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Exploiting aspectual features and connecting words for summarization-inspired temporal-relation extraction

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Abstract

This paper presents a model that incorporates contemporary theories of tense and aspect and develops a new framework for extracting temporal relations between two sentence-internal events, given their tense, aspect, and a temporal connecting word relating the two events. A linguistic constraint on event combination has been implemented to detect incorrect parser analyses and potentially apply syntactic reanalysis or semantic reinterpretation—in preparation for subsequent processing for multi-document summarization. An important contribution of this work is the extension of two different existing theoretical frameworks—Hornstein's 1990 theory of tense analysis and Allen's 1984 theory on event ordering—and the combination of both into a unified system for representing and constraining combinations of different event types (points, closed intervals, and open-ended intervals). We show that our theoretical results have been verified in a large-scale corpus analysis. The framework is designed to inform a temporally motivated sentence-ordering module in an implemented multi-document summarization system.

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1. Introduction

Extraction of temporal relations between events is demonstrably crucial for determining chronology—or timelining—for many natural language processing (NLP) applications, most notably multidocument summarization. This was a central topic of discussion and working group exercises at last year's the Document Understanding Conference (DUC) (Dang & Harman, 2006). Specifically, it can be shown that combining/merging/fusing information from different sentences in multi-document summarization requires temporal-relation knowledge for sentence combination (Barzilay & McKeown, 2005; Lapata & Lascarides, 2004;

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Pustejovsky, Wiebe, & Maybury, 2002), sentence reduction/trimming (Zajic, Dorr, Schwartz, Monz, & Lin, 2005), reordering of extracted sentences (Jing & McKeown, 2000), inferring discourse relations (Marcu & Echihabi (2002)), and imposing discourse coherence (Lascarides & Oberlander, 1993). Additionally, the recent work of Pan, Mulkar, and Hobbs (2006) has demonstrated the importance of deriving event durations in order to determine whether two events overlap or are in sequence.[1]

Other applications for temporal-relation extraction are those that apply question-answering to time-stamped data (Pustejovsky et al., 2002) and sentence generation enhancement from time stamps (Filatova & Hovy, 2001; Schilder & Habel, 2001). These applications have compelled researchers to develop temporal formalisms such as TimeML for the creation of time-stamped gold standards—including TimeBank (Pustejovsky et al., 2004; Radev & Sundheim, 2002), where TIMEX2 tags have been extended to include temporal functions and anchors to events and other temporal expressions (Ferro, Mani, Sundheim, & Wilson, 2000). The work of Setzer (2001, 2002) and Setzer and Gaizauskas (2001), has resulted in a fine-grained time-stamp formalism for the annotation of events, times, and temporal relations in newswire text. Mani and Wilson (2000) and Wilson, Mani, Sundheim, and Ferro (2001) have shown that it is possible to achieve 83.2% accuracy in the annotating of newswire text with time values.

More recently, several researchers have focused on learning temporal annotation rules for TIMEX2 tagging of French data (Baldwin, 2002). In addition, Mani, Verhagen, Willner, Lee, and Pustejovsky (2006) have developed techniques for learning temporal relations for the purpose of ordering sentences in multi-document summarization. The latter approach is distinguished from ours in that it is designed to learn the relative temporal ordering of individual sentences, not sentence-internal event combinations mediated by a temporal connective.

To date, automatic approaches to temporal-relation extraction have relied on parser input that is assumed to be correct (i.e., no reanalysis is needed).[2] Such approaches do not apply linguistic constraints on event combinations to determine if parse-tree reanalysis is required. Moreover, it is generally assumed that there is no way to infer inherent lexical features of verbs participating in events—thus making it more difficult to apply linguistic constraints and determine whether a syntactic reanalysis or semantic reinterpretation is needed.

This paper presents a model that incorporates contemporary theories of tense and aspect and develops a new framework for extracting temporal relations between two sentence-internal events, given their tense, aspect, and a temporal connecting word relating the two events. A linguistic constraint on event combination has been implemented to detect incorrect parser analyses and potentially provide a reanalysis or reinterpretation—in preparation for subsequent processing for multi-document summarization. Inherent aspectual features are automatically extracted (using a large pre-stored database of English verbs (Dorr, 2001)) and are used for distinguishing between punctual events (e.g., *wink*) and events with duration (e.g., *run*) and also for facilitating the assignment of temporal interval/point information to an event.

An important contribution of this work is the extension of two different existing theoretical frameworks—Hornstein's 1990 theory of tense analysis and Allen's 1984 theory on event ordering—and the combination of both into a unified system for representing and constraining combinations of different event types (points, closed intervals, and open-ended intervals). The two frameworks are described further in Section 2.

Consider the (shortened and adapted) excerpts below from the Linguistic Data Consortium's Treebank-3 (1999),[3] where E_1 refers to the time of the event associated with the main (or *matrix*) clause and E_2 refers to the time of the event associated with the subordinate (or *adjunct*) clause.

(1) (i) Unitholders will receive two additional 55 cents-a-unit distribution payments *before* the trust is liquidated.
Temporal Relation: $E_1 < E_2$

[1] Pan et al. (2006) require both WordNet senses and human-annotated training data for deriving temporal relations. The work reported in this article differs in that no training is required and meaning-independent constraints are applied in order to determine temporal relations.

[2] For example, Lapata and Lascarides (2004) rely on the parser to provide relatively accurate information about attachment sites, although they acknowledge that there is unavoidable noise in the data. Our approach is intended to address different sources of noise in the data that could lead to faulty temporal conclusions.

[3] The LDC CD-ROM for Treebank-3 contains databases of disfluency annotated Switchboard transcripts (LDC99T42).

(ii) Predictably, guarantees outstanding have risen by 130 billions *while* direct loans outstanding have fallen by 30 billion.
Temporal Relation: $E_1 = E_2$

(iii) Anti-smoking advocates protested Philip Morris' campaign *after* the company distributed book covers promoting its products to school children.
Temporal Relation: $E_1 > E_2$.

We will see that, although the temporal-relation extraction task appears to be simple in the cases above (where the temporal relations <, =, and > mimic the semantics of the temporal connectives *before*, *while*, and *after*, respectively) the task is much more difficult when one considers the full range of tenses, lexical aspect, and aspectual perspectives.

Extraction of the temporal relation between the two verbs in each of the sentences above would be useful for multi-document summarization where such information plays a role in the ordering and fusing sentences from different (related) documents. For example, in the case of (1) (iii) above, if a multi-document summarizer had access to the chronology of E_1 and E_2, the summarizer might be able to order the following sentences (extracted from multiple documents) so that the text is more fluently presented:

(a) Anti-smoking advocates attacked tobacco giant Philip Morris' new cigarette packaging as an attempt to counter a government plan to add graphic health warnings to the packets.
(b) Many marketers say Morris' approach will be effective but they agree that the ads' implied smoking message is unmistakable.
(c) Philip Morris's anti-smoking ads make kids more likely to smoke.
(d) Philip Morris Cos. is launching a massive corporate advertising campaign that will put the tobacco giant's name in TV commercials.
(e) Some smoking opponents, wary of any help from tobacco companies, say their ads avoid mention of the harsh realities of smoking like lung cancer.

In the context of multi-document summarization, our goal is to accomplish a partial ordering among events in a sentence, from which we later induce a global ordering. Such information is important for tasks such as sentence fusion (Barzilay & McKeown, 2005) and sentence selection (Daume & Marcu, 2006). Specifically, given the event ordering inferred from sentence (1) (iii), a summarizer might produce a sentence ordering that focuses first on Morris' marketing campaign (b,d) and then on anti-smoking reaction (a,c,e).

The main result of this work is the successful incorporation of constrained linguistic theories of tense and aspect in a self-contained module that produces a list of possible temporal relations from a temporally-related matrix/adjunct pair. This module is designed to operate in the larger context of a full text planner, where its output may be further constrained. We show that our theoretical results have been verified in a large-scale corpus analysis. The framework is designed to inform a temporally motivated sentence-ordering module in an implemented multi-document summarization system (Zajic et al., 2005, Zajic, Dorr, Schwartz, & Lin, 2007), where issues concerning redundancy removal and sentence selection have already been addressed.

The next section describes the overall approach to extracting temporal relations from parsed sentences containing temporally related clauses and presents our theoretical results. Details are provided for each step of the approach, along with a number of examples. Following this, we present a corpus-based verification of our theoretical results to justify the linguistic constraints used in our temporal-relation extraction algorithm. We then discuss our approach and findings and present conclusions and future work.

