as a separate class.

With verbs in Vendler's class of achievements, the same participant generally participates in both the initial process and the resulting situation, as in (15):

15. The engine failed at 0800.



Situation type: transition event

Kinesis: active

Boundedness: bounded

Here, the engine participates in some process (*failing*), which culminates in a new state (e.g., *being inoperative*). In each case, however, there are two temporally distinct intervals, as shown in the diagram above, one bounded by the other.

Causative verbs typically denote accomplishments involving subevents in which the action of one participant results in a change in another participant, as in (16):

16. The pump sheared the drive shaft.

Here, a process in which the pump participated (*shearing*) is asserted to have caused a change in the drive shaft (*being sheared*). The consequence of the different argument structures of (15) and (16) on the event representation is discussed in the next section.

The boundary between the two intervals associated with a transition event, the transition bound, is defined as a transitional moment between the initial active interval and the ensuing active or stative interval associated with the new situation. An important role played by the transition bound is that it is the temporal component of transition events that locates them with respect to other times. For example, (15) asserts that the moment of transition to the new situation coincides with 0800. In contrast with examples 9–11, the status of the engine prior to 0800 is asserted to be different from its status at 0800 and afterwards. The components of temporal structure proposed here are intended to provide a basis for deriving what is said about the relative ordering of situations and their durations, rather than to correspond to physical reality. Thus a transition bound

is a convenient abstraction for representing how transition events are perceived and talked about. Since a transition event is one which results in a new situation, there is in theory a point in time before which the new situation does not exist and subsequent to which the new situation does exist. This point, however, is a theoretical construct not intended to correspond to an empirically determined time. It corresponds exactly to the kind of boundary between intervals involved in Allen's (1983, 1984) *meets* relation.

2.2.2 DOWTY'S ASPECT CALCULUS

The intervals for which situations hold are closely linked with the semantic decompositions of the lexical items used in referring to them. This allows PUNDIT to represent precisely what kinds of situations entities participate in and when. The decompositions include not only *N*-ary relational predicates among the verb's arguments (Passonneau 1986), but also the aspectual operators for processes and events proposed in Dowty 1979. The main clauses for examples 9, 10, 15, and 16 are given below as examples 17–20.

17. The pressure was low.
Decomposition: low(patient([pressure1]))
18. The alarm was sounding.
Decomposition: do(sound(actor([alarm1])))
19. The engine failed.
Decomposition:
become(inoperative(patient([engine1])))
20. The pump sheared the drive shaft.
Decomposition:
cause(agent([pump1]),become(sheared(patient([shaft1])))

In (17), the semantic predicate *low* is associated with the predication *be low*, and is predicated over the entity referred to by the subject noun phrase, *the pressure*.¹⁵ The time component recognizes this structure as a stative predication because it contains no aspectual operators.

The decomposition for (18) consists of a basic semantic predicate, *sound*, its single argument, and the aspectual operator *do*, indicating that its argument is in the class of process predicates; the actor role designates the active participant.

The decompositions of transition-event verbs contain the aspectual operator *become*, whose argument is a predicate indicating the type of situation resulting from the event. With inceptive verbs, as in (19), the actor of the initial process is also the patient or theme of the resulting situation, although this dual role is not represented explicitly in the decomposition. If a distinct actor causes the new situation, the verb falls into the class of causatives and the actor of the initial process is conventionally called an *agent*, as in (20). Other decompositional analyses (Dowty 1979, Foley 1984) conventionally represent the initial process of transition-event verbs by associating an activity predicate (e.g., *do*) with the actor or agent of the initial process (e.g., *cause(do(agent(),*

become(inoperative(patient()))). The decompositions in (19) and (20) can be considered abbreviated versions of these more explicit predicate/argument structures.

The *become* operator of transition-event verbs thus provides a crucial piece of information used when deriving representations of transition events. Given a reference to a specific transition event that has already taken place, the temporal component deduces the existence of the new situation that has come into being by looking at the predicate embedded beneath the *become* operator. This is described more fully in Section 4.2.3.

As will be shown in Section 4, PUNDIT represents actual situations as predicates identifying the situation type as a state, process, or event. In order to familiarize the reader with the representation schema without needless repetition of detail, a single example of a situation representation is given below for (17).

17. The pressure was low.
 state([low1],
 low(patient([pressure1])),
 period([low1]))

Each situation representation has three arguments: a unique identifier of the situation, its semantic decomposition, and its time argument, in this case, the interval (or *period*) over which the predicate holds. The same pointer (e.g., [low1]) is used to identify both a specific situation and its time argument because the actual time for which a situation holds is what uniquely identifies it. The participants in a situation help distinguish it from other similar situations, but while the same entities can participate in other situations, time never recurs.

Having introduced the distinct situation types and the temporal structures that distinguish them, the next steps are to show how they are computed and how they permit a simple computation of temporal location. This will be done in Section 4. Since the preceding discussions also introduced the representation of lexical aspect and the relevance of the verbal categories, it is now possible to clearly summarize the input which the temporal analysis component receives.

3 INPUT TO THE TEMPORAL COMPONENT

PUNDIT's time component performs its analysis after the sentence has been parsed and recursively after the semantic decomposition of each predicating element in the sentence has been created (Palmer 1986). Although this paper focuses on the temporal analysis of certain kinds of tensed verbs, the basic algorithm described here has been extended to handle other cases as well. Describing the full input to the temporal component provides an opportunity to mention some of them.

The input to the time component for each tensed clause includes not only the surface verb and its tense and aspect markings, but also the decomposition produced by analyzing the verb and its arguments (cf. Section 2.2.2.). The input to the time component is thus a list of the following form:

[[Tense, Perfect, Progressive],
 Verb, Decomposition, {Context}]

Each element of the list will be described in turn.

3.1 VERBAL CATEGORIES

The first element in the input list is itself a list indicating the form of the verb, i.e., its grammatical inflection.

[[Tense, Perfect, Progressive],
 Verb, Decomposition, {Context}]

The tense parameter is either past or present.¹⁶ If the verb is in the progressive or perfect, the corresponding parameter appears while absence of either in the input sentence is reflected in its absence from the list.

