

# CONTROLLED NATURAL LANGUAGE WITH TEMPORAL FEATURES

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**A Temporal Modifiers**

**114**

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## Abstract

A controlled natural language (CNLs) is a fragment of a given natural language that is computer processable. Initially created to serve as a tool for teaching non-native speakers of a given natural language, controlled natural languages have more recently served as an interface between natural languages and formal languages. Many CNLs with different base languages have been defined over the past two decades. These controlled languages have very varied domains of application such as software and hardware specification, ontology authoring and editing, air traffic control etc. Controlled natural languages have gradually gained some level popularity in the real world.

From a survey of existing CNLs, we observe the lack of a controlled natural language able to parse temporal expressions. In order to be able to provide correct syntactic structures and corresponding semantic interpretations for these temporal expressions, we consider thousands of generated sentences analyzing the various tense, aspect, aspectual class and temporal modifier configuration. We also analyze sentence extracts from the Brown corpus. From which we are able to define semantic interpretations for the various temporal modifiers of interest, taking into consideration how these interpretations are affected by the sentence tense and aspect and aspectual class configuration.

From this analysis we are able to provide syntactic rules defined with context free grammars. Natural languages are known to be very robust, representing it with a context free grammar therefore would require consideration of factors other than syntactic categories. In order to be able to cater for these other syntactic restrictions such as tense and number agreement, we assign parameters to each terminal and non-terminal symbol in our grammar. We can therefore define rules to satisfy these syntactic restrictions using assigned parameters before the production rules are being applied. We apply Montague semantics to these syntactic rules which enables us generate semantic interpretations from the syntactic structures for sentences in our language.

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# Chapter 1

## Introduction

The term language can be easily considered as a form of communication between two parties. Natural language on one hand appears to be an intuitive mode of communication amongst humans. We are able to parse sentences and easily assign appropriate interpretations to these sentences based on a given context of discourse and appropriate responses are thus provided. There are formal languages on the other hand with very precise syntactic structures and the interpretations of their sentences are concise without any chance of ambiguity. While natural languages are intuitive to humans, formal languages appear quite complicated and difficult to understand to the average person who is not conversant with the syntax and semantics of the formal language of interest. We can therefore say that we humans are adapted to communicate in natural languages and machines are able to parse formal languages more easily.

Having humans and machines adapted to two different forms of languages is not particularly of much advantage. There needs to be a way to bridge the gap between the difficulty of parsing formal languages by humans and the occasional vagueness of natural languages sentences, and a lack of definitive grammar. The need for this bridge serves as a motivation for controlled natural languages. Given that formal languages are often difficult to parse by humans, having a natural language interface for a given formal language, provides a bridge.

Therefore a controlled natural language (we sometimes abbreviate as CNL) is a language that has exactly one base natural language for example English, such that its syntax is a regimented version of the said base language syntax. Although controlled natural languages were not originally designed for machines

but rather for easy learning for the non-native speakers of the CNL's base language, the controlled of natural language syntax has more recently been applied in computing. Hence sentences of CNLs are now often translated to some formal language.

We are therefore able have various applications of controlled natural languages. For example Attempto controlled English (Fuchs et al. [2010]) is a controlled English that was originally designed to aid writing software specification documents. There has been similar applications to hardware specifications as well. Controlled natural languages has also been applied as interface for web ontology authoring, editing and query. Its also extensively used in air travel communication. There are a few less popular areas of application. For example, fraud detection, business contract development, speech recognition interfaces etc. Current controlled natural languages also exist with varied base languages. Most common being English, we however have other languages such as Mandarin, Greek, Portuguese and some less popular languages such isiZulu and Runyankore.

## 1.1 Aims and Objectives

Despite the growing popularity of controlled natural languages and its various applications, there has been little attempt of including the interpretation of temporal expressions as they occur commonly in our use of natural languages. Our primary objective therefore is to define a controlled natural language with temporal features. A controlled natural language with temporal features is one that provides formal interpretations for sentences with the inclusion of temporal information. In order to achieve this we require interpretations for temporal expressions – tense, aspects and temporal modifiers, taking into account the effect of these expressions have on the interpretation of a given sentences where they interact together.

