Selecting Tense, Aspect, and Connecting Words In Language Generation

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Abstract

Generating language that reflects the temporal organization of represented knowledge requires a language generation model that integrates contemporary theories of tense and aspect, temporal representations, and methods to plan text. This paper presents a model that produces complex sentences that reflect temporal relations present in underlying temporal concepts. The main result of this work is the successful application of constrained linguistic theories of tense and aspect to a generator which produces meaningful event combinations and selects appropriate connecting words that relate them.

1 Introduction

Reasoning about temporal knowledge and formulating answers to questions that involve time necessitate the presentation of temporal information to users. One approach is to incorporate the temporal information directly into natural language paraphrases of the represented knowledge. This requires a method to plan language that contains not only tense selections, but aspect selections, and temporal connecting word selections. This paper describes a language generation model that incorporates contemporary theories of tense and aspect and develops a new framework for selecting temporal connecting words. We explore the interrelationships between choices in each of these categories, and then show how individual selections models — one for aspect, one for tense, and one for connecting words — combine into a single interdependent model.

Our model is designed to operate within a text planning process that provides input in the form of a conjunction of two timestamped literals and their corresponding verb tokens.[1] Our assumed input is in a form that is compatible with representations provided in temporal databases such as those defined by [Snodgrass, 1990] and used in temporal logic programs. Information about time is manipulated in the form of temporal intervals as defined by [Allen, 1983; 1984]. These intervals are used to semantically analyze temporal connecting words and to augment the tense theory of [Hornstein, 1990] so that it applies to events that have duration.

We focus on the mapping of the timestamped input into a *matrix* (*i.e.*, main) clause and an *adjunct* (*i.e.*, subordinate) clause conjoined by a connecting word. Consider the following input form:

(1) fall(John,15:01,15:01) $\wedge$ laugh(Mary,15:01,15:03)

This logical expression may be expressed in several different matrix/adjunct combinations including *Mary laughed while John fell*, *Mary laughed after John had fallen*, *Mary had laughed as John fell*. When the facts are expressed in the same sentence, aspectual considerations and the choice of connecting words become important. The timestamp information enables the selection of tense, connecting words, and certain aspectual properties for the verbs of the matrix and adjunct clauses corresponding to these two literals.[2]

In this paper, events are allowed to have duration and are viewed in terms of a fuller theory of aspect through the use of Allen's interval theory. We show how constraints on aspect affect the final selection of aspectual features; and we analyze how aspectual selections can alter the meanings of connecting words and thus affect their final selection. We illustrate the algorithm by showing the full set of sentences that are then filtered by linguistic constraints.[3]

*This work was supported in part by NSF grant IRI-9120788, NYI grant IRI-9357731, DARPA grant N00014-92-J-1929, ARO contract DAAL03-91-C-0034, ARI contract MDA-903-92-R-0035.

†This work was supported in part by the DOE Office of Scientific Computing, contract W-31-109-Eng-38. Dr. Gaasterland holds a joint appointment in the Department of Computer Science at the University of Chicago

[1] A literal is an expression of the form $p(x_1, \ldots, x_n)$ where p is a relation name and each x_i is either a variable or a constant. The timestamp is expressed in terms of a start time and stop time for each fact. For example, the literal *laugh(Mary,14:01,14:03)* describes an event in which Mary laughs for two minutes, and *draw(John,circle,14:00, 14:10)* describes an event in which John draws a circle for 10 minutes.

[2] We restrict candidate connecting words to those that function only temporally — this precludes, for example, *when* which has a strong causality component to its meaning [Moens and Steedman, 1988].

[3] The actual implementation uses the standard AI tech-

The main result of our work is the successful application of constrained linguistic theories of tense and aspect to a generator which produces meaningful event combinations and selects appropriate connecting words that relate them. We distinguish between inherent and non-inherent aspectual features of verbs and describe an algorithm that uses these features to select tense, aspect, and temporal connecting words for generated text based on timestamped information.

The following section provides background on linguistic theories of aspect and tense. Section 3 describes our extension of Hornstein's theory of tense to handle not only point events but also events with duration. Section 4 describes the algorithm for generating text from temporal expressions and provides details behind selecting aspect and connecting words.

2 Background

Both aspectual and temporal knowledge are used for generation of natural language expressions that reflect temporal relations present in underlying concepts. This section describes the representations used for these two types of knowledge.