2. Approach

Given a matrix clause dominating a temporal adjunct clause, our task is to infer the temporal interval relationship between the events associated with each of these clauses. We first extract *non-inherent* features (i.e., finiteness, non-finiteness, and aspectual perspective) directly from Penn Treebank tags in our parse trees, as in the work of Lapata and Lascarides (2004). We then take the analysis a step further by applying automatic

Table 1
Temporal/aspectual information inferred from Penn Treebank categories and lexical database specifications

Non-finite:
inf (VB), *-ing* form (VBG), *-en* form (VBN)
Finite:
present (VBZ, VBP), past (VBD), future (MD + VB)
(Non-Inherent) Aspectual Perspective:
simple (VBZ, VBP, VBD), prog (be-form + VBG), perf (have-form + VBN)
(Inherent) Lexical Aspect:
state[$-d$], activity[$+d, \pm a, -t$], achievement[$+d, +a, +t$], accomplishment[$+d, -a, +t$]

Table 2
BTSs, time intervals/points, CDTS, and temporal connectives used to infer Allen's interval relations

Basic Tense Structures (BTSs):
pres simp, pres prog ⇒ S,R,E
past simp, past prog ⇒ E,R_S
fut simp, fut prog ⇒ S_R,E
pres perf ⇒ E_S,R
past perf ⇒ E_R_S
fut perf ⇒ S_E_R
Time Intervals/Points:
Closed: E_s ●—● E_f Open: E_s ●—○ E_f Point: E_s,E_f ●
CDTS: Given two BTSs corresponding to a matrix/adjunct pair, the association of S and R points must not cross over
Temporal Connectives: *after*, *as*, *before*, *once*, *since*, *until*, *when*, *while*

techniques reported previously (Dorr & Voss, 1996; Dorr & Olsen, 1996; Olsen, Traum, van Ess-Dykema, & Amy Weinberg, 2000, 2001) to infer *inherent* aspectual features (i.e., lexical aspect). For this we use a combination of the verb's surface form in its given context and an aspectual specification provided in a large database of English verbs (Dorr, 2001). Verbs are thus classified using features shown in Table 1.[4]

Next, we compute a Basic Tense Structure (BTS) for each verb based on its tense and aspectual perspective. That is, we determine the placement of the speech time (S) and reference point (R) with respect to the event time (E) associated with each verb (Reichenbach, 1947). From the BTSs, we then infer a set of possible time points/intervals for each event; these are pared down subsequently using inherent and non-inherent features.

We then organize the BTS pair into a complete tense structure that is verified for validity using Hornstein's linguistic Constraint on Derived Tense Structures (CDTS) (Hornstein, 1990). The initial parse structure may then be revised (or later semantically reinterpreted) if there is a CDTS violation. Following this, we rule out certain unlikely tense combinations based on the temporal connectives relating the pairs of verbs (i.e., *after*, *before*, *while*, etc.).[5] Table 2 summarizes the types of information used for this process.

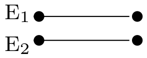
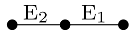
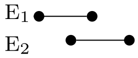
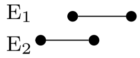
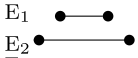
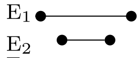
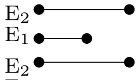
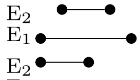
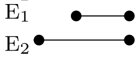
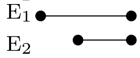
Finally, using the temporal connective and interval/point information, we determine the subset of Allen's 13 interval relations (Allen & Koomen, 1983; Allen, 1984)[6] that applies to the two event times, E_1 and E_2: *before* (<), *after* (>) *during* (d), *contains* (di), *overlaps* (o), *overlapped by* (oi), *meets* (m), *met by* (mi), *starts* (s), *started by* (si), *finishes* (f), *finished by* (fi), and *equal* (=). These are illustrated in Table 3, where each line indicates an interval. Note that there are no point intervals (i.e., all intervals are represented with a line between a start and end point) and all intervals shown here are closed (i.e., there are closed circles at either end). Shortly, we will see examples of how we extend this notation to cover both open intervals (indicated by an open circle) and point events (indicated by a single closed circle).

[4] The aspectual features associated with state, activity, achievement, and accomplishment (±d[ynamic], ±a[tomic], and ±t[elic]) will be described in a later section.

[5] The list of temporal connectives for this research was extracted from those that occur in the Treebank-3 hand-tagged corpus of 19,315 sentences, namely, *after*, *as*, *before*, *once*, *since*, *until*, *when*, and *while*. (Our corpus analysis is described in more detail in Section 3.)

[6] Recently, a set of temporal interval relations—or *RelTypes*—has been developed to represent 12 out of Allen's 13 relations in the TimeML annotation scheme. These have been used in a number of recent related studies, including in Mani et al. (2006).

Table 3
Allen's 13 interval relationships

$E_1 = E_2$			
$E_1 < E_2$		$E_1 > E_2$	
$E_1 m\ E_2$		$E_1 \text{mi} E_2$	
E_1 o E_2		E_1 oi E_2	
E_1 d E_2		E_1 di E_2	
E_1 s E_2		E_1 si E_2	
E_1 f E_2		E_1 fi E_2	

Input:

- An **input sentence** S consisting of two verbs V_1 and V_2 for events E_1 and E_2 and a temporal connective C that relates the two verbs.
- A **parse tree** P associated with S, in which V_1 and V_2 are associated with tenses T_1 and $T_2 \in$ {*present, past, future*} and aspectual perspectives A_1 and $A_2 \in$ {*simple, progressive, perfective*}.
- A **lexical specification** for verbs V_1 and V_2 consisting of inherent aspectual features F_1 and F_2, where $F_i \in \{\pm\text{atomic}, \pm\text{dynamic}, \pm\text{telic}\}$.
- A **set of Matrix/Adjunct pairs** MA initially containing the pair (V_1,V_2) and its associated parse tree P.

Output:

- The time interval/point representation for events E_1 and E_2, a set of temporal relations T between E_1 and E_2, and the (potentially corrected) parse tree P' associated with V_1 and V_2

Fig. 1. Input and output for temporal relation(s) extraction algorithm.

Fig. 1 formally presents the input/output for the temporal-relation extraction algorithm. The algorithm itself is shown in Fig. 2. Each step of the algorithm is described in more detail in the sections below.

2.1. Step 1: compute BTSs for matrix/adjunct verbs and construct CTS

In step 1, we compute the Basic Tense Structure (BTS) of the matrix and adjunct verbs from their tenses (pres, past, and fut) and aspectual perspectives (simp, perf, and prog). For past, present and future tenses, the relationship between the event time, E, and the speech time, S, may be characterized as $E = S$ for present tense; $E < S$ for past tense; and $S < E$ for future tense. However, as one considers tenses like past perfect (e.g., *John had left the office by 3:00 pm*), present perfect (e.g., *Mary has left the office*), and future perfect (e.g., *John will have left the office by 3:00 pm*), the speech time and event time are not sufficient for distinguishing the tenses. For example, in both the past perfect tense and the past tense, event time precedes speech time, that is, $E < S$. To encode the distinction between these, Reichenbach (1947) introduced a reference timepoint, labeled R, that provides enough information to characterize all of the tenses that occur in natural language.

To illustrate R, consider the past perfect tense. There is some point in time that occurs between event time and speech time. Prior to this intermediate point in time, the event being described has already occurred; thus,

Procedure:

1. Using T_1, T_2, A_1 and A_2 compute the corresponding BTS sets, BTS_1 and BTS_2 (Table 2) and a set of Event/Speech relationships and possible interval/point representations (Table 4); organize the BTSs into a complex tense structure (CTS).
2. Apply CDTS to the CTS containing BTS_1 and BTS_2 (Table 5). If there is a violation and there is a dominating or dominated verb phrase (VP), parse-tree reanalysis may be required:
   a. Move the temporal adjunct clause downward to the next lower VP or upward to the next higher VP (unless this reattachment has already been tried).
   b. Using the head of this VP as the new V_1 (and its associated features, F_1, A_1, T_1), add (V_1,V_2) along with the reanalyzed parse tree to MA.
   c. If the violation survives reanalysis, retain the original (V_1,V_2) for later reinterpretation.
   d. Go to step 1 (until no more reattachment points).
3. Sort MA by corpus-based frequency according to occurrences of tense pairs for the given connective C (Table 6).
4. For each pair (V_1,V_2) in MA: Using F_1, F_2, A_1, and A_2, pare down the set of possible intervals/points for events E_1 and E_2. (Figure 5.)
5. For each pair (V_1,V_2) in MA: Using the set of possible temporal intervals (from Step 4), the temporal connective C, and the BTSs (from Step 1), determine the set of possible interval relations $T \in \{<, >, =, d, di, o, oi, m, mi, s, si\}$ between E_1 and E_2. (Tables in Section 2.5.) If no relations are found, this matrix-adjunct pair and its associated parse tree are ruled out as possibilities (deleted from MA). Otherwise, the relation T is stored along with (V_1,V_2) in MA.
6. Return the time interval/point representation for events E_1 and E_2, the set of temporal relations T for the highest ranked (V_1,V_2) pair in MA, and the (potentially corrected) parse tree P' associated with this pair. (Reinterpretation may be applied to pairs retained in Step 2c.)

Fig. 2. Algorithm for extraction of temporal relation(s) from a matrix/adjunct pair.

```
(S1
  (S (NP-SBJ (NP (NNP John)))
     (VP (VBD caught) (NP (PRP his) (NN plane))
       (SBAR-TMP (IN before)
         (S (NP-SBJ (NP (NNP Mary))) (VP (VBD arrived)))))))
```

Fig. 3. Penn Treebank representation of temporally related matrix/adjunct pair.