We therefore analyze the syntactic behaviour and semantic interpretation of each of these temporal expressions. It is of course the case that each of these expression are not used in isolation by rather interact with each other. We observe that the interaction of these expressions produce interesting interpretations. Our analysis therefore involves an attempt to define rules based on the interaction of these expressions – tense, aspects and temporal modifiers. These rules are then included in the definition of a controlled natural language with temporal features.

## 1.2 Main Contributions

The primary contribution of this thesis is the design of a controlled natural language such that its member sentences include those with temporal expressions. Achieving such a language design requires analyses of the interactions of tenses, grammatical aspects, temporal prepositions and adverbials. We therefore carry out an analysis of temporal modifiers and how they behave within different configurations of verb aspectual class, tense and aspect.

## 1.3 Thesis Outline

Chapter 2 introduces the technical tools required for the definition of a controlled natural language. We begin by introducing what languages are and how they are formally defined by grammars. We then proceed to describe various formal grammars. Finally chapter 2, concludes by discussing how we can generate the semantic interpretation of natural language sentences from their syntactic structure.

In chapter 3 we introduce formal representation of temporal information. We present theories of temporal instant logic and temporal interval logic highlighting which is more appropriate for the definition of a controlled natural language. We proceed to discuss temporal expressions in natural language providing a brief introduction on how they can be formally represented.

Chapter 4 provides an overview of controlled natural languages, their applications and a summary of how a controlled natural language with temporal features can be defined.

In chapter 5 we consider temporal modifiers – temporal prepositions, temporal conjunctions and temporal adverbials. We considered the syntactic structures of temporal prepositional phrases as well as the tense/aspect construction of their main clauses. Similarly we consider the syntactic construction of temporal conjunction sentential complements as well as their main clauses. We also provide semantic interpretation for each of the temporal modifiers discussed.

Following the discussion of temporal modifiers in chapter 5, we provide a design of controlled natural language with temporal features in chapter 6, showing how the lexicon, grammar and semantic interpretations are defined.

Chapter 7 draws concluding remarks on the contributions of this thesis and



provides suggestions for future research.

# Chapter 2

## Technical Preliminaries

Controlled Natural Languages are just natural languages with regimented syntax. We are however not only interested in the syntactic representation of our proposed language but we also aim to provide appropriate unambiguous semantic interpretation for sentences in the language. In order to achieve this we need to consider a number of techniques and tools employed in achieving our set goals. We will often describe a natural language utterance as grammatical or not, but many speakers are not necessarily aware of the role grammar plays in the definition of their spoke language. In this chapter we therefore consider the meaning and definition of a language in section 2.1, section 2.2 provides a brief description of the syntactic tool – grammar, we consider a few examples of grammar in that section. In section 2.3, we consider the various formal languages that can be used in expressing meaning. Section 2.4 shows how our syntactic representation and semantic interpretations, come together to provide a formal though regimented fragment of natural language.

### 2.1 Language

The term *language* according to the Oxford dictionary is described as the method of human communication, either spoken or written, consisting of the use of words in a structured and conventional way. The dictionary description of language can be considered rather inadequate particularly for formal languages. Hopcroft and Ullman [1969] therefore define a language as any set of *sentences* over an alphabet or vocabulary. It is expected in reality that most languages contain an infinite number of *sentences*. An *alphabet* or *vocabulary* is a finite set of symbols

for example, the Greek alphabets, Latin alphabets,  $\{a, b, c, \dots, z\}$ , and the binary alphabet  $\{0,1\}$  etc.

Natural languages can be defined similarly. For example, English can be considered a set of sentences where the vocabulary is a set of English words such as those found in the dictionary. Given the vocabulary of a language we require a set of rules that determines correct sentences of the said language. In elementary English language we speak often of the term grammar. Technically a grammar can be described as an algorithm that systematically generates successive sentences of a given language. Sentences of formal languages are strictly constructed by one form of grammar or the other. Natural languages tend to be vague and hence do not necessarily have definitive grammars. Hence the idea of Controlled Natural Languages which are hybrid languages between formal and natural languages with more strictly defined and regimented syntax. We consider various forms of grammar in the following section.