2.1 Aspectual Knowledge

Following [Dowty, 1979] and [Vendler, 1967], aspect is taken to have two components, one comprised of *non-inherent* features (*e.g.*, those features that define the perspective such as simple, progressive, and perfective) and another comprised of *inherent* features (*e.g.*, those features that distinguish between states and events).[4] Non-inherent features are dependent on temporal context; thus, they are not stored with the lexical item and may be controlled during language generation. These are distinguished from inherent features, which are stored with the lexical item and are used for lexical selection.

Suppose we are generating a sentence from the following timestamped input:

(2) go(John,store,14:00,14:40) $\wedge$ arrive(Mary,14:30,14:31)

These events may be realized in a number of different aspectual combinations:[5]

(3) (i) John went to the store before Mary arrived
(simple) (simple)
(ii) John went to the store before Mary had arrived
(simple) (perfective)
(iii) John had gone to the store before Mary arrived
(perfective) (simple)
(iv) John had gone to the store before Mary had arrived
(perfective) (perfective)

The aspectual variations shown here are primarily a function of values of non-inherent features (*i.e.*, perfective *vs.* simple). These feature values must be determined before the two events can be combined since this information is necessary for selecting the appropriate temporal connectives (*e.g.*, *before*, *after*, *while*, *etc.*).

Regarding the representation of inherent features, a number of aspectually oriented representations have been proposed that readily accommodate the types of aspectual distinctions that are of concern here including [Jackendoff, 1983; 1990; Bach, 1986; Comrie, 1976; Mourelatos, 1981; Dowty, 1979; Passonneau, 1988; Vendler, 1967; Nirenburg and Pustejovsky, 1988; Pustejovksy, 1988; 1990; 1991; Pustejovsky *et al.*, 1993; Crouch and Pulman, 1993; Hwang and Shubert, 1994; Olsen, 1994]. The current model implements an aspectual classification through the use of three features proposed by [Bennett *et al.*, 1990] following the framework of [Moens and Steedman, 1988]: ±dynamic (*i.e.*, events *vs.* states), ±telic (*i.e.*, culminative events (transitions) *vs.* nonculminative events (activities)), and ±atomic (*i.e.*, point events *vs.* extended events).

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

(4) (i) John ransacked the house every day
(ii) * John obliterated the house every day

2.2 Temporal Knowledge

Tense is taken to be the external time relationship between a given situation and others. (See, for example, [Bennett *et al.*, 1990]). For example, each event in (2) has its own temporal structure. In the case of *go* (*John went to the store*), the event is associated with the Reichenbachian Basic Tense Structure (BTS) E,R_S, which indicates that the event is in the past.[6] Consider each event in example (2). In the case of *go* (*John went to the store*), the event is associated with the BTS E,R_S, which indicates that the event is in the past. The aspect of this clause is "simple" (as opposed to progressive or perfective). In the case of *arrive* (*Mary arrived*), the event is associated with the same Reichenbachian temporal representation (E,R_S) and aspect (simple), since it too is in the simple past tense.

As for relating these two events, the approach adopted here is based on a neo-Reichenbachian framework proposed by [Hornstein, 1990] in which the BTSs are organized into a Complex Tense Structure (CTS) as follows: the first event (*i.e.*, matrix clause) is written over the BTS of the second event (*i.e.*, adjunct clause) and the

nique of constraint compilation and table look-up, thus eliminating most of the overgeneration.

[4] We will see shortly that events are further subdivided into activities, achievements, and accomplishments.

[5] The term *perfective* refers to either the present or the past (plu) perfective (*i.e.*, it does not specify the tense).

[6] It is assumed that the reader is familiar with [Reichenbach, 1947] which postulates three theoretical entities: S (the moment of speech), R (a reference point), and E (the moment of the event). The key idea is that certain linear orderings of the three time points get grammaticalized into six basic tenses in English. The corresponding BTSs are: S,R,E (present), E,R_S (past), S_R,E (future), E_S,R (present perfect), E_R_S (past perfect), S_E_R (future perfect). 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).