3.2 THREE ORDERS OF VERBS

The next two elements in the input to the time component are the surface verb and its decomposition. Lexical aspect is encoded in the decomposition as described in Section 2.2.2 for the cases where it is relevant. However, it is a more fundamental classification pertaining to the verb which helps determine the cases where aspect is relevant.

[[Tense, Perfect, Progressive],
 Verb, Decomposition, {Context}]

Since this information is only for treating more complex cases than are described in this paper, the following discussion is intended only to indicate that the model has been extended to cover verbs whose semantic structure contains temporal information of a different order than the inherent temporal structure of an actual situation. After a brief description of three temporal orders of verbs, the discussion will return to explication of the input required for implementing the basic model.

In addition to the aspectual distinction among state, process, and transition-event verbs, there are other distinctions related to temporal semantics. A particularly significant one is among what I call first-, second-, and third-order verbs, by analogy with the distinction among first-, second-, and third-order logics. A first-order verb is one whose arguments are concrete entities, e.g., humans, machines, and other physical objects. A second-order verb takes as its arguments states, processes, and events, but does not in and of itself refer to a situation. Rather, its semantic content is primarily temporal or aspectual (e.g., *occur*, *follow*). Third-order verbs refer to complex situations (e.g., *result*, *cause*) whose participants are themselves situations. The aspectual distinctions among verbs referring to states, processes, and transition events are only relevant to first-order verbs.

Second-order verbs can be identified by the impossibility of temporal modification of a situation referred to by the verb, independent of the situation(s) referred to by the verb's argument(s) (Newmeyer 1975), as can

Order	Examples	Definition
First	“fail”, “operate”	verbs that denote situations and whose arguments are not propositional
Second	“occur”, “follow”	verbs that provide temporal information about their propositional arguments
Third	“result”, “cause”	verbs that denote situations but which also provide temporal information about their propositional arguments

Table 1. Three orders of verbs.

be seen by contrasting examples 21 and 22 with (23) and (24).

21. The failure occurred on Tuesday.
22. The failure was discovered on Tuesday.
23. *The failure that happened on Monday occurred on Tuesday.
24. The failure that happened on Monday was discovered on Tuesday.

Example 22 mentions two distinct situations, a *discovery* and a *failure*. In (21), however, the subject of the sentence, *the failure*, denotes an event, but the verb *occur* does not denote a separate situation. It provides tense and aspect information for interpreting its argument. In other words, the temporal information in (21) is very similar to that contained in (25):

25. Something failed on Tuesday.

A pragmatic difference between the two sentences is that in (21) it is not necessary to mention what failed whereas in (25), the verb *fail* must have a subject. Other verbs in this class are *follow*, *precede*, *continue*, *happen*, and so on. Because these verbs contribute primarily temporal information, they are conventionally referred to as **aspectual verbs** (Freed 1979, Lamiroy 1987, Newmeyer 1975).

It is easy to see that the analysis of aspectual verbs must be implemented somewhat differently from verbs like *fail*, which directly denote situations. In a sentence like (25), the relevant temporal information is contained in the verb and its tense and aspect marking alone. In contrast, the temporal information in (24) pertaining to the *fail* event is distributed not only in the verb and its tense and aspect markers, but also in its subject. Temporal analysis of sentences like (24) must be performed not only at the main clause level, but also at the level of embedded propositions. In essence, analysis of aspectual verbs is of a different order. Consequently, verbs like *fail* are classified here as first-order verbs while the so-called aspectual verbs are classified as second order.

PUNDIT's temporal component also handles a third class of verbs, classified as third order. A third-order verb denotes a real-world situation, but its arguments are other situations. Consequently, the verb may contribute temporal information about the arguments as well as about the situation it denotes. The verb *result* illustrates this type. Sentence 26 asserts the existence of a **result** situation; the **result** relationship holds between

an instigating situation mentioned in the noun phrase *loss of air pressure*, and a resulting situation mentioned in the noun phrase *failure*.

26. Loss of air pressure resulted in failure.

Additionally, the meaning of *result* includes the temporal information that the instigating situation (the *loss*) precedes the resulting situation (the *failure*). A full temporal analysis of sentences like (26) requires two steps. The first is to analyze the temporal structure of the situation denoted by the verb. The second is to draw the correct temporal inferences about the verb's propositional arguments. Such verbs combine some of the properties of both first- and second-order verbs and thus constitute a third order of analysis. Classifying a verb as a third-order verb drives the search for temporal inferences associated with its arguments.

The classification of these three orders of verbs, summarized in Table 1, is recorded independently of the lexical decompositions used by both the temporal-analysis component and the semantic interpreter. At present, verb-order information is used only by the temporal-analysis component. It essentially selects for the appropriate flow of control through the temporal-processing procedures. Although PUNDIT recognizes the distinction between first-, second-, and third-order verbs, and processes the relevant temporal information in each case, the remainder of the paper will deal only with the analysis of first-order verbs.

3.3 LEXICAL ASPECT

The third element in the input list is the decomposition structure produced by the semantic analysis of the verb and its arguments.

[[Tense, Perfect, Progressive],
Verb, **Decomposition**, {Context}]

The important aspectual features of the decompositions, discussed in Section 2.2.2, can be summarized as follows. If the decomposition of a first-order verb contains a *become* operator, the verb is in the transition-event class; otherwise, if it contains a *do* operator, the verb is in the process class; else, the verb (or other predicate) is stative.

3.4 DISCOURSE CONTEXT

The final element in the input to the temporal component is a data structure representing the current discourse context.

[[Tense, Perfect, Progressive], Verb, Decomposition, {Context}]

The first element of this data structure is a list of unanalyzed syntactic constituents. At this stage of processing, PUNDIT has produced a full syntactic analysis of a surface sentence (or sentence fragment), and a semantic decomposition of some predication within the sentence. After the semantic analysis of a clause, the constituent list contains all those syntactic constituents that do not serve as arguments of the verb, e.g., adverbial modifiers of the verb phrase and sentence adjuncts. After the analysis of the main clause of Sentence 27, for example, the constituent list would contain two unanalyzed constituents; the prepositional phrase introduced by *during*, and the subordinate clause introduced by *when*.

27. The pump failed during engine start, when oil pressure dropped below 60 psig.

This list of constituents is processed after the temporal content of a predication is analyzed in the search for temporal adverbials that modify the predication (cf. Section 5 below). The data structure representing the current discourse context contains temporally relevant information, such as the tense and voice of the main clause. The main-clause tense is used for the analysis of situations mentioned in embedded tenseless constituents, while voice is used in analyzing adjectival passives.