## 2.2 Grammar

Having discussed languages, we attempt in this section to define how they can be syntactically defined – grammars. A grammar is a procedure responsible for systematically generating correct sentences of a given language. Initially a linguistic concept primarily used for the representation of natural languages, grammars have been applied in the development of formal and computer languages as well. Chomsky [1956] states that a properly formulated grammar should determine unambiguously the set of legal sentences of a given language. Grammars provide rules that define what is or is not a valid sentence of a given language as well as providing structural descriptions of the said language's sentences. One of the aims of having a formal grammar for representing natural language is to enable machines process natural languages like English. Unfortunately, we do not have a definitive grammar for English and indeed any other natural language. Computer languages however have well defined grammars for their representation.

Formally as defined by Chomsky [1956], we denote a grammar as a tuple

$$G = \langle V_N, V_T, P, S \rangle$$

where,

- $V_N$  is a set of *non-terminal* symbols which are also known as *syntactic categories*;
- $V_T$  is the set of *terminal* symbols these are the actual words ;
- $P$  is a set of *production rules* which show the relationship between various strings of non-terminals and terminal symbols;
- $S$  is the *start symbol* such that  $S \in V_N$ .

It is assumed that  $V_N$  and  $V_T$  have no common elements, that is  $V_N \cap V_T = \emptyset$ . The production rules  $P$  are usually expressions of the form  $\alpha \rightarrow \beta$ , where  $\alpha$  is a string in  $V^+$  and  $\beta$  is a string in  $V^*$ .

Given a grammar  $G$ , we need to provide a definition for the language it generates. In order to do that we need to provide a few definitions first: If  $\alpha \rightarrow \beta$  is a production and  $\gamma$  and  $\delta$  are strings in  $V^*$ , then  $\gamma\alpha\delta \xrightarrow{G} \gamma\beta\delta$  means the production  $\alpha \rightarrow \beta$  is applied to string  $\gamma\alpha\delta$  to obtain  $\gamma\beta\delta$ . Thus  $\xrightarrow{G}$  relates two strings when the second is obtained from the first by the application of a single production. Assuming  $\alpha_1, \alpha_2, \alpha_3, \dots, \alpha_m$  are strings in  $V^*$ , and  $\alpha_1 \xrightarrow{G} \alpha_2, \alpha_2 \xrightarrow{G} \alpha_3, \dots, \alpha_{m-1} \xrightarrow{G} \alpha_m$ . Then we say  $\alpha_1 \xrightarrow{G}^* \alpha_m$ , meaning we obtain  $\alpha_m$  from  $\alpha_1$  by applying some number of production rules. We can now define the language  $L(G)$  generated by the grammar  $G = \{w \mid w \in V_T^* \text{ and } S \xrightarrow{G}^* w\}$ . That is,  $w$  is a string or sentence in  $L(G)$  if;

1. The string consists solely of terminals ( $V_T$ )
2. The string can be derived from  $S$

The language of  $G$ , is a set of terminal strings that have the head of their production rules as the start symbol;

$$L(G) = \{v \in V_T^* \mid S \xrightarrow{G}^* v\}$$

We say grammars  $G_1$  and  $G_2$  are equivalent if  $L(G_1) = L(G_2)$ .

Chomsky [1959] described a theory of language as containing a specification  $F$  of functions from which grammars for particular languages may be drawn. According to him there are several forms of restrictions with different strengths that can be placed on the specification  $F$ . This leads us to the concept of types of grammar (Chomsky hierarchy).

From the type 0 grammar otherwise known as the unrestricted grammar Chomsky defined three levels of restriction which as a result produced three grammars namely the *type 1*, *type 2* and *type 3* grammars. These grammars are otherwise known as the context sensitive grammars, context free grammars and regular expressions respectively. Chomsky however suggested the context free grammars to be most suitable for the representation of natural language syntax. We therefore consider the consider CFGs in more detail next.