S and R points are then associated.[7] The entire temporal/aspectual structure for this example would be specified as follows:

E_1,R_1__S_1 aspect$_1$ = simp
| |
E_2,R_2__S_2 aspect$_2$ = simp

Tense is determined by factors relating not to the particular lexical tokens of the surface sentence, but to the temporal features of the context surrounding the event coupled with certain linguistically motivated constraints on the tense structure of the sentence. In particular, it has been persuasively argued by [Hornstein, 1990] that all sentences containing a matrix and adjunct clause are subject to a linguistic (syntactic) constraint on tense structure *regardless* of the lexical tokens included in the sentence. For example, Hornstein's linguistic Constraint on Derived Tense Structures (CDTS) requires that the association of S and R points not involve crossover in a complex tense structure: E_1,R_1 __S_1

S_2,R_2,E_2

This structure would be associated with a sentence such as * *John went to the store while Mary arrives.* Here, the association of R_2 and R_1 violates the CDTS, thus ruling out the sentence.

3 Handling Events with Duration

Hornstein's theory of tense [Hornstein, 1990] assumes that events are points in time. To extend this theory to events that have duration, we analyze events in terms of Allen's theory of temporal interval relationships [Allen, 1983; 1984].[8] Allen proposes that seven basic relationships and their inverses may exist between two intervals:*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* (=).[9]

To associate a tense with an event that has duration, we first determine the interval relationship between the event time interval and speech time. A BTS is associated with the event if it preserves the relationship between the event time E and speech time S. For example, if it is determined from a logical expression that the event E_1 *John went to the store* and event E_2 *Mary arrived* have both occurred in the past, then the time S of the linguistic utterance is *after* the two event times (assuming S = now). For both E_1 and E_2, the only BTS's that preserve the interval relationship between E and S are: E,R_S (past), E_S,R (present perfect), and E_R_S (past perfect). In each case, at least one line separates event time E and speech time S, indicating that E occurs before S.

[7]In the general case, the association of the S and R points may force the R_2 point to be moved so that it is aligned with the R_1 point. The E_2 point is then placed accordingly.

[8]The theory of interval relationships has been used for a number of artificial intelligence and natural language understanding applications. (See [Allen, 1983; Galton, 1990; Lesperance and Levesque, 1990; Vilain *et al.*, 1990; Williams, 1990].)

[9]The inverse of *equal* is *equal*, so there are a total of 13 different interval relationships.

Time Points	Salient Relationship	Allowable BTSs
E_s E_f S	$E_s < E_f < S$	E_{sf},R_S (past) 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.) S_R_E_{sf} (fut. perf.) S,R,E_{sf} (pres.)
E_s S E_f	$E = S$	S,R,E_{sf} (pres.)
	$E_s < S$	E_{sf},R_S (past) E_{sf}_R_S (past perf.) E_{sf}_R,S (pres. perf.)
	$S < E_f$	S_R,E_{sf} (fut.) S_R_E_{sf} (fut. perf.)
E_s E_f S	$E_s = S$	S,R,E_s (pres.)
	$S < E_f$	S_R,E_f (fut.) S_R_E_f (fut. perf.)
	$S = E_s < E_f$	S,R,E_{sf} (pres.) S_R,E_{sf} (fut.) S_R_E_{sf} (fut. perf.)

Figure 1: Mapping Between E/S Time Relationships and Allowable BTS's, Part I

Time Points	Salient Relationship	Allowable BTSs
E_s E_f S	$E_s < S$	E_s,R_S (past) E_s_R_S (past perf.) E_s_R,S (pres. perf.)
	$E_f = S$	S,R,E_f (pres.)
	$E_s < E_f < S$	S,R,E_{sf} (pres.) E_{sf},R_S (past) E_{sf}_R,S (pres. perf.)
E_{sf} S	$E_{sf} < S$	E_{sf},R_S (past) E_{sf}_R_S (past perf.) E_{sf}_R,S (pres. perf.)
E_{sf} S	$E_{sf} = S$	S,R,E_{sf} (pres.)
S E_{sf}	$S < E_{sf}$	S_R,E_{sf} (fut.) S_R_E_{sf} (fut. perf.)
E_s S E_f	$E_s < S$	E_s,R_S (past) E_s_R_S (past perf.) E_s_R,S (pres. perf.)
	$E \leq S$	E,R,S (pres.)
S E_s E_f	$S < E_s$	S_R,E_s (fut.) S_R_E_s (fut. perf.)
	$S < E$	S_R,E (fut.) S_R_E (fut. perf.)

