Splitting the Reference Time: Temporal Anaphora and Quantification in DRT - Technical Report

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Abstract

We present an analysis of temporal anaphora in sentences which contain quantification over events, within the framework of Discourse Representation Theory. The analysis in [12] of quantified sentences, introduced by a temporal connective, gives the wrong truth-conditions when the temporal connective in the subordinate clause is \textit{before} or \textit{after}. This problem has been previously analyzed in [19] as an instance of the \textit{proportion problem}, and given a solution from a Generalized Quantifier approach. By using a careful distinction between the different notions of reference time, based on [16], we propose a solution to this problem, within the framework of DRT. We show some applications of this solution to additional temporal anaphora phenomena in quantified sentences.

1 Introduction

The analysis of temporal expressions in natural language discourse provides a challenge for contemporary semantic theories. The notion of \textit{temporal anaphora} was introduced in [11], to account for ways in which temporal expressions depend on surrounding elements in the discourse for their semantic contribution to the discourse. In this paper, we discuss the interaction of temporal anaphora and quantification over eventualities. Such interaction, while interesting in its own right, is also a good test-bed for theories of the semantic interpretation of temporal expressions. We discuss cases such as:

(1) \textit{Before} John makes a phone call, he \textit{always} lights up a cigarette. [12]

(2) \textit{Often, when} Anne came home late, Paul had already prepared dinner. [19]

(3) \textit{When} he came home, \textit{he always} switched on the tv. He took a beer and sat down in his armchair to forget the day. [19]

(4) \textit{When} John is at the beach, \textit{he always} squints \textit{when} the sun is shining. [19]

The analysis of sentences such as 1 in [12], within the framework of Discourse Representation Theory (DRT) [8] gives the wrong truth-conditions, when the temporal connective in the sentence is \textit{before} or \textit{after}. In DRT, such sentences trigger box-splitting with (markers for) the eventuality of the subordinate clause and an updated reference time in the antecedent box, and the eventuality of the main clause in the consequent box, causing undesirable universal
quantification over the reference time. This problem is analyzed in [19] as an instance of the proportion problem and given a solution from a Generalized Quantifier approach. We were led to seek a solution for this problem within DRT itself, because of DRT's advantages as a general theory of discourse, and its choice as the underlying formalism in another research project of ours, which deals with sentences such as 1-4, in the context of natural language specifications of computerized systems. In this paper, we propose such a solution, based on a careful distinction between different roles of Reichenbach's reference time [15], adapted from [16].

2 Background

An analysis of the mechanism of temporal anaphoric reference hinges upon an understanding of the ontological and logical foundations of temporal reference. Different concepts have been used in the literature as primitives. These range from temporal instants in Tense logic [14], through intervals of time [2] as in the analysis of temporal connectives in [3], to event structures [7] as in Hinrichs' analysis of temporal anaphora in [4].

An important factor in the interpretation of temporal expressions is the aspctual classification of situations into different aspctual classes (or Aktionsarten), which is based on distributional and semantic properties. In this paper, we will only consider events and states, together termed eventualities in [1]. In narrative sequences, event clauses seem to advance the narrative time, while states block its progression. The mechanism used to account for this phenomena in [4] and [12], is based on the notion of reference time, originally proposed by [15].

Reichenbach [15] uses three temporal indices to account for the interpretation of tense forms. These are the utterance time, event time and reference time, which denote respectively, the time the clause was uttered, the time the event described occurred, and the time point from which the event is viewed. Different tense forms are interpreted as involving different temporal relations between these three indices. For example, in both the simple past and the present perfect tense forms, the event time precedes the utterance time. The difference between these two tense forms is the reference time from which they are viewed. In the present perfect, the reference time coincides with the utterance time, whereas in the simple past, the reference time coincides with the event time. The reference time, according to [15] is determined either by context, or by temporal adverbials.