### 2.2.1 Context Free Grammar(*cfg*)

Similar to our definition of grammars above, if  $G$  is a *cfg*, then  $G = \langle V_N, V_T, P, S \rangle$  such that  $V_N$  is a finite set of non-terminal variables or syntactic categories,  $V_T$  is a finite set of alphabet or words,  $P$ , the finite set of production rules recursively define sentences in the language. Given that each production rule consists of a non-terminal variable defined by the production rule known as the *head*, the production symbol  $\rightarrow$  followed by a string of terminal words and or non-terminal variables called the *body*. We are therefore able to form strings of the language of the head variable. Thus more head variables can be derived from previously defined ones.

#### Parse Trees

The derivation of sentences with the use of context free grammar can be represented graphically with the aid of parse trees. Given a grammar  $G$  defined as usual –  $G = \langle V_N, V_T, P, S \rangle$ , where the tree leaf is a node without any children, the parse trees of  $G$  must have each node labelled by a member of  $V_N$  excepts for the leafs which are labelled with either the empty string  $\epsilon$  or a terminal symbol ( $V_T$ ). Note when a leaf is labelled by  $\epsilon$ , it must be the only child of its parent. Given a node labelled  $Y$ , and its children are labelled  $X_1, X_2, \dots, X_n$  from left to right respectively, the production rule for the said node is given as  $Y \rightarrow X_1, X_2, \dots, X_n$ .

- (1) John loves Mary

Given a sentence such as (1), from basic English grammar we know the sentence consists of the categories noun phrase followed by a verb phrase. We can define a context free grammar to generate sentence (1) with its corresponding parse tree as seen in Table 2.3 and Figure (2.1) respectively.

|                               |
|-------------------------------|
| $S \rightarrow NP, VP$        |
| $NP \rightarrow PN$           |
| $VP \rightarrow TV, NP$       |
| $PN \rightarrow \text{John}$  |
| $PN \rightarrow \text{Mary}$  |
| $TV \rightarrow \text{loves}$ |

Table 2.1: Simple CFG rules

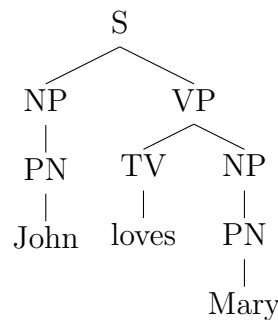


Figure 2.1: Simple Parse Tree

There are however other grammars that are capable of representing the syntactic structure of natural language sentences. Some of these grammars include Categorical grammars, Tree adjoining grammars, Dependency grammars etc. There has been sufficient research on these other formalisms as well with several attempts to find relationships between them such as equivalence. Before we consider possible relationships between some of these grammars, lets briefly discuss how they work.

### 2.2.2 Categorical Grammar

There are various forms of categorical grammars, we begin by introducing Bar-Hillel et al. [1960] bidirectional categorical grammar (we will sometimes refer to this grammar as AB-grammar). The basic idea behind this grammar is that the syntactic category of a given lexical item is determined by what it is required to be concatenated with on its right and on its left to form a sentence. AB-grammar therefore have the following rules:

1. Replace a string of two category symbols of the form  $[\alpha/\beta], \beta$  by  $\alpha$

$$[\alpha/\beta], \beta \Rightarrow \alpha$$

2. Replace a string of two category symbols of the form  $\beta, [\alpha \setminus \beta]$  by  $\beta$

$$\alpha, [\alpha \setminus \beta] \Rightarrow \beta$$

The first rule means given an alphabet or string with category  $\alpha/\beta$ , it is required to concatenate to its right with another alphabet or string of category  $\beta$  to produce a string with category  $\alpha$ . The second rule means given an alphabet or string with category  $\alpha \setminus \beta$ , it concatenates to its left with another alphabet or string of category  $\alpha$  to produce a string with category  $\beta$ .

To appreciate the way the AB-grammar works, lets attempt to apply it to an English sentence like sentence (1). We assign the category  $S$  to the sentence as a whole, let *John* and *Mary* be assigned the category NP. The interesting part of the categorial grammar is the category we assign to *loves*. The lexical entry *loves* is a transitive verb, that is it takes an NP on either side. We therefore assign to the verb *loves* the category  $NP \setminus S / NP$ . What this means is, *loves* is a lexical entry that takes a noun phrase NP to its right and another to its left to produce a sentence S.