Figure 2: Mapping Between E/S Time Relationships and Allowable BTS's, Part II

The full extension of Hornstein's theory to events with duration requires a more detailed analysis of the E point in the BTS representation. In particular, we require E to be divided into a start time E_s and a stop time E_f, corresponding to the timestamps in the logical expression. We shall denote the interval as E_{sf}. A second interval (actually a point) is defined as the current (speech) time denoted by S. The time interval for a literal may be *open* (corresponding to a stop time of ∞) or *closed* (corresponding to a stop time containing an actual value). Given a timestamped logical expression and the current time, we can obtain a partial ordering over E_s, E_f, and S, and we can derive the temporal interval relationship between E_{sf} and S with Allen's representation.

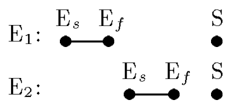
Figures 1 and 2 represent the full extension of Hornstein's BTS representation to events that have duration. The table shows the mapping from events that are either points or intervals into BTSs. The last three cases in Figure 2 cover Hornstein's original analysis.

Suppose we have the following logical expression:

(5) go(john,store,15:00,15:15) $\wedge$ arrive(mary,15:31,15:32)

Let the label E_1 refer to the time interval for the first literal, and let the label E_2 refer to the time interval for the second literal. Suppose that *now*, speech time, is 18:00. Then the start time and stop time for both E_1 and E_2 are prior to *now* and both events are represented as a closed interval preceding S:

(6)



Both events correspond to the first case in Figure 1 since the entire closed interval event precedes the speech time. This means there are three allowable BTSs for each event: past tense (E,R_S); past perfect (E_R_S); and present perfect (E_S,R). All of these preserve the ordering between E_s and S and between E_f and S. Hornstein's CDTS (described above in Section 2) can be used to identify which pairs of BTSs for the two literals are allowed to occur together in a complex matrix/adjunct sentence.

In the next section we will describe an algorithm that realizes tense, aspect, and connecting words for two events, E_1 and E_2, and we will show that this algorithm relies on the temporal relationship between E_1 and E_2 and the allowable BTSs described in this section.

4 Algorithm for Selection of Tense, Aspect, and Connecting Words

The algorithm that generates surface sentences is designed to work within a text planning process that provides input in the form of conjunctions of two time-stamped literals and their corresponding verb tokens. The algorithm seeks to place the verb tokens in a matrix/adjunct structure if possible; if there are several allowable realizations for a given conjunction, then all alternatives are produced. For ease of presentation, the algorithm is illustrated by showing the full set of sentences that are filtered by linguistic constraints.

Figure 3 shows the six steps of this algorithm. Steps 1–3 are a straightforward application of the framework described in Section 3. Steps 4–6 require elaboration; we will briefly describe each of these steps in turn.[10]

4.1 Tense Selection Process

As we saw in the previous section, BTSs are determined for each event in the logical expression based on the interval relationship between event time and speech time.

[10]The selection order was chosen based on data dependency and optimal constraint application. Part of step 5 (selecting between progressive and simple aspect) requires that the tense already be established. It is generally advantageous to apply linguistic constraints as soon as possible. When tense is selected before aspect, the CDTS may be applied immediately to eliminate illicit tenses; the alternative order would require the CDTS to be applied after aspect selection has already multiplied out many illicit possibilities.

Generate_Matrix_Adjunct_Pair:
Input: Timestamped literals $L_1 \wedge L_2$
Output: *sentence* M CW A, where M is a matrix clause for L_1, A is an adjunct clause for L_2, and CW is a temporal connecting word.
Procedure:
1. Let $E_1 = L_1$ time interval and $E_2 = L_2$ interval.
2. Determine temporal relation T between E_1 and E_2.
3. Find allowable BTSs B_1 and B_2 for E_1 and E_2.
4. Select the set S of possible tense combinations (*i.e.*, matrix (M) / adjunct (A) pairs) using the CDTS on each BTS pair from step 3.
5. Select the set S′ of possible aspectual perspectives for each M/A possibility in S using linguistically motivated restrictions on non-inherent aspectual features.
6. Select temporal connecting word CW for each possibility in S′ using the temporal relation T, the set S of tense possibilities, the (non-inherent) aspectual perspective (from step 5) and the (inherent) aspectual features associated with the verbs in each M/A pair; return the final M CW A combination.