2.1 A unified analysis of temporal anaphora

Hinrichs' and Partee's use of a notion of reference time, provides for a unified treatment of temporal anaphoric relations in discourse, which include narrative progression especially in sequences of simple past tense sentences, temporal adverbs and temporal adverbial clauses, introduced by a temporal connective. This concept of reference time is no longer an instant of time, but rather, an interval. This approach can be summarized as follows: in the processing of a discourse, the discourse-initial sentence is argued to require some contextually determined reference time. Further event clauses in the discourse introduce a new event, which is included within the then-current reference time. Each such event also causes the reference time to be updated to a time 'just after' [12] this event. State clauses introduce new states, which include the current reference time, and do not update it. As an example of such an analysis consider the following narrative discourse [12]:

(5) John got up, went to the window, and raised the blind. It was light out. He pulled the blind down and went back to bed. He wasn't ready to face the day. He was too depressed.

We construct a DRS for the first two sentences of this discourse, according to Hinrichs' and Partee's analysis. The n in the top DRS is a mnemonic for 'now'- the utterance time. The
first event in the discourse, \( e_1 \) - John’s getting up - is interpreted relative to a contextually understood reference time, \( r_0 \). The event \( e_1 \) is included in the current reference time, \( r_0 \). A new reference time marker, \( r_1 \) is then introduced. \( r_1 \) lies immediately after \( r_0 \). We represent this condition as \( r_0 \preceq r_1 \). \( r_1 \) serves as the current reference time for the following event \( e_2 \). We continue in this fashion, updating the reference time, until the second sentence in the discourse is processed. This sentence denotes a state, \( s_1 \), which includes the then-current reference time.

\[
\begin{align*}
    r_0 & \preceq r_1 \preceq r_2 \preceq r_3 \preceq s_1 \\
    \forall r \in \{r_0, r_1, r_2, r_3\} & \exists e \in \{e_1, e_2, e_3\} : e \preceq r
\end{align*}
\]

Figure 1:

Adverbial phrases, whether phrasal (e.g. ‘On Sunday’) or clausal (e.g. ‘When Bill left’), are processed before the main clause. They introduce a reference time, which overrides the current reference time, and provides an anaphoric antecedent for the tense in the main clause. This mechanism is used to explain how tense and temporal adverbials can combine to temporally locate the occurrence, without running into problems of relative scope [5]. The tense morpheme of the main clause locates the event time with respect to the reference time, whereas temporal adverbials are used to locate the reference time.

\( \text{When}-\text{clauses}, \) for example, introduce a new reference time, which is ordered after the events described in the preceding discourse. The eventuality in the \( \text{when}-\text{clause} \) is related to this reference time in a way similar to that discussed earlier with respect to narrative progression: a state includes its reference time, while an event is included in it. The eventuality in the main clause is interpreted with respect to this reference time. If the main clauses is an event-clause, this event introduces a new reference time, just after the event time of the main clause. As an example, consider the following discourse [12]:

(6) Mary turned the corner. When John saw her, she crossed the street. She hurried into a store.

Following [12], we will not construct a full DRS for this discourse, but illustrate it with a diagram in Figure 2, with circles denoting inclusion.

\[
\begin{align*}
    e_{\text{turn}} & \preceq r_1 \preceq e_{\text{see}} \preceq e_{\text{cross}} \preceq e_{\text{hurry}} \preceq r_4
\end{align*}
\]

Figure 2:
2.2 Quantification over events

Partee [12] extends Hinrichs' treatment of temporal anaphora to the analysis of sentences, which contain a temporal adverbial and quantification over eventualities. According to her analysis, these trigger box-splitting as do if or every clauses in DRT [8]. Consider the following example from [12]:

(7) Whenever Mary telephoned, Sam was asleep.

\[
\begin{align*}
\text{Whenever } & \text{ Mary telephoned, Sam was asleep.} \\
\begin{array}{|c|c|}
\hline
\text{y telephone} & \text{Mary(y)} \\
\hline
\text{Sam(x)} & \text{s} \\
\hline
\text{e} & \text{r} \\
\text{e} & \text{r} \\
\text{e} & \text{r} \\
\text{e} & \text{r} \\
\hline
\end{array}
\end{align*}
\]

According to this analysis, the antecedent clause cannot be interpreted relative to a single reference time, since Mary's telephoning is not specified to occur at some specific time. Still, the sentence needs to be interpreted relative to a reference time. This reference time can be a large interval, and should contain each of the relevant occurrences of Mary's telephoning during which Bill was asleep. This reference time is represented as \( r_0 \) in the top sub-DRS.