Lambek [1958] presented three sequent rules using the Gentzen style sequent presentation. Consider below Lambek sequent rules

1. 
$$\frac{\Gamma_2 \Rightarrow \beta : B \quad \Gamma_1, \beta : B, \Gamma_3 \Rightarrow \alpha : A}{\Gamma_1, \Gamma_2, \Gamma_3 \Rightarrow \alpha : A} \text{ C}$$
2. 
$$\frac{\Delta \Rightarrow \beta : B \quad \Gamma_1, \alpha(\beta) : A, \Gamma_2 \Rightarrow \gamma : C}{\Gamma_1, \alpha : A/B, \Delta, \Gamma_2 \Rightarrow \gamma : C} /L$$
3. 
$$\frac{\Delta \Rightarrow \beta : B \quad \Gamma_1, \alpha(\beta) : A, \Gamma_2 \Rightarrow \gamma : C}{\Gamma_1, \alpha : B \setminus A, \Delta, \Gamma_2 \Rightarrow \gamma : C} \setminus L$$

Where  $\Gamma_1, \Gamma_2, \Gamma_3, \Delta$  are lexical entries,  $\alpha, \beta, \gamma$  are the semantic interpretation of the lexical entries or string,  $A, B, C, A/B, B \setminus A$  are syntactic categories. Rule 1. is called the cut rule which enforces the transitivity of the derivation relation. It says that  $\Gamma_1, \Gamma_2, \Gamma_3 \Rightarrow \alpha : A$  if  $\Gamma_2 \Rightarrow \beta : B$  and  $\Gamma_1, \beta : B, \Gamma_3 \Rightarrow \alpha : A$ .

Rules 2. and 3. are called the elimination rules, similar to the reduction rules of the AB-grammar. Like we did with the context free grammar and the AB-grammar, let us illustrate the sequents rules in Lambek grammar with a sentence. Note that we omit the semantic interpretation of the each of the syntactic categories in the derivation tree below. We show later in this chapter how they can be included and used in generating the semantic interpretation of a sentence.

$$\frac{\frac{John}{John : NP} \quad \frac{\frac{loves}{loves : NP \setminus S/NP} \quad \frac{Mary}{Mary : NP}}{loves Mary : NP \setminus S} /L}{John loves Mary : S} \setminus L$$

Figure 2.2: Derivation of simple English sentence using Lambek's Elimination rules.

Figure 2.2 illustrates the right and left cancellation rules of the Lambek calculus. It produces a derivation tree that shows how a lexical item concatenates with another to form a sentence based on its syntactic category.

Lambek's categorial grammar more commonly known as type logical grammar does in fact recognise the same language as the AB-grammar. Pentus [1993] proved that context free grammars and type logical grammars generate the same language as well.

### 2.2.3 Tree-adjoining Grammar (*TAG*)

Tree Adjoining Grammars are tree generating systems consisting of a number of elementary trees as opposed to context free grammars which are string generating systems consisting of production rules. The set of elementary trees in tree adjoining grammars are divided into two – *initial* ( $\alpha$ ) trees and *auxiliary* ( $\beta$ ) trees. Suppose we are given a sentence such as 1, we represent it in Tree Adjoining Grammar as given in figure 2.3, where  $\downarrow$  represents substitution. We can

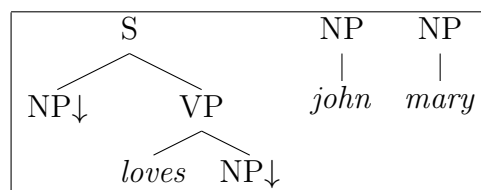


Figure 2.3:  $\alpha$ -trees

intuitively observe the similarity between CFG and the subtrees in Figure 2.3. The above diagram does not quite totally describe the Tree Adjoining Grammars it can rather be referred to as Tree Substituting Grammars(TSG). Its worth mentioning that TSGs and CFGs are weakly equivalent. Suppose we attempt representing sentence (2) with the TAG.