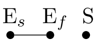
for the past perfect tense, we may say that $E < R < S$. The key idea is that certain linear orderings of the three time points (E, R, and S) get grammaticalized into basic tenses. English uses six basic tenses, as shown in the top part of Table 2. Note that, in the BTS representation, the S, R, and E points may be separated by a line (in which case, the leftmost point is interpreted as temporally earlier than the other) or by a comma (in which case, the points are interpreted as contemporaneous).

Step 1 of our algorithm uses this table to determine the appropriate BTS for each verb, but it must first extract the tenses and aspectual perspectives from the input sentence. To achieve this, a set of tense/aspect extraction templates are applied to a Penn Treebank-style analysis of the input sentence (e.g., the output of parsers by Collins, 1996 or Charniak, 2000). For example, a Penn Treebank-style analysis of *John caught his plane before Mary arrived* is shown in Fig. 3, where the matrix clause starts with the first S and the adjunct clause begins with the SBAR-TMP node. Note that we examine only the matrix/adjunct pairs that contain an SBAR-TMP node, in an attempt to separate out temporally related clauses from those that are causally related. The set of templates used to extract tense/aspect information from trees of this form are similar to those of Lapata and Lascarides (2004).[7] Details can be found in Dorr and Gaasterland (2007).

Another component of step 1 is the determination of the relationship between the event time E and the speech time S. From these, we can compute a set of possible time intervals/points corresponding to the event. Given that the original BTS framework does not cover events with duration over some interval in time, we have designed and implemented an extended framework that accommodates both point and interval events. We consider the event E to have two time-stamps, a starting time-stamp E_s and a finishing time-stamp E_f. Either of E_s and E_f may be *open* or *closed*. We assume speech time S to be a point interval, i.e., an interval with identical start and stop times.

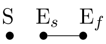
We shall now inspect each configuration of E_s and E_f and S for E_s and E_f open and closed, respectively, and we will derive the set of BTSs that preserve the relationship in each case. Note that, due to ambiguity, certain of the tense realizations (e.g., *had run*) appear in more than one E/S configuration.

Consider the ordering $E_s < E_f < S$. The interval relationship is $E_{sf} < S$ as in *He* {*ran, was running, had run, has run*} *for an hour*:

(2) 

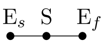
For this configuration, three BTSs preserve the relationship: past *E,R_S*, past perfect *E_R_S*, and present perfect *E_S,R*.

For the opposite configuration, as in *He* {*will run, will be running, will have run, is running*} *for an hour*,

(3) 

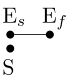
there are three possible tenses that preserve the relationship between *E* and *S*: future *S_R,E*, future perfect *S_E_R*, and present *S,R,E*.

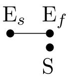
When the start time for an event precedes the speech time and the stop time follows the speech time, as in *He* {*runs, is running, had run, has run*} *for an hour*,

(4) 

a decision can be made to focus on the ongoing event E_{sf}, the starting point E_s, or the finishing point E_f, in which case that point is used to determine the possible basic tenses.

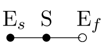
When either the start time or the stop time coincides with the speech time, as *He* {*runs, is running, will run, will be running, will have run*} *for the next hour* or *He* {*ran, was running, had run, has run, is running*} *for the last hour*,

(5) 

(6) 

a decision must be made about whether to focus on the entire event's relationship to *S* or on either start time or stop time.

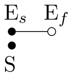
Now let us consider intervals that have an open stop time, i.e., an event or state that is ongoing. If the start time precedes speech time, as in *He* {*is, was, has been*} *running*,

(7) 

[7] These templates were developed in 2003 and further enhanced in 2004, following an earlier draft of this work (Dorr & Gaasterland, 2002). Lapata and Lascarides (2004) later developed a set of templates with the same basic idea. The software that uses these templates is available at: ftp://ftp.umiacs.umd.edu/pub/~bonnie/CDTS-Solution-2006.lsp.

the event or state is true now and will continue to be true for some period of time. A decision must be made whether to focus on the start time (in which case, E_s is used to determine the set of tenses) or to focus on the ongoing event (in which case, $E_{sf} \leqslant S$ is used).

If the start time is the same as the speech time, then the remainder of the event is in the future (i.e., $E_s = S < E_f$), as in *He is running*:

(8) 

Alternatively, if the start time is in the future, then the whole event is in the future (i.e., $S < E_s \leqslant E_f$), as in *He will be running*:

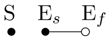
(9) 

Table 4
Step 1 of Algorithm in Fig. 2: using tense (pres, past, fut) and aspectual perspective (simp, perf, prog), compute BTS and determine E/S relationship and interval/point representation

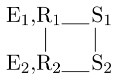
Interval/point rep	E/S relationship	Allowable BTSs
E_s E_f S	$E_s < E_f < S$	E_{sf},R_S (past simp/prog.) $E_{sf}\_R\_S$ (past perf.) E_{sf}_R,S (pres. perf.)
S E_s E_f	$S < E_s < E_f$	S_R,E_{sf} (fut. simp/prog.) $S_E_{sf}_$R (fut. perf.) S,R,E_{sf} (pres. simp/prog.)
E_s S E_f	$E_{sf} = S$	S,R,E_{sf} (pres simp/prog.)
	$E_s < S$	$E_s\_R\_S$ (past perf.) E_s_R,S (pres. perf.)
	$S < E_f$	S_R,E_f (fut. simp/prog.) $S\_E_f\_R$ (fut. perf.)
E_s E_f / S	$E_s = S$	S,R,E_s (pres. simp/prog.)
	$S < E_f$	S_R,E_f (fut. simp/prog.) $S\_E_f\_R$ (fut. perf.)
	$S = E_s < E_f$	S,R,E_{sf} (pres. simp/prog.) S_R,E_{sf} (fut. simp/prog.) $S\_E_{sf}\_R$ (fut. perf.)
E_s E_f / S	$E_s < S$	E_s,R_S (past simp/prog.) $E_s\_R\_S$ (past perf.) E_s_R,S (pres. perf.)
	$E_f = S$	S,R,E_f (pres. simp/prog.)
	$E_s < E_f = S$	S,R,E_{sf} (pres. simp/prog.) E_{sf},R_S (past simp/prog.) E_{sf}_R,S (pres. perf.)
E_s S E_f	$E_{sf} = S$	S,R,E_{sf} (pres. prog.)
	$E_s < S$	$E_s\_R\_S$ (past prog.) E_s_R,S (pres. perf. prog.)
E_s E_f / S	$E_s = S < Ef$	E_s,R,S (pres. prog.)
S E_s E_f	$S < E_s \leqslant E_f$	S_R,E_s (fut. prog.)
E_{sf} S	$E_{sf} < S$	E_{sf},R_S (past simp/prog.) $E_{sf}\_R\_S$ (past perf.) E_{sf}_R,S (pres. perf.)
E_{sf} / S	$E_{sf} = S$	S,R,E_{sf} (pres. simp/prog.)
S E_{sf}	$S < E_{sf}$	S_R,E_{sf} (fut. simp/prog.) $S\_E_{sf}\_R$ (fut. perf.)

Finally, let us consider intervals that are actually points: i.e., $E_s = E_f$. For $E_{sf} < S$ (e.g., *He winked*), the set of past tenses can be used. For $E_{sf} = S$ (e.g., *He winks*), only the present tense can be used. For $E_{sf} > S$ (e.g., *He will wink*), the set of future tenses can be used.

Table 4 shows the compilation of the analysis above. From the interval/point representations (column 1) and E/S relationships (column 2), we have computed all allowable BTSs for closed intervals, points, and open intervals for each possible relationship of the interval to S (column 3). Note that the original BTS analysis of Reichenbach (with point events) only covers the last three cases in the table.

Step 1 uses Table 4 as follows: once the BTS for each verb is computed from its tense/perspective, the rows containing a BTS (in column 3) matching that of each verb are selected and, from the selected rows, the interval/point representation (column 1) and E/S relationships (in column 2) are selected for each verb. These are retained for consideration during later processing (e.g., in Step 4).

Once two BTSs are assigned—one for each event—we adopt a framework proposed by Hornstein (1990) to organize the two BTSs into a Complex Tense Structure (CTS) as follows: the BTS of the first (matrix) clause is written over the BTS of the second (adjunct) clause and the S and R points are then associated. In the general case, the association of the S and R points may force the R point in the second BTS (R_2) to be moved so that it is aligned with the R point in the first BTS (R_1). (In the current example, the two R points are already aligned.) The second E point (E_2) is then placed accordingly. For example, the CTS for the sentence *John caught his plane before Mary arrived* would be specified as follows:

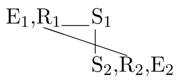


As we will see next, the CTS representation is used as the basis for application of a linguistic constraint that allows us to detect illegal clause combinations that may require parse reanalysis or semantic reinterpretation.