The next section describes an algorithm for interpreting the four pieces of information relevant to actual references to states, processes, and events. It demonstrates how the temporal structure and temporal location are generated from the verb's grammatical categories of tense, perfect, and progressive, and from its lexical aspect.

4 ALGORITHM FOR THE TEMPORAL ANALYSIS OF INFLECTED VERBS

The introductory and discussion sections have undoubtedly reinforced the view that semantic processing of temporal information is a complicated problem, even when the scope of the problem is constrained to the simple cases addressed here. Relevant information is distributed within and across distinct constituents, and their contribution to temporal information can depend upon co-occurring elements. Yet these are in no way insurmountable problems. The fundamental design principles behind my approach to temporal processing have been to carefully separate the analysis into distinct subtasks, to pare down to a minimum the information available to each task, and to provide a simple compositional semantics for each kind of temporal input. In

this section, I outline the basic algorithm for the temporal analysis of inflected verbs. This algorithm analyzes the four components of the inflected verb described in the preceding section (lexical aspect, progressive, perfect, tense). The output that is generated can then serve as input for further temporal processing. Section 5 illustrates the integration of this basic algorithm into a more global procedure that successively interprets the main and subordinate clauses of complex sentences where the subordinating conjunction is a temporal adverbial.

The basic algorithm for the temporal analysis of inflected verbs has a simple tripartite control structure designed to answer three distinct questions:

1. Does the predication denote a specific situation with **actual time** reference?
2. If so, what is the **temporal structure** of the situation, i.e., how does it evolve through time and how does it get situated in time?
3. Finally, what is the **temporal location** of the situation with respect to the time of text production, and what is the temporal vantage point from which the situation is described?

Figure 1 illustrates the algorithm's global control structure, with the modules corresponding to each question as well as the relevant input for each module. The first module examines all four temporal parameters described in Sections 3.1 and 3.5 in order to reject certain cases. The second module requires only the two parameters pertaining to the computation of temporal structure. It sends a component of the temporal structure, the event time, to the third module, which locates the event time by analyzing the remaining two temporal parameters, **tense** and **perfect**.

4.1 MODULE 1: ACTUAL TIME

The first task performed by PUNDIT's temporal component is to identify references to specific situation tokens; that is, instances of situations which have actually occurred. The input is the lexical verb and its grammatical categories. In certain cases, the form of the verb itself can indicate that the predication refers to a type of situation, rather than to a specific token. Thus the screening step described here rejects these cases and otherwise assumes that the predication denotes a specific situation. As pointed out in Section 2.1, the verb itself provides insufficient information in two kinds of cases: those where explicit disconfirming information occurs elsewhere in the sentence (e.g., arguments of the verb, modals, frequency adverbials; cf. examples 2 and 7, repeated below):

2. Tourists flew TWA to Boston.
7. The lube oil pump seized whenever the engine jacked over.

and those where pragmatic features of the discourse context affect the interpretation of semantic input (as in a sportscast). While Module 1 currently serves only as a filter, it could be made to generate informative output

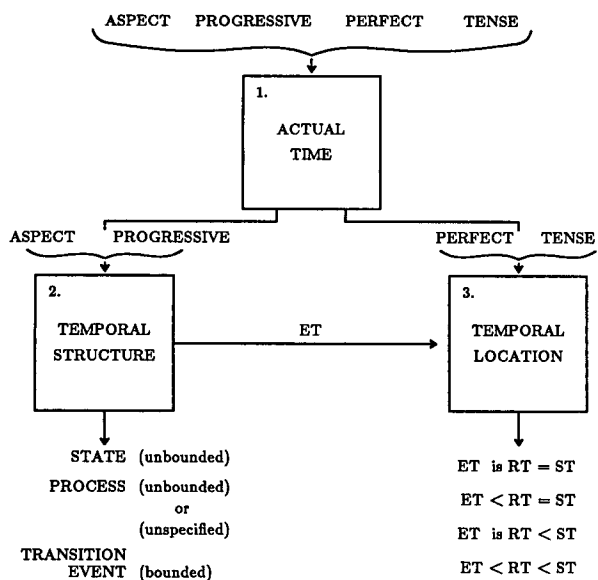


Figure 1. Algorithm for temporal analysis of inflected verb.

for subsequent processing of semantically and pragmatically more complex phenomena.

In Section 2.1 it was shown that two classes of inflected verbs generally denote situation types, rather than actual tokens. These are process verbs and transition-event verbs in the simple present tense (i.e., non-progressive and nonperfect), as exemplified in (28) and (29).

28. Number 2 air compressor operates at reduced capacity. (*operate* is a process verb.)

29. They replace the air compressor every three years. (*replace* is a transition event verb.)

For the compound tenses, present tense interacts with the progressive and perfect verbal categories. The progressive alters the aspectual properties of nonstative verbs so that they refer to unbounded situations, and unbounded situations—unlike the other temporal structures—can be located in the actual present (cf. Section 4.2.2). With the perfect forms, the situation being

referred to is always located in the past, and tense pertains to the situation’s reference time rather than its event time (cf. Section 4.2.3). Thus, as shown in Figure 1, all four elements in the temporal data structure are inspected in order to identify the two cases exemplified in (28) and (29).

Table 2 summarizes the relation between the inflected verb and actual temporal reference.

In the current implementation of PUNDIT, predications that meet the first condition do not receive further temporal analysis.

4.2 MODULE 2: COMPUTE TEMPORAL STRUCTURE

Module 2 computes the first type of specific temporal information associated with reference to an actual situation. It generates an explicit representation of the situation’s temporal structure. This structure includes one or more time arguments associated with the semantic predicates in the decomposition, and the situation’s event time. Each situation type—state, process, transition event—receives an appropriate situation label, time argument(s), and event time. The temporal structure evoked by an inflected verb can be computed entirely on the basis of the values of the two aspectual elements in its input (Lexical Aspect, Progressive), as shown in Figure 1. The algorithm for Module 2, summarized in Table 3, will be described in the following three sections corresponding to the three situation types.