(2) John really loves Mary.



We are unable to provide the tree structure for the given sentence with the grammar given in Figure 2.3. Joshi et al. [1975] therefore introduced the  $\beta$ -trees to deal with such a situation. Consider Figure 2.4 below:

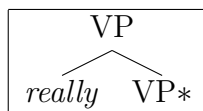


Figure 2.4:  $\beta$ -trees

$\beta$ -trees as in Figure 2.4 are required to have a leaf with the same non-terminal symbol as the root annotated with an asterisk symbol. This tree enables us to suspend the nodes in the  $\alpha$ -tree with the same symbol as the  $\beta$ -tree in this case the VP node. Replacing it with the  $\beta$ -tree and then reintroducing the previously suspended subtree as seen in figure 2.5.

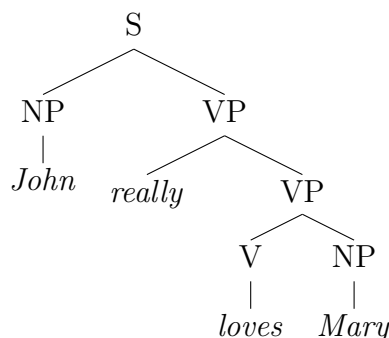


Figure 2.5: Derived Tree

Tree adjoining grammar is regarded to be a stronger grammar than the context free grammar. That is it is able to represent the syntax of more complex languages than CFGs. It is otherwise known to be mildly context sensitive. Although this formalism appears fairly easy to understand, computation is not so easy hence, context free languages still appears more practical in comparison.

## 2.2.4 Dependency Grammar(DG)

Dependency grammar was created by Tesnière [1959]. The basic idea behind dependency grammar is, given a sentence, every lexical item except one in the said sentence is dependent on another lexical item. This lexical item which does not depend on any other item is called the root of the sentence. In most cases this root is the main verb of the sentence. Given a simple sentence as (3);

(3) Every student spoke.

The sentence verb *spoke* acts as the root and therefore depends on nothing. The determiner *a* depends on the noun *student*. The noun *student* is in turn dependent on the root. This relation can be represented graphically as in figure 2.6, where each edge represents dependency of the child(ren) on the parent.

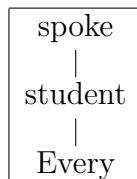


Figure 2.6: DG Graph

Robinson [1970] proposed four axioms to govern the well formed dependency structures;

1. Strictly one element is independent
2. All other elements depend directly on some element
3. No element is dependent directly on more than one other element
4. If A depends on B and some element C intervenes between them, then C depends directly on A or B or some other intervening element.

The first three axioms are self explanatory, the fourth axiom is otherwise called the requirement of projectivity essentially prevents crossing edges in dependency trees.

Hays [1964] and Gaifman [1965] provided a formal definition for the dependency grammar. A dependency grammar is defined as

$$G = \langle R, L, C, F \rangle,$$

where  $R$  is a set of dependency rules over the auxiliary symbols  $C$ ,  $L$  is a set of terminal symbols(vocabulary),  $C$  is a set of auxiliary symbols,  $F$  is an assignment function which assigns terminal symbols to categories. Hays and Gaifman's definition of dependency grammar complies with Robinson's axioms. From the above definition of dependency grammar it is possible to prove that CFGs and DGs generate the same language, hence they are equivalent.

### 2.2.5 Discussion

We have thus far considered various grammar formalisms and how they are used to provide syntactic representation for natural language sentences, precisely English. There are however several choices we make in the development of our language that require justification. The grammars discussed thus far include, the four grammars in Chomsky's hierarchy, categorial grammars, Tree substitution grammars, Tree Adjoining grammars and Dependency grammars. We obviously need to make a choice amongst these formalisms.

Amongst the four languages in Chomsky's hierarchy, the Context Free Grammar was specifically developed to suit the syntactic representation of natural languages, and from section 2.2.2 we observed that categorial grammar in form of Lambek calculus is equivalent to the context free grammar. Therefore we know that the categorial grammar is able to represent the language the context free grammar can. There are however linguists such as Shieber [1987] who believe that the context free grammar is not powerful enough to define natural languages. This led to the development of Tree adjoining grammars which is said to allow lexicalisation more easily than CFGs and is said to also define more complex languages.