2.2. Step 2: apply CDTS to the CTS and (possibly) reanalyze the parse

Once we have determined the appropriate BTSs for the matrix and adjunct verbs, Step 2 imposes a linguistically-motivated constraint on the CTS associated with the sentence, to ensure that the parser (or parse-tree annotator) has provided an appropriate syntactic structure. If not, then a reanalysis or reinterpretation may be needed, as we will see shortly.

The constraint that is applied is called the *Constraint on Derived Tense Structures* (CDTS), stated in Table 2. Hornstein (1990) has argued persuasively that all sentences containing a matrix and adjunct clause are subject to this linguistic (syntactic) constraint on tense structure *regardless* of the lexical tokens included in the sentence. This constraint requires that the association of S and R points not involve crossover in a CTS, as in the following case:



This CTS would be associated with a bad sentence such as *John caught his plane before Mary arrives*. Here, the association of R_2 and R_1 violates the CDTS, thus ruling out the sentence. Note that the CDTS is a syntactic restriction on the manipulation of tense structures, not on the temporal interpretation of tensed sentences. Thus, the constraint holds regardless of the lexical token that is chosen as the connecting word between the two events: **John caught his plane* {*as, before, after, as soon as, while*} *Mary arrives.*

As an initial test of the CDTS predictions above, we conducted an 8-person study (spring, 2003) involving native English speakers who were asked to judge 16 representative sentences—each sentence with different BTS combinations, including the progressive perspective. Of the 16 sentences, six cases were ruled out by CDTS. Of these, at least 75% (six out of eight) of the subjects also ruled it out. This argues strongly for a parser reanalysis or non-temporal interpretation (e.g., detecting habitual, generic, and causal relationships) when such cases are found. Section 3 presents a detailed corpus analysis that backs up the findings of this smaller-scale study.

Table 5
Step 2 of Algorithm in Fig. 2: apply CDTS to determine whether the matrix/adjunct tense pair is allowable

Clause	Fut tense	Past tense	Pres tense
Matrix:	{fut, fut perf}	{past, past perf}	{pres, pres perf}
Adjunct:	{pres, pres perf, fut, fut perf}	{past, past perf}	{pres, pres perf}

```
((S
  (S-TPC-3
   (SBAR-TMP (IN AS)
    (S (S (NP-SBJ (DT SOME) (NNS SECURITIES)) (VP (VBP MATURE)))
     (CC AND)
     (S (NP-SBJ-1 (DT THE) (NNS PROCEEDS))
      (VP (VBP ARE) (VP (VBN REINVESTED) (NP (-NONE- *-1)))))))
   (|,| |,|) (NP-SBJ-2 (DT THE) (NNS PROBLEMS))
   (VP (MD OUGHT) <=== Correct attachment point for SBAR-TMP
    (S (NP-SBJ (-NONE- *-2)) (VP (TO TO) (VP (VB EASE))))))
  (|,| |,|) (NP-SBJ (PRP HE))
  (VP (VBD SAID)  <==== Incorrect attachment point for SBAR-TMP
      (SBAR (-NONE- 0) (S (-NONE- *T*-3)))) (\. \.)))
```

Fig. 4. Example of incorrect high attachment of adjunct clause: *as some securities mature and proceeds are reinvested, the problems ought to ease, he said.*

Interestingly, of the 10 cases that the CDTS did not rule out, there were two cases that the majority of the eight subjects did not like. This suggests that, if we rely solely on CDTS for deciding whether to reanalyze the sentence, we are taking a conservative approach, i.e., reanalysis would not be indicated for all cases that humans might consider to be incorrect.[8]

We have precompiled the allowable tense pairs by combining each basic tense with every other basic tense and then ruling out those that are disallowed by the CDTS. This precompilation procedure produced the table of allowable tense pairs shown in Table 5. Here, each Matrix tense in a particular column may be legally paired with each Adjunct tense in that same column (e.g., *past* may be paired with *past* and *past perf* in the **Past Tense** column). Step 2 of our algorithm ensures that any BTS pair that is not consistent with this table is de-prioritized as described below.

In our corpus analysis (described in Section 3), we found several cases where the CDTS was violated, but the parser analysis was incorrect. An example of an incorrect analysis is shown in Fig. 4, with the incorrect attachment point marked. The parse violates the CDTS because the verb phrase headed by the present-tense verb *mature* is attached too high, under the past-tense verb *said*, thus producing a past/present combination that is not included in Table 5. It should be attached, instead, to the verb phrase headed by *ought* (a modal which, according to Hornstein, is analyzed as a present-tense verb).

Our approach to reanalyzing this is to first try to attach the adjunct clause under the lower VP (marked with ''Correct attachment point'') and then to attempt the CDTS again (which succeeds this time). If it fails, then a higher attachment point is sought. Other types of reanalysis are discussed in Section 3.1. In cases where reanalysis does not lead to satisfaction of the CDTS, the original BTS is retained for future reinterpretation, as discussed in Section 3.2. Note that, if reanalysis results in the elimination of a prior choice of BTS, the corresponding time points and E/S relationships (from Step 1) are also eliminated as possibilities.

2.3. Step 3: prioritize tense pairs based on corpus analysis

If a reanalysis has taken place, Step 3 must prioritize the options resulting from the new attachment point(s), in which case there are potentially several tense combinations under consideration. To achieve this,

[8] The two cases—where at least 63% said the sentence was bad—are: *John caught his plane before Mary was arriving* and *John had caught his plane before Mary was arriving*. Note that the CDTS treats these cases as if the *was arriving* is a past-tense sequence. So the CDTS licenses these sentences, taking them to be on a par with the past-tense analogs, *John caught his plane before Mary arrived* and *John had caught his plane before Mary arrived*, both of which would be acceptable.

Table 6
Step 3 of Algorithm in Fig. 2: prioritize tense pairs with respect to temporal connective **AFTER** using Treebank-3 Corpus Analysis

Connective Table for AFTER	
Total	**Matrix/Adjunct Pairs**
151	[past simp]/[past simp]
35	[past simp state]/[past simp]
17	[past simp]/[past simp state]
10	[past simp state]/[past simp state]
7	[simp gerund]/[past simp], [past simp]/[past perf]
6	[past perf]/[past simp]
5	[fut simp]/[pres simp], [pres simp]/[pres simp state]
4	[pres simp state]/[pres simp state]
3	[fut simp state]/[pres simp state], [fut simp state]/[pres simp], [fut simp]/[pres simp state], [pres simp]/[pres perf], [pres simp]/[pres simp], [past perf]/[past simp state], [past simp state]/[past perf]
1	[past simp]/[simp gerund], [fut simp state]/[pres perf], [fut simp]/[pres perf], [simp gerund]/[pres perf], [simp gerund]/[pres simp state], [simp gerund]/[past perf], [simp gerund]/[simp gerund], [pres simp state]/[pres simp], [past prog]/[past perf], [past prog]/[past simp]

a combination ranking scheme that uses a Treebank-based corpus analysis is employed. Specifically, the top-choice tense combination associated with the current temporal connective (i.e., C in the algorithm in Fig. 2) is selected from a ranked list of possibilities for that connective. An example of ranked possibilities is shown in Table 6 for the connective *after*.

In these tables, in addition to the tense and aspectual perspectives that define the standard BTSs (i.e., {pres, past, fut} and {simp, prog, perf}), we have also included *gerund* (the non-finite *-ing* form of Table 1). According to Hornstein (1990), gerunds correspond to R,E relations in the absence of S,R relations; thus, there are no CDTS violations for combinations including gerunds, e.g., *While acknowledging his presence, she* {*ignored, ignores, will ignore*} *him*. The table also refers to one component of inherent aspectual features—state vs. non-state (to be described below)—which provides a more refined prioritization of tense combinations for each connective.

2.4. Step 4: pare down the number of temporal interval/point possibilities

Recall that a set of possible interval/point representations were selected in Step 1. These possibilities must further be constrained according to both *inherent* and *non-inherent* aspectual features (see bottom half of Table 1) associated with the two verbs in the input. Step 4 achieves this by imposing constraints consistent with those proposed by Dorr (1992), Olsen (1997) and Dowty (1979) in order to arrive at a smaller set of interval/point possibilities.

As indicated earlier (in Table 1), aspect is taken to have two components, *non-inherent* features (e.g., those features that define the perspective such as simple, progressive, and perfect) and *inherent* features (e.g., those features that distinguish between states and events). Non-inherent features are dependent on temporal context; thus, they are not stored with the lexical item and may be controlled during language generation. The non-inherent aspectual features define the aspectual *perspective* of the verb phrase and may be viewed in terms of the following two contrasts: (1) *perfect vs. non-perfect* and (2) *progressive vs. simple*.

These are distinguished from inherent aspectual features (i.e., *lexical* aspect), which are stored with the lexical item and correspond to primitive units that distinguish, e.g., states from other types of events. A number of aspectually oriented representations have been proposed for inherent features that readily accommodate the types of aspectual distinctions that are of concern here (Bach & Harms, 1968; Comrie, 1976; Crouch & Pulman, 1993; Dowty, 1979; Hwang & Schubert, 1994; Jackendoff, 1983, 1990; Mourelatos, 1981; Nirenburg & Pustejovsky, 1988; Olsen, 1994; Passonneau, 1988; Pustejovksy, 1988, 1991a, 1991b, 1993; Steedman, 1997; Vendler, 1967).