The 'whenever' triggers box-splitting. The event marker - \( e_1 \) is introduced in the antecedent box, with the condition that it be temporally included in the current reference time, \( r_0 \) and be prior to \( n \). The 'whenever' also causes the introduction of \( r_1 \), a new reference time marker. \( r_1 \) lies 'just after' \( e_1 \). The stative clause causes the introduction of \( s_1 \), which includes the reference time \( r_1 \).

The embedding conditions for the whole construction are just like those for a regular 'if' or 'every' clause, i.e. the sentence is true, if every proper embedding of the antecedent box can be extended to a proper embedding of the combination of the antecedent and the consequent boxes. This means, as desired, that for each choice of an event \( e_1 \) of Mary's telephoning, and reference time \( r_1 \) 'just after' it, there is a state of Sam's being asleep, that surrounds \( r_1 \).

A sentence such as 7, in which we replace 'whenever' by 'when' and add 'always' in the main clause, as in example (7a), would get the same DRS:

(7a) When Mary telephoned, Sam was always asleep.

2.3 Extending the analysis

As noted in [12], this analysis does not extend in a straightforward manner to cases in which the operator when is replaced by (an unrestricted) before or after, in such quantified contexts. Constructing a similar DRS for such sentences gives the wrong truth conditions. For example, consider sentence 1. Constructing a DRS for this sentence in accordance with the principles above, would place \( r_1 \) - the reference time, used for the interpretation of the consequent main clause - in the universe of the antecedent box. The embedding conditions determine, that this reference time be universally quantified over, causing an erroneous reading in which for each
event, $e_1$, of John’s calling, for each earlier time $r_1$, he lights up a cigarette. Paraphrasing this, we could say that John lights up cigarettes at all times preceding each phone call, not just once preceding each phone call. We did not encounter this problem in sentence (7a), since although the reference time $r_1$, is universally quantified over in that sentence as well, it is also restricted, to immediately follow $r_1$. It is similarly restricted if ‘before’ is replaced with ‘just before’ or ‘ten minutes before’. But, (unrestricted) ‘before’ is analyzed as ‘some time before’, and thus the problem arises. We will henceforth informally refer to this problem as Partee’s quantification problem.

In [12] Partee suggests that in these cases we somehow have to insure that the reference time, $r_1$, appears in the universe of the consequent DRS, causing it to be existentially quantified over, giving the desired interpretation. Simply moving $r_1$ to the right-hand box does not agree with Hinrichs’ assumption that temporal clauses are processed before the main clause, since they update the reference time, with respect to which the main clause will be interpreted. In our proposed solution, the ‘reference time’ is indeed moved to the right box, but it is a different notion of reference time.

3 Partee’s quantification problem as an instance of the proportion problem

De Swart [19] sees Partee’s quantification problem as a temporal manifestation of the proportion problem, which arises in sentences such as [6]:

\[(8)\] Most women who own a cat are happy.

The sentence is false in the case where out of ten women, one owns 50 cats and is happy, while the other nine women own only one cat each, and are miserable. This will not be predicted by the unselective binding of quantifiers in DRT, which quantify over all the free variables in their scope, in this case women-cat pairs.

According to [19] Partee’s problem is similar. The unselective binding of the universal quantifier in sentences such as 1 over both the event and the updated reference time in the antecedent box, is responsible for the wrong truth conditions for the sentence. The quantificational scheme in the analysis of the examples considered above is universal quantification over a pair of event and reference time, where it should in fact be universal for the event and existential for the reference time.

Several attempts at solving this problem within DRT are considered and rejected in [19]. Instead, de Swart offers a solution from a Generalized Quantifier approach. Her analysis divorces the use of reference times in the interpretation of temporal connectives, from the quantificational structure of the sentence. Temporal connectives are viewed as relations, $TC$, between two sets of events:

\[(9)\] $\{<e_1,e_2> | <e_1,e_2> \in TC\}$

The analysis of sentences which contain a temporal connective is based on the analysis of the quantificational structure of quantified NPs in transitive sentences. In both cases, this structure involves two sets of individuals (events in the temporal case, and nouns in transitive sentences) and a binary relation (the temporal connective or the transitive verb). This quantificational structure can be analyzed either by an iteration of monadic quantifiers, or as a single dyadic quantifier of type $<1,1,2>$. In the first approach, adverbs of quantification (Q-adverbs) are assigned the structure:

\[(10)\] $Q(S_s, \{e_1 \exists(S_m, TC_{e_1})\})$
In $10$, $S_s$ and $S_m$ denote, respectively, the sets of events described by the subordinate clause and the main clause, $TC_{e_1}$ denotes the image set of $e_1$ under the temporal connective $TC$, i.e. the set of events $e_2$ which are related to $e_1$ via the relation $TC$, (presented in 9). In the second approach, the structure is:

$$(11) \ [Q, \exists](S_s, S_m, TC)$$

In the analysis of [19], the reference time is an implicit variable, which is needed in the interpretation of the temporal relation $TC$, but is not part of the quantificational structure.

DeSwart’s solution does overcome Partee’s quantification problem, although not within DRT. As such, the existential quantification in 11 has to be stipulated, whereas our analysis acquires this existential quantification ‘for free’.

## 4 Splitting the role of reference time

Our analysis of Partee’s quantification problem uses a different notion of reference time than that used in the accounts in the exposition above. Following [16], we split the role of the reference time, which was used to account for a large array of phenomena, into several independent mechanisms. By this separation, we propose an analysis in DRT of temporal subordinate clauses in quantified sentences, which avoids Partee’s problem altogether. The mechanisms we discuss are: the location time, $Rpt$ and $perf^1$. DRSs will contain temporal markers corresponding to location times and $Rpts$.

The location time is an interval, used to temporally locate eventualities, in accordance with their aspectual classification. Events are included in their location time (this condition is recorded in the DRS as $e \subseteq t$ on the respective markers), while states temporally overlap their location time (recorded as $s \cap t$). The tense of the verb determines the relation between the location time and the utterance time. If the tense is simple past, the location time lies anteriorly to the utterance time. When it is simple present, the location time coincides with the utterance time$^2$. Temporal adverbials restrict the location time: temporal adverbs introduce a DRS-condition on the location time, while temporal subordinate clauses introduce a relation between the event time$^3$ of the subordinate clause and the location time of the main clause. The exact temporal relation denoted by a temporal connective depends on the aspectual classes of the eventualities related by it$^4$. We illustrate these principles with the following sentences:

$$(12) \ Mary \ wrote \ the \ letter.$$  
$$(13) \ Mary \ is \ writing \ the \ letter.$$  
$$(14) \ Mary \ wrote \ the \ letter \ on \ Sunday.$$  
$$(15) \ Mary \ wrote \ the \ letter \ when \ Bill \ left.$$  

In sentence 12, the event triggers the introduction of an event marker $e$, and location time marker $t$, into the DRS with the DRS-condition that $e$ is included in $t$. The past tense of the verb adds the condition that $t$ lies in the past of $n$. Sentence 13 denotes a state, which holds at the

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$^1$An additional mechanism is the $TPpt$, which for reasons of simplicity will not be discussed in this paper.

$^2$Since the utterance time, $n$ is a point in [16], the overlap relation between a state, that holds in the present and $n$ reduces to inclusion.

$^3$The event time $t$ of an eventuality $e$ is the smallest interval which includes $e$. This relation is recorded in a DRS as $t = loc(e)$.  

$^4$For the sake of the current presentation, we assume the following relations for $When$: if both the $when$-clause and the main clause denote states, then their respective time indices overlap. If both are events then the times are temporally close, with the exact relation undetermined. When one is a state and one an event, then the time index of the state includes that of the event cf. [4].
present. It triggers the introduction of a state marker, $s$, which includes its temporal location, $n$. Sentence 14 is processed in a way similar to sentence 12, with the added DRS-condition on the location time $t$ of the event $e$, that $t$ is an interval which ‘falls’ on (a contextually appropriate) Sunday. Finally, we come to sentence 15, in which the location time of the event in the main clause is restricted to fall (just) after the event time of the event of the subordinate clause.

Narrative progression is dealt with by using the feature $Rpt$ (or reference point). The $Rpt$ can be either an event or a time discourse marker, already present in the DRS (recorded as assignment $Rpt := e$). Eventualities are interpreted with respect to the $Rpt$ - events are taken to follow the current $Rpt$, while states include it. The $Rpt$ is reset during the processing of the discourse. Note that in a ‘terminal’ DRS (ready for an embedding test), all the auxiliary $Rpts$ “disappear” (do not participate in the embedding).