We are therefore faced with the problem of which of these languages best suits the the development of a controlled natural language. Having established that context free grammars, categorial grammar and the dependency grammar are known to be weakly equivalent, choosing between them will therefore be up to convenience. Since the context free grammar initial purpose is for the representation of natural language syntax, its application is fairly intuitive in comparison with the categorial and dependency grammars. We will also observe in section 2.4.2, how we can easily annotate context free grammar categories with simply typed logical semantics. This is not to say you can achieve this with other grammars, the context free grammar is apparently more straight forward.

However given that the Tree adjoining grammar was developed to cater for the weakness of CFGs, one might expect it to be the grammar of choice for our proposed language. We however observe that while it is easy to apply to natural language theoretically, it is not very easy to parse automatically (Abeillé and Rambow [2000]). What sets the tree adjoining grammars apart from CFGs is the adjunction property, while this permits lexicalisation of the trees and we can provide more restriction for more complex languages. Some of these productions

can also be achieved with CFGs with recursive production rules although this might cause over generation. Although there are restrictions that permit a better defined set of sentences with the use of TAG, the resulting sentence can also be generated with the CFG production rules as in Table 2.2 below. We therefore use

|            |
|------------|
| S→NP, VP   |
| NP→PN      |
| VP→TV, NP  |
| VP→ADV, VP |
| ADV→really |
| PN→John    |
| PN→Mary    |
| TV→loves   |

Table 2.2: Recursive CFG rules

Context Free Grammars for the syntactic representation of our controlled natural language, as it is more easily applicable than the Tree Adjoining Grammar

## 2.3 Natural Language Semantics

We often tend to represent the meaning of natural language sentences with aid of some formal language. One of such formal languages is propositional logic. In propositional logic we are interested in the truth or falsity of a given proposition without consideration of the internal structure of the said proposition. From our discussion of the various grammar formalism, it is quite obvious that the internal structure of sentences of our proposed language is of considerable interest. We therefore require a different formal language that considers the internal structure of sentences. An example of such language is first order logic. Given therefore a sentence such as

(4) Every boy loves some girl,

we interpret (4) as

(5)  $\forall x(\text{boy}(x) \rightarrow \exists y(\text{girl}(y) \wedge \text{love}(x, y)))$ .

Unlike propositional logic, first order formulas like (5) considers the internal structure of the sentence such that we can quantify existentially or universally over variables which represents object where there are predicates that provide information about the relations between these variables.

There are however linguistic/philosophical issues to observe before we can consider first order logic as being adequate for the interpretation of natural language sentences. Amongst these issues include the interpretation of time and temporal expressions, representing temporal information in first order logic has been a constant topic of discussion in computational linguistics for many decades. Although there are many theories on how it should be done there is still not an agreed upon approach. For example, one of the main questions in the interpretation of temporal expression is whether or not temporal variables should represent time instants or time intervals.

Another issue of interest is predicate adverbials. For example, given a sentences such as

(6) John is walking quickly,

we are unable to represent verbal modifiers like *quickly* in first order logic.

Finally we consider anaphora. While first order logic is able to provide interpretation for sentences with anaphoric references, it can tend to be confusing particularly if we want to provide an anaphoric reference in a discourse for an already quantified variable. There is however a variant of first order logic that enables us to provide interpretation to anaphoric references a lot easier. The first order logic variant is called Discourse Representation Theory. We discuss it next in the following subsection.

### 2.3.1 Discourse Representation Theory

Discourse Representation Theory was proposed by Kamp [1981], it is excellent in handling linguistic and logical issues such as anaphora, conditionals and quantification. DRT is amongst a family of semantic framework known as dynamic semantics. DRT involves a level of representation of a discourse and not just simple sentences in what is referred to as Discourse Representation Structures.