The current model implements an aspectual classification using three features proposed by Bennett, Herlick, Hoyt, Liro, and Santisteban (1990) following the framework of Moens and Steedman (1988): [±dynamic] (i.e., events vs. states), [±telic] (i.e., culminative events (transitions) vs. non-culminative events (activities)),

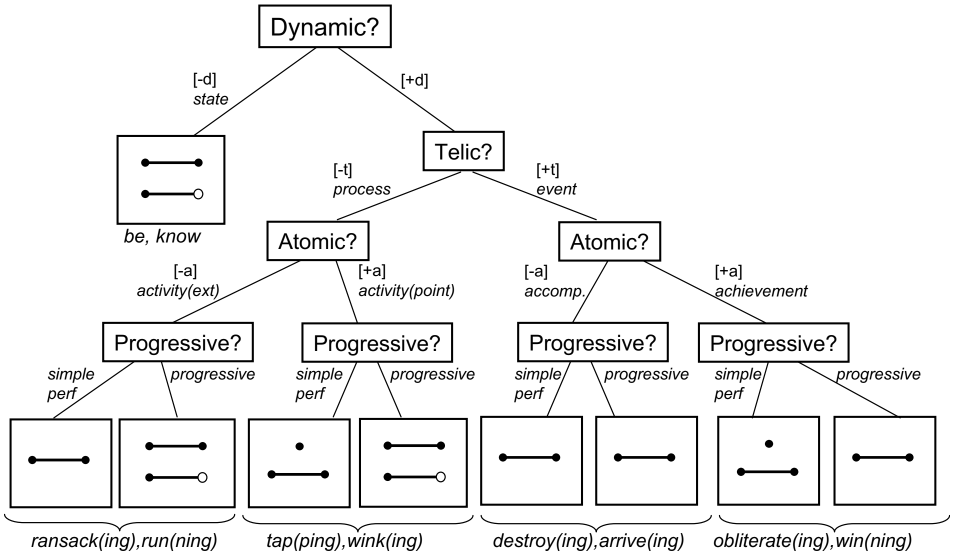


Fig. 5. Step 4 of Algorithm in Fig. 2: pare down the number of temporal interval/point possibilities.

and [±atomic] (i.e., point events vs. extended events).[9] In our implementation, all inherent features (±atomic, ±dynamic, ±telic) are derived using techniques described in Dorr (1992), Olsen (1997) and Dowty (1979) in conjunction with the aspectual specification provided in a publicly available English lexicon of 10,000 verb entries (Dorr, 2001).

Consider the two verbs *ransack* and *obliterate*. These are distinguished by means of aspectual features: $[+d, -t, -a]$ (extended activity) for the verb *ransack* and $[+d, +t, +a]$ (achievement) for the verb *obliterate*. Although these two verbs are semantically similar, the feature-based framework of Dorr (2001) accounts for surface distinctions such as the following:

10 (i) John ransacked the house every day.
(ii) ∗John obliterated the house every day.

We have recast a set of aspectual constraints on the relationship between inherent verb features and the progressive/simple, perfect/non-perfect distinction in terms of a decision tree, as illustrated in Fig. 5. This tree is the basis for the automatic procedure in step 4, i.e., it allows us to pare down the number of interval/point possibilities produced by step 1 for a particular verb, *V*.

The first question asked in the decision tree is whether *V* is a dynamic verb; if not, it is stative $[-d]$ and is either a closed interval, as in *He was angry (until Mary approached him)*, or an open interval, as in *He knew Spanish (when Mary taught him English)*. Either way, no further questions are asked—consistent with Dowty's constraint on states, i.e., that a state cannot participate in the progressive construction: **I was knowing the answer*. Note that, if *V* is a state, it necessarily has duration; it cannot be a point. Thus, this part of the decision tree pares down the interval/point choices made for *V* in step 1 to just closed and open intervals; points are eliminated.

If *V* is not dynamic, it is either a process $[-t]$ or an event $[+t]$; if the former, it is either an extended activity $[-a]$ or a point activity $[+a]$; if the latter, it is either an accomplishment $[-a]$ or an achievement $[+a]$. Note that, if *V* is $[-a]$, it can never be a point-interval; thus, points that were assigned to *V* in step 1 are eliminated. Olsen (1997) provides a *privative* analysis that predicts this non-correspondence; she adopts the marked feature [+durative] which cannot be changed to its unmarked counterpart [∅durative].

[9] Androutsopoulos (1999) provides a coarser-grained analysis of aspectual categories of verbs, classified in a specific (airport) domain. Our goal is to provide a wide range of verbs, taking into account values of durativity, telicity, and atomicity—for broader applicability.

On the other hand, if *V* is inherently [+*a*], it *can* be associated with either an open or closed interval, as in iterative readings of punctual verbs: *He* {*has winked, was winking, winked*} *for an hour* or *He* {*has won, is winning, won*} *several races today*. Thus, such selections made in step 1 for *V* are retained. This is consistent with aspectual frameworks by Dorr (1992) and Olsen (1997) where an inherently [+*a*] verb (e.g., *win*) is interpreted as, or *coerced* to, [−*a*] in certain contexts. Olsen's privative analysis provides a more systematic account than Dorr's coercion analysis: an achievement is inherently unmarked for durativity ([∅durative]) but can become marked ([+durative]), behaving more like an activity in the context of a progressive morpheme ("-ing" in English).

Once the values of inherent features have been ascertained, the decision tree asks whether *V* is progressive. Each case is slightly different. If *V* is an extended activity, only the progressive form licenses the acceptability of an open interval (e.g., *I was ransacking the house when he arrived*); thus, if *V* is simple, all open intervals selected in step 1 are eliminated. If *V* is a point activity, the simple form licenses both a point-interval (e.g., *He winked*) and a closed interval (e.g., *He winked for hours*), whereas the progressive form licenses both an open interval (e.g., *He was coughing when John walked in*) and a closed interval (e.g., *He was coughing until John walked in*).

If *V* is an accomplishment or achievement—the constraints operate similarly to those imposed on extended activities and point activities, respectively, except that there are no open intervals allowed: In all cases, *V* has a guaranteed state of completion (the defining feature for *telic* verbs), e.g., *They won the game as soon as John got a goal*. The simple form represents a complete action as a (e.g., *John won/ran*) whereas the progressive represents an action that is not necessarily complete (e.g., *John was winning/running*). Note that this scheme provides the necessary mechanism for retaining the non-point interval reading of inherently atomic events—the desired result for either analysis, coercion or privative.

For the purpose of the discussion in the next section, we will refer to closed intervals as **C**, open intervals as **O**, and point-intervals as **P**.

2.5. Step 5: determine set of temporal relations

Once the possible temporal points/intervals have been pared down for each of the two verbs in a CTS, step 5 uses these—in conjunction with the temporal connective and BTS combinations—to select a set of possible interval relations between the two verbs.

Each temporal connecting word may correspond to several temporal interval relationships. Conversely, each temporal interval relationship corresponds to multiple temporal connecting words. For example, in terms of Allen's temporal relations, the word *while* can represent =, *oi*, *s*, *d*, or *f*, and the temporal interval relationship *f* can be expressed as *after* or *while*. In addition, the tense and time interval/point of the matrix and adjunct verb can alter the meaning of the connecting word. For example, if a past/past BTS combination contains two open intervals **O**, the connecting word *before* is endowed with the possible meanings *o*, *m*, *fi*, and <.

In the following sentences, *before* covers all four temporal interval relationships simultaneously:

(11) (i) John was unhappy before Mary was walking outside. (**O/O**)
(ii) John was happy before Mary was sick. (**O/O**)

Since the matrix phrase is either a progressive event or a simple state, the intervals are open, and the adjunct phrase might start after the matrix finishes (<), as the matrix finishes (*m*), or before the matrix finishes (*o, fi*).