Figure 3: Algorithm: Producing Matrix/Adjunct Sentences Reflecting Temporal Relations

The tense selection process (step 4 of the algorithm in Figure 3) must then determine which combinations of BTS pairs are legal using a linguistic constraint on tense pairs in matrix/adjunct structures called CDTS [Hornstein, 1990] as reviewed in Section 2). Any tense pairs that have no crossover in the corresponding complex tense structure may be used as the tenses in a complex sentence. 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 has provided a table of allowable tense pairs as shown in Figure 4.

Reconsider the conjunction in (5). Recall that the set of allowable tenses for each literal was {past, past perfect, present perfect}. Suppose that the first literal has been selected as the matrix. Then for each of the three basic tenses for the matrix literal, we use the chart of allowable tense pairs, compiled from the CDTS, to determine the allowable adjunct tenses. Here, the allowable matrix/adjunct pairs are the following: {(past,past),(past,past perfect),(past perfect,past), (past perfect,past perfect), (present perfect, present perfect)}.

For the purposes of illustration, suppose that the temporal connecting word *before* is to be selected (by an independent process) to connect the two sentences. We can then generate the following alternative sentences (given sufficient grammatical information about the two literals):

(7) (i) John went to the store *before* Mary arrived
(ii) John went to the store *before* Mary had arrived
(iii) John had gone to the store *before* Mary arrived
(iv) John had gone to the store *before* Mary had arrived
(v) John has gone to the store *before* Mary has arrived

Next, we shall see how aspectual feature values (*e.g.*, simple *vs.* progressive) can be selected using the temporal interval information. Then, in Section 4.3, we show how the selection of the connecting word interacts with the final selection of the tense and aspectual features.

Future Tenses

Matrix Tense	Fut. Fut. Perf.
Adjunct Tense	Pres. Pres. Perf. Fut. Fut. Perf.

Past Tenses

Matrix Tense	Pres. Pres. Perf.
Adjunct Tense	Pres. Pres. Perf.

Present Tenses

Matrix Tense	Fut. Fut. Perf.
Adjunct Tense	Pres. Pres. Perf.

Figure 4: Allowable Tense Pairs for Matrix/Adjunct Sentences

4.2 Aspect Selection Process

As described in Section 2.1, aspect is taken to have two components, one comprised of *non-inherent* features and another comprised of *inherent* features. The task of selecting aspect (step 5 of the algorithm in Figure 3) involves finding values for non-inherent features. The final aspectual realization that is present in a generated sentence emerges from the composition of inherent verb properties and these chosen values. The two aspectual features that are not inherent are: (1) *progressive vs. simple* and (2) *perfective vs. non-perfective*. Together these two features define the *perspective* of a verb phrase. When both *perfective* and *non-perfective* are compatible with the CDTS both alternatives are produced. We address the choice of *progressive vs. simple* for the remainder of this section. Our method to select between *progressive* and *simple* relies on a set of restrictions based on work by [Dowty, 1979] that we have adapted for generation of temporal information. We have recast Dowty's constraints on the relationship between inherent verb features and the choice between progressive and simple as follows:

(8) (i) If the natural language verb selected for a literal is inherently a state (-dynamic), then the verb must be *simple*.

(ii) If the interval for a literal is actually a point, that is, the start time and stop time are the same, then the literal is considered to be +atomic and the natural language verb for the literal must be *simple*.[11]

(iii) If the interval is open, that is, the stop time is unknown, then the literal is considered to be -atomic and the natural language verb for the literal must be *progressive*.

(iv) If the interval is closed, that is, the stop time is known, then the literal is considered to be ±atomic and the natural language verb for the literal may be *simple* or *progressive*.

The only case where a decision is not definitive is the case of closed intervals (restriction (iv)). However, we can inspect the timestamps to decide whether or not a literal depicts an instantaneous or prolonged process or event. If a conclusion cannot be reached, then the default selection is progressive for present tense verbs and simple for past.

In our ongoing example (5), both literals are associated with closed, past temporal intervals. Both verbs *go* and *arrive* are +atomic so information about the completion of the event is lost if the progressive is selected.

[11]This restriction blocks the realization of an activity in the progressive, even though such cases do arise. However, it is assumed that in such cases there is a process of *coercion* going on. This point is discussed further in [Dorr, 1992].