Though not shown in the figure or in Table 3, Module 2 also receives another input data structure: the semantic decomposition. The decomposition is analyzed during the processing of transition-event situations in order to associate distinct time arguments with distinct semantic predicates in the decomposition. This procedure is explained in the appropriate section below.

4.2.1 STATES

As shown in Table 3, if the lexical aspect of the predicate is stative (Aspect = stative), then the progressive parameter is irrelevant for computing temporal structure. Lexical stativity is sufficient to identify the

LEXICAL ASPECT	PROGRESSIVE	PERFECT	TENSE	ACTION
Nonstative	no	no	present	reject
				accept

Table 2. Module 1: Actual Time.

LEXICAL ASPECT	PROGRESSIVE	LABEL	TIME ARGUMENT	EVENT TIME (ET)
stative	Yes/No	State	unbounded stative interval	includes ET
process or transition event	Yes	Process	unbounded active interval	includes ET
process	No	Process	unspecified active interval	has ET
transition event	No	Event	transition bound	<i>unifies with ET</i>

Table 3. Module 2: Temporal Structure.

situation as a state whose time argument is an unbounded stative interval.

Example 30 gives a simple stative sentence, the relevant input to Module 2, and the final situation representation. Note that (30) illustrates the use of the progressive with a verb in the locative class of statives noted in Dowty 1979, and mentioned in Section 2.2.1.¹⁷

30. Metallic particles are clogging the strainer.

Lexical Aspect = stative

Situation Representation:

```
state([clog1],
  clog(instrument([material1]), theme ([strainer2])),
  period([clog1]))
```

As soon as the lexical aspect is recognized to be stative, Module 2 generates the state label and period time argument used in creating the representation depicted above. A period time argument in the context of a state representation denotes a stative interval. The situation representation in (30) indicates that a specific state, *clog1*, holds over the stative interval, *period([clog1])*; the decomposition in the representation indicates the participants and the relation between them that holds over this interval. By definition, this interval also has an event time associated with it, whose relation to the interval we can determine by its boundedness feature.

Stative intervals are assumed to be unbounded unless an endpoint is provided by further processing (e.g., through adverbial modification, inference). For unbounded intervals, the event time is always an arbitrary moment *included* within the interval. This is represented as a binary predicate of the following form, where the *moment* time argument is the event time:

Event Time = moment([clog1])

such that includes(period([clog1]), moment([clog1]))

This predicate and the state representation given above exemplify the output of Module 2 for state situations. The event time generated here is then passed to Module 3 in order to determine its temporal location. We will return to this same example in the discussion of temporal location in Section 4.3.

4.2.2 PROCESSES

There are three surface forms that denote process situations: nonprogressive process verbs, progressive process verbs, and progressive transition-event verbs. The nonprogressive and progressive cases have distinct temporal structures, due to differences in the relation of the event time to the active interval over which the process holds. Since this is the only difference among the three cases, the similarities in temporal structure will be presented before the event time is discussed.

A nonstative predication that either has a process verb or is in the progressive (i.e., the three combinations of nonprogressive process, progressive process, and progressive transition-event) evokes a process representation. Thus the following three example sentences would each be represented with a process label

and a period time argument, representing the active interval over which the process holds. Examples 31 and 32 illustrate the two forms of process verbs that evoke process situations; since they receive the same representation, it is shown only once. Example 33 shows the third type of reference to a process, with a progressive transition-event verb.

31. The diesel operated.

Lexical Aspect = process

Progressive = no

32. The diesel was operating.

Lexical Aspect = process

Progressive = yes

31–32. Situation Representation:

```
process([operate1],
  do(operate(actor([diesel])))
  period([operate1]))
```

33. The pump is failing.

Lexical Aspect = transition event

Progressive = yes

Situation Representation:

```
process([fail1],
  become(inoperative(patient([fail1])),
  period([fail1]))
```

The process representation for (33) contains the full decomposition for the verb *fail* with its aspectual operator *become*. In this context, the *become* operator does not denote a transition to a new situation, but rather, indicates a process of *becoming*, which might or might not culminate in such a transition.

Referring again to Table 3, we note that the active intervals for both (32) and (33) will be unbounded, in contrast to (31), where the active interval is unspecified for boundedness. The consequence of this difference on the representation of the event time is outlined in the following paragraphs.

Unbounded processes. The predicate specifying the relation between the event time of an unbounded process and the period over which the process holds is identical to that for states. That is, the period time argument *includes* an arbitrary moment, which serves as the situation's event time, as shown below.

32. The diesel was operating.

Event Time = moment([operate1])

such that includes(period([operate1]), moment([operate1]))

33. The pump is failing.

Event Time = moment([fail1])

such that includes(period([fail1]), moment([fail1]))

The progressive always implies unboundedness, and in this respect resembles lexical statives. Again, it is important to remember that an unbounded interval can acquire endpoints through further processing (e.g., of temporal adverbials, as in *The diesel was operating until the pump failed.*)

Unspecified processes. For nonprogressive process verbs, the period associated with the predication is unspecified for boundedness (cf. discussion of Example

LEXICAL ASPECT	PROGRESSIVE	LABEL	TIME ARGUMENT	EVENT TIME (ET)
transition event	No	Event	transition bound	<i>unifies with ET</i>

(From) Table 3.

11 in Section 2.2.1). This gives rise to an indeterminate relationship between the event time and the period time argument over which the process holds; i.e., the event time may start, end, or be included within the period. This unspecified relationship is represented by means of a binary *has* predicate, as shown in example 31.

31. The diesel operated.
 Event Time = moment([operate1])
such that has(period([operate1]), moment([operate1]))

Both event-time predicates given so far (i.e., *includes*, *has*) indicate a relation between an arbitrary moment and a single interval over which a state or process holds. There is otherwise nothing distinctive about the moment selected to be the event time of a process or state situation. In contrast, as Table 3 indicates, and as discussed in Section 2.2.1, the event time of a transition event is equated with a distinctive component of its temporal structure, viz., the transition bound between a process that initiates the event and the new situation reached at the culmination of the process.

4.2.3 TRANSITION EVENTS

Table 3 shows only one component of the temporal structure of a transition event (the relevant line of the table is repeated below).