On the other hand, if the second interval of the past/past BTS combination is closed **C**, the same connecting word is interpreted only as <:

(12) (i) Mary was drawing a circle before John wrote a letter. (**O/C**)
(ii) Mary was sick before John wrote a letter. (**O/C**)

For each temporal connective, we have conducted an extensive analysis of sample sentences—such as (11) (i)–(ii) and (12) (i)–(ii)—and have determined the possible temporal interval meanings associated with nine

Table 7
Step 5 of Algorithm in Fig. 2: determine the set of temporal relations for past/past

Mat/Adj	AFTER	BEFORE	SINCE	UNTIL	WHEN	WHILE
Temporal Relation Table for Past/Past						
C/C	>	<	m f>	s m	oi s si d f >	=o oi s d f
C/O	oi mi f >	o m fi <	–	s m	= oi s si d mi f	= o oi s d f
C/P	>	<	m f >	s m	oi s d f >	= o oi s d f
O/C	>	<	–	s m	= o oi s si d di m mi f fi >	= o oi s d f
O/O	oi mi f >	o m fi <	–	s m	= o oi s si d di mi f	= o oi s d f
O/P	>	<	–	s m	oi s d f >	= o oi s d f
P/C	>	<	m f >	s m	oi s si d	= s d f
P/O	oi m f >	o m fi <	–	s m	oi s si d >	= s d f
P/P	>	<	m f >	s m	= oi s d >	= s d f fi

interval combinations corresponding to all legal BTS combinations. We examined Treebank-3 examples for each of the matrix/adjunct combinations in Table 6 for *after*, and also for other connectives not shown here.[10]

From this information, we have constructed *analysis charts*, which associate temporal interval relationships with connecting words for each BTS/interval combination. These charts also indicate the aspectual categories, i.e., states, activities, achievements, accomplishments, as an additional piece of information. However, the temporal intervals/points derived from these categories (in step 4) are what drive the interpretation of the temporal connectives. That is, the distinction between activities, achievements, accomplishments has no impact on the interpretation of the temporal connective. Thus, the analysis charts have been compiled into more succinct, *temporal relation tables*—where each *row* corresponds to a particular combination of time intervals/points (**O**, **C**, or **P**), and each *column* corresponds to a specific temporal connective.[11] The cells of the table contain different subsets of Allen's relations corresponding to the temporal interpretation of the connective in that column. For example, the temporal relation table for *after*, *before*, *since*, *until*, *when*, and *while* that apply to the Past/Past BTS combination is given in Table 7.

Note that certain combinations have no temporal interpretation and thus have no value in the table, e.g., the **P/O** sense of *since* in *He won the race since Mary was angry*. In general, such interpretations are available only under the causal reading and thus are not assigned a temporal relation.

Once step 5 has determined the set of possible temporal relations for the given matrix/adjunct pair, step 6 returns this result along with the time interval/point representation for each verb, and the (potentially corrected) parse tree P' associated with this pair. The temporal relations may then be passed forward to a sentence-ordering module for a multi-document summarization system.

3. Corpus-based verification of theoretical results

We conducted a corpus-based analysis on the sentences of the human-tagged Treebank-3 data in order to verify the use of Hornstein's CDTS as a practical constraint on tense combinations. Our goal was to validate our technique for reanalyzing temporally conjoined clauses that were incorrectly annotated and also to determine the types of new temporal or non-temporal reinterpretations that might be indicated by a CDTS violation. Interestingly, we found that—although this corpus was not automatically parsed—the number of human errors in the parse-tree annotations was high enough to test the CDTS and the reanalysis component.

Verification of the CDTS involved several "counting" experiments. We built a Lisp program to analyze all 19,315 sentences of Treebank-3. Of these, 2411 were found to contain a temporal connective—tagged by the human as SBAR-TMP. We counted the number of occurrences of different types of Matrix/Adjunct clauses and checked for consistency with Hornstein's analysis. We found that there were a total of 195 apparent CDTS violations out of 2411 cases—about 8% of all temporally conjoined sentences.

[10] Space limitations preclude the inclusion of seven additional connective tables, but see Dorr and Gaasterland (2007) for more details.
[11] Details of the analysis charts and the corresponding (more succinct) temporal relation tables are in Dorr and Gaasterland (2007).

Table 8
Disallowed and allowed tense combinations in Treebank-3

Disallowed		**Allowed**	
Tense Pair	**Count**	**Tense Pair**	**Count**
Fut/Past	0	Fut/Pres	126
Fut/Past Perf	0	Fut/Pres Perf	7
Fut Perf/Past	0	Fut/Fut	2
Fut Perf/Past Perf	0	Fut/Fut Perf	0
Past/Fut	0	Fut Perf/Pres	1
Past/Fut Perf	0	Fut Perf/Pres Perf	0
Past/Pres	36	Fut Perf/Fut	0
Past/Pres Perf	1	Fut Perf/Fut Perf	0
Past Perf/Pres	1	Past/Past	1019
Past Perf/Pres Perf	0	Past/Past Perf	18
Past Perf/Fut	0	Past Perf/Past	36
Past Perf/Fut Perf	0	Past Perf/Past Perf	0
Pres/Fut	0	Pres/Pres	513
Pres/Fut Perf	0	Pres/Pres Perf	20
Pres/Past	71	Pres Perf/Pres	21
Pres/Past Perf	1	Pres Perf/Pres Perf	14
Pres Perf/Past	63	Gerund/Another Tense	67
Pres Perf/Past Perf	0	Another Tense/Gerund	49
Pres Perf/Fut	0	Gerund/Gerund	19
Pres Perf/Fut Perf	0		
Fut/Unknown	1		
Past/Unknown	3		
Past/Unknown	1		
Pres/Unknown	8		
Pres/Unknown	1		
Unknown/Past	2		
Unknown/Past	1		
Unknown/Pres	1		
Unknown/Pres	4		
Total	195	Total	1931

The full set of results is grouped into **Disallowed** (CDTS violation) and **Allowed** (no CDTS violation) as shown in Table 8. The disallowed cases corresponded to those where the CDTS could not match the human-annotated matrix or adjunct clause to a legal basic tense; in such cases, the CDTS automatically assigned the label ‘‘Unknown’’.

Note that the total of allowed and disallowed cases was only 2126, not 2411. This is due to the lack of applicability of CDTS to two categories of tense pairs: (1) infinitivals—222 cases (9%), e.g., *He said he told clients to BUY selected West German blue chips [after] they FELL by about 10%*; and (2) adjectival clauses—63 cases (3%), e.g., *Superconductors CONDUCT electricity [when] COOLED*. If we treat infinitives and adjectivals the same way that gerunds are treated by Hornstein (i.e., gerunds may be paired up with any other tense, as in *He {took, takes, will take, was taking, is taking} no risks while traveling around the country*), there would in fact be no CDTS violations among the $222 + 63 = 285$ sentences. Disregarding these two categories, there were 1931 sentences out of 2126 that conform to the CDTS—i.e., a rate of 91% constraint satisfaction in Treebank-3.

Our analysis of the remaining 195 disallowed cases was done manually to gain a better understanding of where (and why) a CDTS violation occurred and what features of such cases could prove useful for an NLP application such as summarization, e.g., the presence of a habitual, generic, or causal relationship.

Table 9 shows that the violation types fell under two broad headings: (1) Those that were subject to reanalysis (and subsequent re-application of the CDTS); and (2) Those that were indicative of a new temporal or non-temporal reinterpretation (marked *Reinterpretation required* in column 2).

We discuss each of these categories below. In the associated examples, we use uppercase for matrix/adjunct verbs and brackets ([ ]) for the temporal connective.

Table 9
Counts of pre- and post-reanalysis CDTS violations

Tense pair	Violation	Violation pre-count	Reanalysis count	Violation post-count
Past/Pres	Faulty Attachment (said-quote)	15	15	0
	Faulty Attachment (other)	1	1	0
	Incorrect Tense annotation	2	2	0
	Reinterpretation required	18	–	18
Past/Pres Perf	Reinterpretation required	1	–	1
Past Perf/Pres	Incorrect Tense annotation	1	1	0
Pres/Past	Incorrect Tense annotation	6	6	1
	Faulty Attachment (says-quote)	12	12	0
	Faulty Attachment (other)	3	3	1
	Reinterpretation required	50	–	50
Pres/Past Perf	Reinterpretation required	1	–	1
Pres Perf/Past	Reinterpretation required	63	–	63
Fut/Unknown	Incorrect POS (Unknown → Pres)	1	1	0
Past/Unknown	Incorrect POS (Unknown → Past)	3	3	0
	Incorrect POS (Unknown → Past Perf)	1	1	0
Pres/Unknown	Incorrect POS (Unknown → Pres)	8	8	0
	Incorrect POS (Unknown → Untensed)	1	1	0
Unknown/Past	Incorrect POS (Unknown → Past)	2	2	0
	Incorrect POS (Unknown → Pres)	1	1	1
Unknown/Pres	Incorrect POS (Unknown → Pres)	1	1	0
	Incorrect POS (Unknown → Pres)	4	4	0
Total		195	62	136

3.1. Syntactic reanalysis

As shown in Table 9, the CDTS identified 62 cases for possible reanalysis, i.e., Treebank-3 sentences that were potentially mis-annotated by the human. Our analysis revealed that these cases corresponded to incorrect part-of-speech tags, incorrect tense annotations, and faulty attachments.

3.1.1. Incorrect POS tags

There were 22 cases of incorrect Treebank-3 part-of-speech tags, referred to as *Incorrect POS*. For example, the verb *fades* was incorrectly tagged as a noun (NNS) instead of a present-tense verb (VBP) in the following sentence:

(13) **Pres/Pres:** Health benefits REMAIN a central lobbying effort even [until] Section 89 FADES.

Such cases were automatically detected and flagged by the CDTS as "Unknown".
After manual correction of all 22 cases, our CDTS algorithm detected only one violation:

(14) **Pres/Past:** Why DOES Renaissance's computer LIKE stocks with the DOW at 2653.28 [when] it DIDn't with the DOW at 2200?