WHILE	=	o	oi	s	si	d	di	m	mi	f	fi	<	>
Dp/Dp	Y		Y	Y		Y				Y			
Dp/Ds	Y		Y	Y		Y				Y			
Dp/Ss	Y		Y	Y		Y				Y			
Ds/Ds	Y		Y	Y		Y				Y			
Ds/Dp	Y		Y	Y		Y				Y			
Ds/Ss	Y			Y		Y				Y			
Ss/Dp	Y		Y	Y		Y				Y			
Ss/Ds	Y			Y		Y				Y			
Ss/Ss	Y			Y		Y				Y			

BEFORE	=	o	oi	s	si	d	di	m	mi	f	fi	<	>
Dp/Dp		Y									Y	Y	
Dp/Ds												Y	
Dp/Ss		Y									Y	Y	
Ds/Dp												Y	
Ds/Ds												Y	
Ds/Ss												Y	
Ss/Dp		Y									Y	Y	
Ss/Ds												Y	
Ss/Ss		Y									Y	Y	

Figure 5: Selection Charts for Past/Past Tense Combination

Restriction (8)(ii) dictates that the simple must be selected for both phrases, as in *John went to the store before Mary arrived*.

4.3 Selecting Temporal Connecting Words

Earlier in example (7), we assumed that an independent process would select the temporal connective between two sentential concepts. In this section, we discuss this process (step 6 of Figure 3). Two pieces of information contribute to the selection of a temporal connecting word for a matrix/adjunct sentence. First, the temporal interval relationship between the two literals provides a means to select a particular subset of candidate connecting words. Second, inherent aspectual features (*e.g.*, +dynamic *vs.* -dynamic) and non-inherent aspectual features (*i.e.*, progressive *vs.* simple) that have been determined for the individual literals can further restrict the set of possible connecting words.

Each temporal connecting word may correspond to several temporal interval relationships. Conversely, each temporal interval relationship corresponds to multiple temporal connecting words. In addition, the aspectual features of the matrix and adjunct verb can alter the meaning of the connecting word. For example, the progressive perspective of the verb endows the connecting word *before* with the possible meanings <, o, and fi. In the following sentences, *before* covers all three temporal interval meanings simultaneously:

(9) (i) Mary was drawing a circle before John was writing (event/event)

(ii) Mary was drawing a circle before John was laughing (event/process)

(iii) John was laughing before Mary was drawing a circle (process/event)

(iv) John was laughing before Mary was walking to the store (process/process)

Since the matrix phrase is progressive, the adjunct phrase might start after the matrix finishes (<) or before the matrix finishes. If the adjunct phrase starts before the matrix finishes, it might finish at the same moment as the matrix (fi) or after the matrix (o). The interpretation changes significantly if the adjunct clause is realized in the simple perspective, in which case only the (<) reading is available:[12]

(10) (i) Mary was drawing a circle before John wrote a letter
(ii) Mary was drawing a circle before John laughed
(iii) John was laughing before Mary drew a circle
(iv) John was laughing before Mary walked to the store

We have determined the possible temporal interval meanings associated with the ±dynamic/ ±progressive feature combinations through an analysis of sample sentences such as (9)(i)–(iv) and (10)(i)–(iv). From this information, we have constructed *analysis charts*, which associate temporal interval meanings with connecting words for each ±dynamic/±progressive combination. The information in the analysis charts has been compiled into two dimensional *selection charts* for each connecting word. The selection charts for *while* and *before* that apply to the Past/Past tense pairs are given in Figure 5.[13]

Given an interval relation and values for ±dynamic and ±progressive, each chart can be inspected to determine whether its connecting word can be used. The charts are used, in order, from sparsest to densest. A word with a sparse chart has a more specific meaning than one with a dense chart, since it can take fewer meanings. For example, given an Ss matrix and an Ss adjunct, and the temporal interval o (overlaps), the connecting word *before* would be selected since the *before* chart contains a *yes* for the coordinates (matrix = Ss, adjunct = Ss, interval relationship = o) and since this chart is sparser than the *while* chart.