As noted in Section 2.2.1, a transition event has three temporal components: an initial active interval leading up to a transition, the moment of transition, and the interval associated with the new, resulting situation. In theory, then, one could represent the full temporal structure of a transition-event predication (e.g., *The pump failed*) as three contiguous states of affairs: an initial process (e.g., *failing*) leading up to a transitional moment (e.g., *becoming inoperative*) followed by a new state of affairs (e.g., *inoperative*). At present, PUNDIT explicitly represents only the latter two components of transition-event predications: the moment (transition bound) associated with an event of becoming, and the period associated with the resulting situation. This representation has been found to be adequate for the current applications. Thus transition events are actually assigned two situation representations: an event representation with a moment time argument, represented with the input decomposition, and a resulting state or process situation with a period time argument, for which a new decomposition is derived from the input decomposition. Example 34 illustrates a typical transition-event sentence, the relevant input for computing temporal structure, and the two situation representations.

34. The pump failed.
 Lexical Aspect = transition event
 Progressive = no
 Situation Representation:
 event([fail1],
 become(inoperative(patient([pump1]))),
 moment([fail1]))
 Situation Representation:
 state([fail2],
 inoperative(patient([pump1])),
 period([fail2]))

The first situation representation corresponds to the transition event itself. Module 2 generates the event label and moment time argument used in creating the type of event representation shown above for nonprogressive transition event verbs. The moment argument of a transition event is the transition bound implying the onset of a new situation. When Module 2 creates an event with a moment argument, it also creates a representation for the implied situation. In Example 34, the new situation is a state. When creating the representation for the situation resulting from a transition event, it is necessary to determine the appropriate situation label, time argument, and semantic decomposition for the new situation. This is where the semantic decomposition for transition events plays a role, as will be described below.

All transition-event verbs contain a state or process predicate embedded beneath an instance of the aspectual operator *become*. The full decomposition represents the type of situation associated with the moment of transition. The portion embedded beneath *become* is the situation type associated with the new situation. For example, the decomposition passed to the time component for Sentence 34 would be:

become(inoperative(patient([pump1]))).

As shown in (34), this decomposition appears in the representation of the transition event itself. The argument to the *become* operator is then extracted for use in the new situation representation:

inoperative(patient([pump1]))

The extracted decomposition is inspected to determine its aspectual class, completely analogously to the procedure for determining the aspectual class of the input predicate (cf. Section 3). In this case, the embedded predicate decomposition is stative because it contains no aspectual operators. If it contained the *do* operator, the new situation would have been a *process*.¹⁸ In this fashion, the decomposition guides the selection of the

situation label and time argument for the situation inferred to result from the transition event.

The final piece of temporal structure derived for a transition event is the temporal relation between the moment associated with the transition event (e.g., `moment([fail1])`) and the period associated with the resulting situation (e.g., `period([fail2])`). The event moment is the onset of the period. Following Allen 1983, this is called a **start** relationship. By definition, then, every transition bound starts some period. In the case of Example 34, the moment of failure starts the period for which the pump is in an inoperative state.

`start(moment([fail1]), period([fail2]))`

The event time of a transitional event is always identified with the transition bound. Thus for examples like (34), the moment time argument serves as the event time of the transition event. This identity relation is not represented as a predicate, but rather, is handled via unification, as indicated in Table 3.

4.3 MODULE 3: COMPUTE TEMPORAL LOCATION

PUNDIT's temporal component employs a Reichenbachian analysis of tense whereby situations are located in time in terms of three temporal indices: the event time, speech time, and reference time.¹⁹ It diverges from Reichenbach primarily by distinguishing between the event time and the temporal structure of a situation. While Reichenbach acknowledged that the progressive, for example, pertains to temporal duration, he did not discuss the differences in temporal structure associated with distinct situation types and their interaction with tense. Here, the event time is only a single component of the full temporal structure of a situation. In this section, we will see how this method of defining the event time makes it possible to compute temporal location independently of lexical or grammatical aspect while preserving the distinctive temporal information they contribute to references to actual situations.

The tense and perfect parameters specify the sequencing relations among the event time, reference time, and speech time, with each of the four configurations of tense and perfect specifying a distinct ordering, as shown in Figure 1 and repeated below:

- ET is RT = ST simple present
- ET < RT = ST present perfect
- ET is RT < ST simple past
- ET < RT < ST past perfect

The speech time, or time of text production, is given. It serves as the temporal fulcrum with respect to which the other temporal indices are located. As shown in Table 4, the presence or absence of the perfect indicates whether the event time and reference time are distinct, in which case the event time precedes the reference time, or whether they are identical. Tense is taken to

indicate the relation between the reference time and the speech time, following Reichenbach's suggestion: *the position of R[T] relative to S[T] is indicated by the words "past", "present", and "future"* (Reichenbach 1947).

PARAMETER	VALUE	RULES
Perfect	Yes	precedes(ET,RT)
	No	ET is RT
Tense	Past	precedes(RT,ST)
	Present	coincide(RT,ST)

Table 4. Module 3: Temporal Location.

Since we are dealing here with actual time, rather than potential or hypothetical time, there is only past or present. That is, the reference time either precedes or coincides with the speech time.

The reference time and the event time are identical to one another for the simple tenses (ET is RT), which has the effect that tense applies to the event time. Thus, for the simple present, the event time and the speech time *coincide*. Note that a distinction is made here between *identity* and *coincidence* of distinct indices. For any speech act or text containing a description of a situation, the speech situation and the described situation are always conceptually and observationally distinct, thus also their respective temporal indices. These indices are therefore represented as distinct times, which, in the present tense, happen to coincide. However, with the simple tenses, there is no reason to create a distinct reference time and a relation saying that it coincides with the event time. Rather, there are two different functions, which, in the case of the simple tenses, are filled by the same temporal index. The function of the reference time is explained more fully below.

Webber (this volume) reviews and expands upon the role reference time plays in intersentential temporal reference. Reference time also plays a role in interpreting relational adverbials like *now*, *yesterday*, *when*, and so on. Adverbs like *now* and *yesterday* relate the reference time of a predication to an implicit time, viz., the speech time. Relational adverbs like *before*, *after*, and *when* relate the time of the predication they modify to an explicitly mentioned time, i.e., the reference time associated with their syntactic complements. In the absence of the perfect, the reference time is identical with the event time, as in (35) and (36).