In this case, the verb *like* was annotated as a preposition (IN), although it should be a verb (VB). After reanalysis, however, the sentence still violated the CDTS (a present/past construction). We will see shortly that the present tense may be reinterpreted to have a generic meaning when used in combination with the past tense. In addition, the connective *when* does not have a temporal meaning in this context, but could be paraphrased as *given that*.

3.1.2. Incorrect tense annotation

Another type of annotation error is that of incorrect tense annotation. There were nine such cases (under Past/Pres, Past Perf/Pres, and Pres/Past), eight of which conformed to the CDTS upon reanalysis. An example is the following sentence, where the e.g., the verb *rose* was mis-tagged as a VBP (a present-tense verb) rather than a VBD (a past-tense verb):

(15) **Past/Past:** Third-quarter spreads WIDENED to the highest level in two years [as] loan portfolio yields ROSE.

These nine cases were drawn out by the CDTS automatically and, after manual correction, only one violation remained:

(16) **Pres Perf/Past:** The transaction HAS HAD a series of setbacks [since] the financing problems BECAME known.

This is an example of a case that was subject to reinterpretation, as we will see in Section 3.2.

3.1.3. Faulty attachment

The third type of annotation error was that of faulty attachment. There were 31 such cases (under Past/Pres and Pres/Past), including the example given in Fig. 4:

(17) **Pres/Pres:** [As] some securities MATURE and proceeds ARE reinvested, the problems OUGHT to ease, he said.

Here, the *as* clause was incorrectly attached to the VP headed by *said* (which was taken as a past-tense verb); however, this became a legal Pres/Pres combination after the *as* clause was reattached to *ought*.[12]

We note that 27 out of the 31 cases that were corrected by reattachment—such as the example above—involved quoted material associated with verbs such as *say*, *lecture*, *recall*, *contend*, *explain*, etc. It is not clear that Hornstein's CDTS was ever intended to apply to this literary style of reporting. The fact that such cases consistently required reanalysis argues for a parameterizable version of the CDTS that might be adjusted for the genre of the source text.

Of the four remaining cases that were subject to reanalysis, three were corrected by reattachment and one remained in violation of the CDTS. Consider the following example of correct reattachment:

(18) **Pres/Pres:** The US did manage to supply the Dutch with oil; [once] oil IS shipped, no one CAN tell its source.

Here, the *once* clause was originally incorrectly attached to the VP headed by *did* (which was taken as a present-tense verb); however, this became a legal Pres/Pres combination after the *once* clause was reattached to *can*.

In one case, it was not possible to find a non-violating reattachment:

(19) **Pres/Past:** I don't know how people CAN say the junk bond market disappeared [when] there WERE 1.5 billion of orders for $550 million dollars.

where the *when* clause was incorrectly attached to the *can* clause, instead of to the *do(n't)* clause. However, even when reattached to the correct position, there was a CDTS violation because the resulting Pres/Past combination was still invalid. This is similar to example (14) above. Such cases—present tense used generically—will be discussed further in Section 3.2.

We have demonstrated above that the CDTS serves an important role in the detection of cases for reanalysis. Of the 62 incorrect tense annotations flagged by the CDTS, reanalysis corrected 59 cases. We found this

[12] Recall that our approach to reanalyzing this is to first try to attach the adjunct clause under the lower VP and then to seek a higher attachment point if this fails.

Table 10
Counts of reinterpretation cases: summarization impact and triggering environments

Reinterpretation	Summarization impact	Triggering environment	Tense pair	Count
Pres as Generic or Habitual	Enables coherent rendering of an enduring state that either starts or ends at the point of a concrete time-stamped event; enables summaries for causal queries	Non-modal matrix/ adjunct with un-modified connective	Past/Pres Pres/Past Pres/Past Perf	8 18 1
Modal as Past	Enables coherent rendering of a past event that might otherwise be conveyed as a current event	Would/could in matrix or adjunct	Past/Pres Pres/Past	10 24
Extend Past up to Pres	Enables coherent rendering of an enduring state that leads up to the starting point of a current event	Non-modal matrix/ adjunct with temporally modified connective	Pres/Past	8
One-way Causal Relnship	Enables coherent summaries for causal queries	Any connective	Pres Perf/Past Past/Pres Perf	63 1
Total:	136			

95% rate of success to be quite remarkable, particularly given that the 59 cases represented 30% of the overall CDTS violations. Thus, the CDTS serves not only as a component of temporal analysis but also as a diagnostic tool in the face of noisy data. Such a capability is important for NLP applications that use trained automatic parsers (which also provide noisy output) such as the one used in the Multi-document Trimmer summarization algorithm (Zajic et al., 2005).

3.2. Semantic reinterpretation

The CDTS also serves an important role in the detection of cases that require semantic reinterpretation. Specifically, a careful examination of the remaining 136 CDTS violations reveals that it is possible to algorithmically categorize all of these into different temporal and non-temporal reinterpretations as shown in Table 10. Note that the table includes: (1) possible impacts of each category on different summarization contexts; and (2) triggering environments for each category.[13] Below we examine the violations that correspond to the non-perfect forms (Past/Pres and Pres/Past) before turning to the remaining violations (Pres Perf/Past, Past/Pres Perf, and Pres/Past Perf).

3.2.1. Past/Pres and Pres/Past

Of the 68 Past/Pres and Pres/Past CDTS violations, there are three categories of reinterpretation. The first is a *non-temporal* reinterpretation of the present tense as the generic or habitual reading (cf. Hornstein, 1990, p. 206, fn.20), which accounts for 26 (8 Past/Pres and 18 Pres/Past) CDTS violations. Consider the following examples:

(20) (i) **Past/Pres:** That share issue WAS postponed [until] market conditions STABILIZE.
(ii) **Pres/Past:** I CANnot recall any disorder in currency markets [since] the 1974 guidelines WERE adopted.

In example (20) (i), it is understood that market conditions tend to wax and wane habitually. In example (20) (ii), there is no single moment at which *not recalling* occurred; rather, the event is generically interpreted. Although there is a non-temporal component of meaning in the cases above, the present-tense event may be thought of as having an open-ended duration in our framework. This knowledge is important for producing coherent textual renderings of an enduring state (e.g., “lack of disorder”) that either starts or ends at the point of a concrete time-stamped event (e.g., “adoption of guidelines”). That is, one might produce an abstractive summary that recasts example (20) (ii) as *Upon adoption of 1974 guidelines, disorder in currency markets ceased.*

[13] The triggering environment must be taken in conjunction with the tense pair to match the given context.

It is important to note that the temporal connective may be multiply ambiguous in such contexts. Moens and Steedman (1988) show that *when* often indicates a causal or enablement relation in the Past/Past combination. Our experiments reveal similar interpretations of *when* in the Pres/Past combination, as in the *given that* contexts of examples (14) and (19) given earlier. Moreover, we observed causal/enablement interpretations for other connectives as well, e.g., in (20)(i) the connective *until* assigns "lack of stability" as a cause of the postponement, and in (20) (ii) the connective *since* assigns "adoption of the guidelines" as an enabler of the lack of disorder. Hornstein discusses causal cases extensively, arguing that CDTS cannot be expected to apply in such cases. We see this as an opportunity to use CDTS to our advantage: It may, perhaps, be the key to discerning between temporally related clauses and causally related clauses. Detection of this type of information is crucial in summarization applications—particularly for query-focused summaries (as in the DUC task (Dang & Harman, 2006))—where one is asked to produce a summary for a query such as "causes of share issue postponement".

A second reinterpretation category accounts for 34 CDTS violations involving the modals *could* and *would* (10 Past/Pres cases and 24 present/past cases). Hornstein suggests these should be treated as a present tense verb (Hornstein, 1990, p. 33), but our study indicates that a clear past-tense interpretation is available, as in the following two cases:

(21) (i) **Past/Pres:** It TOOK three-quarters of an hour [before] prices COULD be worked out.
(ii) **Pres/Past:** Farmers WOULDn't sell [until] prices ROSE 20 cents.

Manual inspection of the 34 CDTS violations involving *could* and *would* indicates that all such cases should be systematically reinterpreted to a past-tense reading. Our temporal extraction algorithm could easily be modified to re-encode *could* or *should* as a past-tense verb when it co-occurs with a past-tense verb.[14] Such information is important for temporal ordering in summarization in that it enables the coherent textual rendering of an event in the past where it might otherwise be conveyed as a current event, e.g., *Prices were worked out after three-quarters of an hour had passed*.

A third reinterpretation category, applicable to the remaining eight Pres/Past violations, involves the use of temporal-connective modifiers to extend a past event up to the present-day event, as in the following example:

(22) **Pres/Past:** The report which COMES [25 years after] the surgeon general ISSUED a report warning against the dangers of smoking ...

The temporal modifier *25 years* (associated with the connective *after*) serves to extend the past event to the present state of affairs. Such information is important for summarization systems in that we may want to represent an enduring a state such as a "longstanding warning" that leads up to the starting point of a current event, as in *A warning issued 25 years ago against the dangers of smoking has culminated in today's release of a new report*.