We shall complete the application of the Figure 3 algorithm to our example:

(11) go(john,store,15:00,15:15) ∧ arrive(mary,15:31,15:32)

In Section 3 we determined that both literals of this example correspond to case 1 of Figure 1, *i.e.*, the set of allowable BTSs in both cases is {past, past perfect, present perfect}. Thus, we have already completed steps 1–3 of the algorithm on this example.

Step 4 of the algorithm requires the CDTS to be applied to all 9 BTS combinations (*i.e.*, 3 matrix and 3 adjunct). In Section 4.1, we used the precompiled CDTS table to determine that only five of the nine tense pairs are legal: the possibility set S = {(past, past), (past perfect, past), (past, past perfect), (past perfect, past perfect), (present perfect, present perfect)}.

Now, in step 5 of the algorithm, we apply the restrictions on the relationship between inherent verb features and the choice between progressive and simple. Since both verbs are +dynamic and the interval is closed in both cases, the default aspectual selection for the BTSs is simple (in cases where the past tense is used). Thus, there are five possibilities for S′, all of which correspond to the combination Ds/Ds (*i.e.*, both matrix and adjunct are dynamic and simple):

(12) (i) John went to the store *CW*[14] Mary arrived
(ii) John had gone to the store *CW* Mary arrived
(iii) John went to the store *CW* Mary had arrived
(iv) John had gone to the store *CW* Mary had arrived
(v) John has gone to the store *CW* Mary has arrived

Finally, step 6 determines the appropriate temporal connectives for each of these cases. For each table corresponding to a possible tense, the algorithm examines the Ds/Ds row under the "<" column. In Figure 5, the only connective applicable to the Ds/Ds combination under the "<" relation is *before*. Thus, case (12)(i) allows *before* to substitute *CW*. The next four cases require access to different selection charts (not shown here). Case (12)(iii) allows only the *before* connective. Case (12)(v) does not allow any choice of connective and is eliminated. Cases (ii) and (iv) allow only *before* to be selected. Thus, the final result consists of four alternative realizations:

(13) (i) John went to the store before Mary arrived
(ii) John had gone to the store before Mary arrived
(iii) John went to the store before Mary had arrived
(iv) John had gone to the store before Mary had arrived

5 Conclusions

The approach to selecting tense, aspect, and connecting words described in this paper is a general method to handle temporal information in the generation of language. The ability to handle time is not only essential to database interface systems, but it is also essential in other applications such as machine translation since language cannot be produced without tense and aspect assignment.

The main results of this paper are the following. We have provided a theory for selecting tenses for individual events that may be either points or intervals in time. The selection theory extends the theory of tense by [Hornstein, 1990] through a theory of temporal interval representation by [Allen, 1983; 1984]. For literals that are to be combined in a matrix/adjunct structure, selected tenses are constrained by Hornstein's constraint on derived tense structure. Next, we have provided a theory for aspect selection that is constrained by the tenses already selected for an event; the aspectual constraints are adapted from [Dowty, 1979]. Finally, we have given

[12] Although the progressive auxiliary *be* is used in (10), we view the matrix verb to be non-stative. The assignment of aspectual features is based on information associated with underlying lexical items, not on surface forms that result from their combination with other lexical items.

[13] Analogous charts, not shown here, have been built for other tense pairs as well. For the present discussion, we have condensed the inherent feature information into the single featural distinction ±dynamic and we have combined this featural specification with the non-inherent featural specification ±progressive. We shall abbreviate +dynamic/+progressive as Dp; +dynamic/-progressive as Ds (since -progressive is simple); -dynamic/-progressive as Ss (since -dynamic is state). One axis of the selection chart holds pairs of values for aspectual class and perspective. The other axis holds the temporal intervals. For each pair of aspectual values and for each temporal interval, a Y (= *yes*) signifies that a word covers that temporal interval meaning for that pair of aspect values.

[14] At this point, the temporal connective has not yet been selected; thus, the label *CW* is used as a connective placeholder.

a theory for selecting connecting words that is driven by a set of tables that associate temporal interval meanings with combinations of connecting word and aspectual values. The connecting word selection is constrained by the aspectual values already selected for an event.

The theoretical results described here are currently being used as the basis of an implemented system that generates language from instantiated logical expressions that represent the answer to a logic programming or database query [Gaasterland, 1992; Gaasterland and Lobo, 1994]. Moreover, the approach is compatible with a generation module used for interlingual machine translation such as that of [Dorr, 1992; 1993].

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