35. The pressure is normal now.

36. The pressure was low yesterday.

In the perfect tenses, the reference time and event time are distinct. The event time of both the present and past perfect predications in (37) and (38) is past, i.e., the moment of *failure* is in the past.

37. The pump has now failed.²⁰

38. The pump had failed when the gear began to turn.

With the present perfect, it is the reference time that is present, as shown in (37) by the admissibility of the adverb *now*, which also refers to the present. On one reading of (38), the event time, or moment of failure, precedes the reference time, i.e., the time specified by the *when* clause. The perfect tenses can also be used simply to affirm truth or falsehood,²¹ thus (38) has another reading in which the perfect does not contribute a distinct reference time, but merely asserts that it is in fact the case that the pump failed when the gear began to turn.

4.3.1 SIMPLE TENSES

The distinct relations of event time to temporal structure corresponding to the three categories of boundedness—unbounded, unspecified, and bounded—correlate with distinctive behavior of the present tense. If the temporal structure associated with a predication is an unbounded interval, the simple present locates some time within the interval coincident with the speech time. Examples 35–38 illustrate the simple present in the context of the four types of predications that hold over unbounded intervals.

35. The pressure is low.
Lexical aspect: stative
Progressive: no
36. Metal particles are clogging the strainer.
Lexical aspect: stative
Progressive: yes
37. The pump is operating
Lexical aspect: process
Progressive: yes
38. The pump is failing.
Lexical aspect: transition event
Progressive: yes

In these examples, the predicate is asserted to hold for some interval of unknown duration, which includes the speech time. Since this interval corresponds by definition to actual time, it cannot be known to continue beyond the speech time into the future. However, that it can extend indefinitely into the past is illustrated by (39), where the situations referred to in the first and second conjuncts are assumed to be the same.

39. The pressure is low and has been low.
Predications involving process or transition-event verbs in the simple present have already been eliminated by Module 1 on the assumption that sentences like (40) and (41) do not refer to actual time.

40. The pump operates.
Lexical aspect: process
Progressive: no
41. The pump fails.
Lexical aspect: transition event
Progressive: no

If a predication is not explicitly unbounded, i.e., if it has or may have an endpoint, then the present tense cannot

be interpreted as locating the event time in the actual present. An event time located within an unbounded interval corresponds to persistence of the same situation, whereas an event time that may also be an endpoint corresponds to a transition. The way in which examples like (40) and (41) are interpreted can be explained by considering that we cannot announce changes in the world at the exact moment that we perceive them, although in the guise of reportage or sportscasting, we act as though we can.

In contrast to the simple present, the simple past can locate the event time of any temporal structure prior to the speech time. What is distinctive about the past tense in the context of the different temporal structures pertains to the temporal structure surrounding the event time. If the temporal structure is an unbounded interval, then the event time is some moment prior to the speech time within a persisting interval, and the same situation extends unchanged forward towards the present and back into the past. Example 42 illustrates the lack of contradiction in asserting the continuation up to the present of the past, unbounded situation mentioned in the first clause.

42. The pump was failing and is still failing.
The temporal structure associated with the situation mentioned in the first clause of (43), in the simple past, is an unspecified interval. Here it is unclear whether the two conjuncts refer to the same situation. Since the event time of the first conjunct is represented noncommittally, i.e., it may or may not be an endpoint of the interval, both interpretations are provided for by the representations generated here.

43. The pump operated and is still operating.
Finally, the simple past of a predication denoting a transition event definitely locates an endpoint. The event time of (44) is the transitional moment between an initial process of *failing* and a resulting state of *being inoperative*.

44. The pump failed and is still failing.
The first clause of (44) is represented by PUNDIT to assert the following temporal information: there was a moment of transition at which the pump failed, viz., its event time (*moment([fail1])*); this moment started a period in which the pump was inoperative (*start(moment([fail1], period([fail2])))*); and finally, it preceded the speech time (*precedes(moment([fail1]), Speech Time)*). The second clause cannot refer to the same transition event because a unique transition bound cannot both precede and coincide with the speech time, nor can it both be an endpoint of, and contained within, an interval. Rather, the second clause refers to a distinct situation, either a process that the speaker presumes will eventually result in a new failure, or an iteration of successive failure events. Of these two possibilities for the second clause, PUNDIT currently generates only the former.

4.3.2 PERFECT TENSES

The perfect tenses have a more complex semantics and pragmatics than the simple tenses. The semantic interpretation given here accounts for the temporal interpretations assigned to the perfect tenses in which the event time and reference time are distinct from one another. There are uses of the perfect that do not have these temporal effects, as pointed out in McCawley 1971, i.e., cases where the event time and reference time would not be distinct. Here we consider only the temporally relevant uses of the perfect, where each perfect tense specifies two temporal relations: in both cases, the event time precedes the reference time; and tense indicates whether the reference time coincides with or precedes the speech time.

The following examples illustrate the present and past perfect with a variety of temporal structures. The only difference between these examples and the simple present tenses examined in the preceding section is the relation between the reference time and event time. The relation between temporal structure, event time, and speech time is the same as for the simple past.

45. The engine has been operating. (unbounded process)
46. The engine has operated. (unspecified process)
47. The pump has failed. (transition event)
48. The pressure had been low. (state)
49. The pump had failed. (transition event)

5 INTERPRETING TEMPORAL ADVERBIALS

It is assumed that temporal adverbials can be analyzed in terms of the same components of temporal structure and temporal sequencing constraints that apply to situations. The situation representations developed here provide a foundation for interpreting three distinct types of adverbial modification corresponding to the three features represented in temporal structure, i.e., kinesis, intervals, and moments. Rate adverbs like *slowly* and *rapidly*, which modify the manner in which situations evolve through time, modify active intervals and not stative intervals. For an example like (50), no explicit active interval would be represented, thus one would have to be coerced in order to interpret the adverb.

50. The pressure was rapidly low.

Examples like (51), on the other hand, provide a motivation for representing the initial active interval of a transition event (cf. Section 4.2.3), since the adverb essentially selects for such an interval.

51. The engine quickly failed.

Durational adverbials like *for X*, where *X* is a temporal measure phrase, modify any interval, but not their endpoints. Finally, relational adverbs, which specify temporal sequence, modify the reference time of situations.