The perfect is analyzed by using the notion of a nucleus [16] to account for the inner structure of an eventuality. A nucleus is defined as a structure containing a preparatory process, culmination and consequent state. The categorization of verb phrases into different aspectual classes can be phrased in terms of which part of the nucleus they refer to. The perfect is seen in [16] as an aspectual operator. The eventualities described by the perfect of a verb refer to the consequent state of its nucleus. For example, the following sentence 16 denotes the state, $s$, holding at the present, that Mary has met the president. This state is a result of the event $e$, in which Mary met the president. Temporally, the state $s$ starts just when $e$ ends, or as it is put in [16]: $e$ and $s$ abut, (represented as $e \supseteq s$).

(16) Mary has met the president.

5 An alternative solution

By extending the analysis of temporal subordinate clauses in [16], to sentences which include quantification over eventualities, we can propose an alternative DRT solution to Partee’s quantification problem. As in [12], such sentences trigger box-splitting. But now, the location time of the eventuality in the subordinate clause serves as the antecedent for the location time of the eventuality in the main clause. In this approach, each of the relevant temporal markers resides in its appropriate box, yielding the correct quantificational structure. This quantificational structure does not need to be stipulated as part of the $Q$-adverb’s meaning, but arises directly from the temporal system. We illustrate this analysis by constructing a DRS in Figure 4 for sentence 1.

![Figure 4](image-url)

In this DRS, $n$ denotes the utterance time. The subordinate clause triggers the introduction of an event marker, $e$, with its event time marker $t$. The main clause triggers the introduction of an event marker $e'$, and its location time marker, with the DRS-condition, that $e \subseteq t$. The asymmetry in using the event time for $e$ and the location time for $e'$ arises from the interpretation
rules of temporal connectives (for both quantified and non-quantified sentences). Since the temporal connective in this sentence is *before*, the relation between these two markers is one of precedence. In this DRS, we adopt a suggestion by Chierchia in [12], that the whole implication be rendered as a state. This state is no longer an atomic eventuality. It is a complex state denoting John’s habit. This state holds during the present, and so its location time is $n$.

6 Additional phenomena

In this section we see some applications of our analysis to related constructions. First, we consider the past perfect, as in sentence 2. This example is given in [19] to illustrate the inability to interpret temporal connectives without the use of reference times. According to [19], the subordinate clause determines the reference time of the verb, which lies anteriorly to the event time. Trying to use the event times would give the wrong analysis. This would seem to be troublesome for our approach, which uses the location time of the event in the main clause, and not its reference time. However, this is not a problem, since our analysis of the perfect by the use of the operator $\text{perf}$, analyses the eventuality referred to by the main clause, as the result state of a previous event. The temporal relation in the sentence is inclusion between the event time of Anne’s coming home, and the location time of the result state of Paul’s already having prepared dinner.

Next, we consider narrative progression in quantified contexts, as in example 3. The basic construction is just the same as in the paradigm structure, but now we have narrative progression in the consequent box. This narrative progression is handled as ordinary narrative progression in [16], i.e. by resetting the $\text{Rpt}$.

The DRS in Figure 5 describes the complex state $s_1$, that after each event of John’s coming home, there is a sequence of subsequent events referring to his activities.

Finally, we deal with sentences such as example 4, an implicit generic quantifier and *always*. The situation described by John’s always squinting when the sun is shining is analyzed as a complex state $s_3$. This state holds whenever John is at the beach, recorded by the condition that the location time $t_2$ of $s_3$ overlaps the event time, $t_1$ of John’s being at the beach, $s_2$ in Figure 6.
7 Conclusion

In this paper we have analyzed the interaction of quantification over eventualities and temporal anaphora, within the framework of DRT. We have shown how this analysis manages to overcome what we have termed Partee’s quantification problem. Once the basic premise, that quantified sentences, of the type considered above, trigger box-splitting is accepted, the structure of the quantification over the different temporal indices arises as a direct extension of the analysis of non-quantified sentences. This is an improvement upon previous approaches, in which this quantificational structure had to be explicitly stipulated.

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