3.2.2. Pres Perf/Past, Past/Pres Perf, and Pres/Past Perf

There were 65 CDTS violations involving the past or present perfect. We first examine the most prevalent combination, Pres Perf/Past (63 cases plus example (16) given earlier). Consider the following example:

(23) **Pres Perf/Past:** [Since] Mexican President Carlos Salinas de Gortari TOOK office special agents HAVE ARRESTED more than 6000 federal employees.

This particular combination has been the subject of substantial debate between Hornstein, who argues against a temporal interpretation of this tense pair, and his colleagues (notably, Peter Coopmans—in personal communication—who argues that this combination is perfectly fine in Dutch). The frequency of such

[14] Our analysis reveals that the number of *would* and *could* cases that are appropriately paired with present-tense verbs is slightly higher than those paired with past-tense verbs—55 cases. So it would be unreasonable to reinterpret all uses of *would* and *could* as occurring in the past. Thus, we consider reinterpretation to be applicable only to those modals that are paired with a past-tense verb.

cases—slightly higher than the non-violating cases involving Pres Perf (see Table 8) and slightly lower than half of the total number of violations following reanalysis (see Table 9)—merits additional discussion.

Interestingly, it is quite difficult to find such a combination in which there is no plausible causal relation between the adjunct clause and the matrix clause. Indeed, 51 of the 63 cases use the connective *since*, which is well known to have a causal interpretation, even in seemingly temporal contexts (Wickboldt, 1998). However, we have observed this to be true of *all* cases associated with this type CDTS violation. Some other examples are shown here:

(24) (i) **Pres Perf/Past:** Indeed analysts say that payouts HAVE sometimes RISEN most sharply [when] prices WERE already on their way down from cyclical peaks.
(ii) **Pres Perf/Past:** Several candidates HAVE WITHDRAWN their names from consideration [after] administration officials ASKED them for their views on abortion and fetal-tissue transplants.

Such cases are systematically reinterpreted as a one-way causal relationship, i.e., the adjunct event causes the matrix event to occur. Once again the CDTS aids us in discerning between temporally related clauses and causally related clauses, a capability that is crucial in, for example, query-focused summaries (Dang & Harman, 2006).

Now consider the remaining two CDTS violations:

(25) (i) **Past/Pres Perf:** Canada WAS unlikely to sell the reactor to Israel [since] Israel HASn't SIGNED the treaty.
(ii) **Pres/Past Perf:** That FOLLOWS a subtle decline [after] Manhattan rents HAD RUN up rapidly.

We reinterpret sentence (25) (i) as a one-way causal relationship—similar to the examples in (24)—where the adjunct event causes the matrix event to occur. In sentence (25) (ii), the past perfect verb behaves like a past tense verb and—similar to the Pres/Past cases in (20)—the present tense verb is reinterpreted as a generic event (i.e., there is no single moment at which the *decline* occurred).

3.3. Corpus analysis of other tense structures

We also performed an analysis of "Derived Tense Structures (DTS)"—a form that is simpler than the "Complex Tense Structures (CTS)" that are the focus of this paper—where the adjunct is non-verbal (e.g., *yesterday*). There were 943 DTSs extracted from Treebank-3 by our Lisp program. We applied our automatic CDTS procedure to these structures and found only 13 CDTS violations, 7 of which were eliminated after reanalysis. The six remaining cases involved a standard literary convention of newspaper reporting that allows for an extended temporal meaning, e.g., *Now it had come to this*, or where the temporal element expressed a duration within which a past event occurred, e.g., *Today we bounced back*. Note that the ratio of DTSs to CTSs (943:2411) is quite high—thus strengthening the claims made in this paper in that the coverage is not limited to just one type of temporal adjunct. However, the complexity of CTSs has motivated us to focus on these in this article rather than on the simpler DTSs.

4. Discussion

In our experiments, disallowed matrix/adjunct pairs occurred rarely (an average of less than seven occurrences per tense pair) in comparison to allowed matrix/adjunct pairs (an average of 102 occurrences per tense pair). Thus, our analysis provides strong support for the use of Hornstein's CDTS in filtering matrix/adjunct combinations for the purpose of potential reanalysis or reinterpretation. We see this as a success: the cases that violated the CDTS amounted to a mere 9% of the sentences studied, well within the range of broad-scale applicability of the approach. Moreover, upon further examination, we found that 59 of the 195 violating cases were corrected by a simple reanalysis and the remaining 136 were algorithmically categorizable into different temporal and non-temporal reinterpretations. As such, we have shown that our approach enables the detection of a range of important features for NLP tasks such as summarization.

We note that certain of the CDTS-allowable cases did not arise in the corpus and, upon further examination, one might consider such entries "borderline acceptable." An example is the **Fut Perf/Fut** combination, e.g., *? John will have caught his plane before Mary will eat dinner*. It is clear from such cases that the corpus-based decision made in step 3 of Fig. 2 is an important step toward producing a reasonable ranking of output possibilities for the final selection of temporal intervals/points. This suggests that the generalized temporal-relation tables used in this work might be replaced by corpus-specific tables that could be built automatically, using corpus-based techniques. Taking this approach would allow for domain-specific tuning so that the output options would more closely match the contents of the particular corpus that is selected.

The processes described above for analyzing temporally conjoined clauses and extracting temporal relations build on the theoretical work of Allen and Hornstein. From Hornstein's work we gain a careful analysis of tenses and how they fit together in complex sentences, specifically allowing us to re-categorize potentially mis-analyzed matrix/adjunct sentences in a general way. From Allen's work, we gain the ability to represent events that have duration. Without this extension, all events would have to be considered as point events and the only relevant temporal connecting words would be those that express $t_1 < t_2$ (*before*), $t_1 = t_2$ (*at the same time as*), and $t_1 > t_2$ (*after*), where t_1 and t_2 are the timepoints of the events. The amalgamation of Allen's theory of intervals with Hornstein's theory of tense yields a principled theory for assigning basic tenses for events that take place over intervals as well as points.

5. Conclusions and future work

We have provided an approach to temporal-relation extraction for individual events that may be either points or intervals in time. We have implemented an extension of the framework of Hornstein (1990) and brought this together with the temporal interval representation of Allen and Koomen (1983) and Allen (1984). We have also provided a framework that uses aspectual constraints (Dorr & Voss, 1996; Dorr & Olsen, 1996; Olsen et al., 2000, Olsen, Traum, van Ess-Dykema, & Weinberg, 2001) to pare down the number of possible interval/point representations based on both inherent and non-inherent aspectual features. Finally, we have provided a methodology for extraction, reanalysis, and reinterpretation of both temporal and non-temporal relations between two events.

We have focused on the extraction of sentence-internal temporal information from matrix/adjunct sentences that describe two events. To extend the approach to the summarization of multiple events, two directions must be pursued: (1) the connection of three or more events across different sentences, and (2) the discourse level planning of which events to connect, which events should stand alone, and the order in which events would be realized. In addition, the study of other categories of connecting words such as causal and spatial connectives (Elhadad & McKeown, 1990) could further enhance a multi-event approach.

Our work could also benefit from other temporal processing and representational approaches, including: (1) the framework of Androutsopoulos (1999), where a language called TOP is used to provide the semantics behind entries in temporal databases; (2) the techniques developed by Crouch and Pulman (1993) and Hwang and Schubert (1994) for interpreting temporal information in natural language expressions; (3) the work of Lascarides and Oberlander (1993), where temporal connectives are analyzed in a discourse context; and (4) the work of Pan et al. (2006) on adding time duration labels to TimeBank.[15]

Other inferencing capabilities may also be applied to our work. The paradigm of Danlos (1999) and Danlos (2000) uses extra linguistic-knowledge (causality) to determine the ordering of sentential clauses. Techniques developed by Elhadad and McKeown (1990) for a "deep generator" are designed to infer the meaning of temporal connectives from pragmatic features. The framework of Gagnon and Lapalme (1996) generates temporal information from an incrementally updated conceptual representation (Discourse Representation Structure). Such approaches could be combined with ours to assist us in distinguishing between temporal and causal interpretations of certain connectives, e.g., *since*. In addition, these approaches may provide important

[15] Regarding this last point, we might use this information as an enhancement to our procedure for paring down the number of temporal interval/point possibilities (shown earlier in Fig. 5).

knowledge to support the process of combining temporally related clauses from different sentences in multi-document summarization.

Our future work will involve the incorporation of our temporal-relation extraction approach into an implemented multi-document summarization system (Zajic et al., 2005, this special issue, 2007). This system currently has no mechanism for determining the temporal sequencing of events that are reported in different documents. If we resolve intra-sentential temporal relations for two events, we would be in a better position to induce a temporal ordering for two cross-document sentences that are reporting these events. However, more important than providing a critical component for an implemented system is the understanding that we have gained about interconnections between tense, aspect, and temporal connecting words. We believe this understanding provides an adequate basis for the development of additional processing modules and for the extension of linguistic coverage in the field of summarization.

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