Adverbials can combine relational and durational elements. *In X*, where *X* is a temporal measure phrase, not only specifies a duration, but also relates the

endpoint of this duration to some other time, e.g., the time at which the utterance is produced, as in (52).

52. The lights will go off in 10 minutes (e.g., *from now*).

Temporal connectives like *before* and *after* can combine with temporal measure phrases to yield complex adverbials specifying both a duration and a relation, as in (53).

53. The engine seized five minutes before the alarm sounded.

In this section, we will look briefly at the two types of durational phrases compared in Vendler 1967 in order to demonstrate the advantages of the representations developed here for interpreting them. Then we will look briefly at the algorithm for interpreting complex sentences with subordinate adverbial clauses.

5.1 DURATIONAL ADVERBIALS

Unbounded situations. Predications denoting states and processes have duration, as shown by the interpretation of durational adverbial phrases of the form *for X*, where *X* is a time measure, as in (54) and (55):

54. The pressure was low for 10 minutes. (state)

55. The gear was turning for 10 minutes. (unbounded process)

However, as noted in preceding discussions, the past tense in reference to states and unbounded processes does not apply to the whole duration. It applies to the moment within the interval designated as the situation's event time. Since in (54) and (55) the event time is past and the speech time is present, the two temporal indices create an explicit temporal extent within which to locate the durational phrases. The *for* adverbial phrase also evokes an unbounded duration, meaning that the measure phrase does not necessarily encompass the entire duration, as shown by the lack of contradiction in asserting the continuation of the interval up to the present, as in (56) and (57).

56. The pressure was low for 10 minutes and is still low.

57. The gear was turning for 10 minutes and is still turning.

The present perfect would allow one to assert something semantically very similar to (56) and (57), but more laconically (e.g., *The pressure has been low for 10 minutes.*). However, a context in which (56) would be more correct than the corresponding perfect is perfectly possible; it would have to be a context where the pressure is now low, was low over some interval of 10 minutes' duration, but where this interval is more than 10 minutes prior to the present, and where the pressure has continued to be low up to the present (e.g., A: *The alarm should go off if the pressure is low for 10 minutes.* B: *Well, the pressure was low for 10 minutes and it's still low, but the alarm still hasn't gone off.*).

The past tense with an unbounded interval evokes a span of time between the past event time and the present speech time within which to situate the measure of time given by a *for* adverbial. However, there is no

such span of time associated with the present tense of an unbounded interval, hence the impossibility of a *for* measure phrase in examples (58) and (59).²²

58. ? The pressure is low for 10 minutes.

59. ? The gear is turning for 10 minutes.

Note that the present perfect, like the simple past, does provide a temporal point prior to the present, thereby creating a span of time for the durational phrase to apply to, as in (60) and (61):

60. The pressure has been low for three hours.

61. The gear has been turning for five minutes.

The temporal structures generated for examples like (56)–(59) make it possible to correctly interpret the adverbial phrases they contain. The measure phrases in (56) and (57) can be interpreted not simply because the mentioned situations have duration, but more importantly because of the distinctness of the two temporal indices, event time and speech time. In (58) and (59), where event time and speech time coincide, there is no explicit span of time within which to situate the measure phrase. Cases where there is no explicit component of temporal structure in the situation representation to match up with the temporal structure evoked by a temporal adverbial are probably candidates for the kind of coercion discussed in Moens and Steedman (this volume).

The durational adverbial phrases in (62)–(64) not only specify a duration, but also an endpoint (Vendler 1967). Since progressive process predications are unbounded, there is no actual endpoint to be mapped to, hence, under one reading, (62) cannot be interpreted as a situation with an actual time; rather, it seems to refer to an activity that was supposed to take place five minutes from some time previously specified in the discourse context (e.g., paraphrasable as *It was to be the case that the gear would turn five minutes from the present*). There is another possible reading, paraphrasable as *It turned out to be the case that the gear turned five minutes after some previously specified time*, as in the context *I applied some lubricant to the gear and it was turning in five minutes*, which, like (58) and (59) above, may be examples requiring coercion.²³ In contrast, examples 63 and 64 can be interpreted as actual situations whose endpoints coincide with the endpoints of the five-minute duration.

62. The gear was turning in five minutes.

63. The gear turned in five minutes.

64. The engine was repaired in five minutes.

The two types of durational adverbials behave differently when modifying the different types of temporal structures in ways that tend to confirm the representations proposed here.

5.2 COMPLEX SENTENCES

The temporal adverbials encountered in the CASREPs domain consisted predominantly of phrases introduced by temporal connectives, e.g., *when*, *before*, and *after* (Smith 1981). The general problem in analyzing the

strictly temporal information associated with such connectives is to associate some time evoked by the matrix clause with some time evoked by the complement phrase. In general, connectives are represented as associating the reference time of the matrix clause with the reference time of the complement. The procedure involved in analyzing the temporal relations specified by a *before* adverb (or other temporal connective) has the six steps illustrated in (65) below.

(65) The compressor failed before the pump seized.

Step 1: Analyze semantics of the main clause	<i>The compressor failed</i>
Step 2: Find reference time of main clause (RT1)	moment([fail1])
Step 3: Recognize temporal adverb	<i>before</i>
Step 4: Analyze semantics of subordinate clause	<i>the pump seized</i>
Step 5: Find reference time of subord. clause (RT2)	moment([seize1])
Step 6: Look up semantic structure of connective	precede(RT1, RT2)

Result: precedes(moment([fail1]), moment([seize1]))

First, the temporal semantics of the main clause is analyzed. One of the outputs of this analysis is the reference time of the main clause, which in this case would be represented as *moment([fail1])*. Then the time component finds the adverbial phrase *before the pump seized* in the constituent list, which it recognizes as consisting of a temporal connective (*before*) and a complement. The complement clause is sent to the semantic interpreter (Palmer 1985) and is returned to the time component for temporal analysis. The fourth step, the temporal analysis of the subordinate clause, yields the information that the reference time of the subordinate clause is *moment([seize1])*. Finally, the time component looks up the predicate structure representing the semantics of the temporal connective. *Before* is represented as a binary predicate—*precedes*—whose first argument is the reference time of the main clause and whose second argument is the reference time of the complement clause.

Currently, relational adverbs like *before*, *after*, and *when* are represented as predicates relating the reference times of the modified and modifying situations. The procedure for handling temporal connectives assumes a priori that the reference times of the syntactically superordinate and subordinate constituents are the required input. In future work, these and other adverbs will be treated more explicitly as semantic predicates with selectional constraints that guide the search for the appropriate components of temporal structure associated with the referents of the relevant constituents.

6 CONCLUSION

The situation representations presented here model the temporal meaning of inflected verbs by assigning a semantic value to each of four components; the inherent lexical aspect, the tense, and the presence or absence of

the perfect and progressive. Two significant advantages to the overall proposal are the simplicity of the algorithm that computes the representations, and the generality of the building blocks used in constructing them. The algorithm accounts for the context dependencies among the four semantic components through a single mechanism, i.e., an appropriate characterization of the event time and its relation to the full temporal structure of a state, process, or transition event. These temporal structures are composed of intervals that may be active or stative, and that may be bounded, unbounded, or unspecified for boundedness.

The situation representations have certain advantages in and of themselves. For example, the linkage between the components of temporal structure and Dowty's aspect calculus, and the incorporation of a Reichenbachian treatment of tense, make it possible to represent very precisely what predicates hold when. Further, the dual possibility of associating the *become* operator either with an unbounded interval or a transition bound between intervals circumvents the so-called imperfective paradox. An additional advantage is the utility of these representations for further processing. The preceding section illustrated how the three building blocks of the representations (i.e., the notion of persistence of some situation through an interval, kinesis of the situation, and boundedness of the interval) make it possible to interpret accurately three corresponding kinds of temporal adverbials, and to identify those cases where coercion is required. Finally, explicit representation of the reference times and event times within distinct types of temporal structures should make it possible to account for the differential contribution of situations to narratives and other types of discourse.

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NOTES

1. Formerly Paoli Research Center, SDC—A Burroughs Company.
2. Prolog UNDERstanding of Integrated Text: it is a modular system, implemented in Quintus Prolog, with distinct syntactic, semantic and pragmatic components (Dahl 1987a, Dahl 1986, Dowding 1987, Palmer 1986).
3. PUNDIT has now been adapted to four domains.
4. Webber, in work carried out in part at the Paoli Research Center, proposes a focusing algorithm for computing intersentential temporal relations which is analogous to Sidner's focusing mechanism for definite anaphoric expressions. Future work by Webber and Passonneau will integrate the two dimensions of inter- and intrasentential temporal analysis.
5. Various types of tenseless predications are processed by PUNDIT's temporal component, including nominalizations, certain clausal modifiers of noun phrases (e.g., *pressure decreasing below 60 psig caused the pump to fail*), and sentence fragments (Linebarger 1988). However, this paper focuses on the simpler case of tensed clauses.
6. Reference time also plays a role in intersentential temporal reference (cf. Hinrichs, Moens and Steedman, Nakhimovsky, Webber, this volume).
7. For the sake of brevity, the treatment of temporal adverbs with nominal complements is not described in this paper, but cf. Dahl 1987b.
8. These are not currently handled in the PUNDIT system. Predications embedded in any one of these contexts do not directly denote specific situations but rather denote types of situations which, e.g., might occur, have not occurred, or tend to occur. Treatment of these contexts awaits the development of a representation which distinguishes between specific situations which hold for some real time and types of situations which hold for some potential time. One such proposal appears in Roberts 1985, which allows for the creation of temporary contexts.
9. Cf. discussion of examples like *I am thinking good thoughts*, and *My daughter is being very naughty*, in Smith 1986.
10. In general, temporal adverbials can modify an existing component of temporal structure or add components of temporal structure.
11. For comparisons of stativity and the progressive, cf. Vlach 1981, where the two are equated, Smith's counterargument (1986), and the interesting proposal in Mufwene 1984.
12. Nakhimovsky (this volume) makes essentially the same argument, namely that English lacks overt perfective grammatical aspect. In other words, the indeterminacy associated with the simple past of a process verb is evidence for the argument that the **perfective** or **culminated** reading associated with simple past transition event verbs, which are discussed in the next subsection, is a consequence of the interaction between tense and lexical aspect, rather than of the simple past tense itself.
13. This treatment of transition events closely resembles the **event structure** which Moens and Steedman refer to as a **nucleus**. They define a nucleus as a structure comprising a culmination, an associated preparatory process, and a consequent state (Moens 1987).
14. The durational adverbial in (14) forces a stative reading for a predicate which in isolation would be ambiguous between a passive and the adjectival passive (Levin 1986), in which the past participle is interpreted statively or adjectivally.
15. The atom [*pressure1*] is an identifier of the entity referred to in the noun phrase and is created by PUNDIT's reference resolution component (Dahl 1986).
16. For sentence fragments such as *erosion of blade tip evident*, the tense parameter is actually *untensed*. The time component assigns present or past tense readings to fragments, depending on the aspectual class of the fragment (Linebarger 1988).
17. As noted elsewhere, the aspectual classification of verbs is not completely determinate (Talmy 1985). *Clog* may very well be a verb that can refer either to a process or a state, and it might be possible to decide dynamically the lexical aspect of a specific instance through interaction with a sophisticated model, such as one which incorporates the notion of resource use, as suggested by Nakhimovsky (this volume). However, in PUNDIT the aspectual classification of verbs is domain dependent.
18. The embedded decomposition never contains the *become* operator; a decomposition with two *become* operators (e.g., *become(become(inoperative(patient([pump1])))*)) would be incoherent.
19. Reichenbach's (1947) treatment of tense and other *token reflexive* (indexical) elements is similar to Jakobson's (1957).
20. Dowty and others have pointed out that the situation mentioned in a present perfect often persists up to the speech time (1982). However, this is generally not the case with reference to unbounded processes (e.g., *The pump has operated*), and seems to depend on a variety of pragmatic factors for the other situation types.
21. Cf. McCawley's (1971) discussion of the ambiguities of the perfect, especially the *assertorial* perfect.
22. Since isolated sentences can generally be given a variety of readings, it is often necessary to add qualifications regarding the intended reading of linguistic examples. Sentences like (56) and (57), for example, can be interpreted as *the pressure is to be low for 10 minutes*. Such interpretations are outside the scope of this paper, for they pertain to hypothetical rather than actual times.
23. Thanks to Bonnie Webber and Mark Steedman for pointing out the second reading mentioned here.