Informally a DRS is made up of two parts – a universe of discourse referents which represents the object of the said sentences of set of sentences. And a set of DRS condition that encode the information accumulated for from the member sentences of the discourse of interest. Therefore given a simple sentence such as

(7) A farmer chased a donkey,

we represent the DRS thus:

(8)  $[x, y : \text{farmer}(x), \text{donkey}(y), \text{chased}(x, y)]$

Where  $x$  and  $y$  are the discourse referents and  $\{\text{farmer}(x), \text{donkey}(y), \text{chased}(x, y)\}$  is the set of DRS conditions from the given sentence. Supposed we have sentence(7) followed by verb phrase (9).

(9) caught it.

Without the context of the previous sentence, we represent (9) as (10)

(10)  $[v, w : \text{caught}(v, w)]$

Placing sentence(9) within the context of sentence(7), we have the DRS(11).

(11)  $[x, y : \text{farmer}(x), \text{donkey}(y), \text{chased}(x, y), \text{caught}(x, y)]$

. Where the variables  $v$  and  $w$  have been substituted with the  $x$  and  $y$  as they are anaphors of *farmer* and *donkey* respectively.

## 2.4 Automatic Translation

We have discussed a few grammatical formalisms thus far and if anything is worth noting from that brief discussion, it is that grammars are basically responsible for the definition of sentences of a given language from a strictly syntactic perspective. However when given a sentence of a certain language, we are not only concerned about the grammatical correctness and structure of the given expression, but its meaning as well.

If we are to have any chance of representing natural language, we need to concern ourselves with what tools are available for providing a formal semantic interpretation of its sentences. From the discussion on natural language semantics above it appears first order logic has the expressive power to handle this requirement. First order logic is a language in itself and possesses all the properties of a language as enumerated in section 2.1. We therefore attempt in this section to provide an overview of a system that enables us to assign semantic interpretations to sentences of a given natural language from the interpretation of its constituent categories. We begin by discussing the mathematical system Lambda calculus

### 2.4.1 Lambda Calculus

Lambda calculus is a system developed by Church [1940]. Lambda calculus enables us to apply functions to arguments. For example, supposed we are given a polynomial as in (12) and we want to compute the value of the expression if  $x = 4$ .

$$(12) \quad x^2 + 4x - 5$$

We can apply lambda calculus by turning the polynomial into a lambda term as seen below:

$$(13) \quad \lambda x[x^2 + 4x - 5]$$

We can therefore apply it to the argument thus:

$$(14) \quad \lambda x[x^2 + 4x - 5](4) = \\ 4^2 + 4 \cdot 4 - 5 = 27$$

A lambda term is therefore defined thus (adapted from Carpenter [1997]),

**DEFINITION 2.4.1** *TYPES* from a nonempty set **BasTyp** of basic types, the set **Typ** of types is the smallest set such that

1. **BasTyp**  $\subseteq$  **Typ**,
2.  $(\sigma \rightarrow \tau) \in \mathbf{Typ}$  if  $\sigma, \tau \in \mathbf{Typ}$

Types in the form  $\sigma \rightarrow \tau$  are called the functional types, which are elements which map objects of type  $\sigma$  to objects of  $\tau$ . Functional types can be represented in other forms for example, the above functional type can be represented as a tuple:  $\langle \sigma, \tau \rangle$ .

**DEFINITION 2.4.2** *we define  $\lambda$ -term thus. For every type  $\tau$ , we have the following sets*

1. **Var** $_{\tau}$ : infinite set of variables of type  $\tau$
2. **Con** $_{\tau}$ : a collection of constants of type  $\tau$

**DEFINITION 2.4.3** *Definition(1.2):  $\lambda$ -terms* The collection of **Terms** $_{\tau}$  of  $\lambda$ -terms of type  $\tau$  are defined as the smallest set such that

1.  $\mathbf{Var}_\tau \subseteq \mathbf{Term}_\tau$ ,
2.  $\mathbf{Con}_\tau \subseteq \mathbf{Term}_\tau$ ,
3.  $(\alpha(\beta)) \in \mathbf{Term}_\tau$  if  $\alpha \in \mathbf{Term}_{\sigma \rightarrow \tau}$  and  $\beta \in \mathbf{Term}_\sigma$
4.  $\lambda x.(\alpha) \in \mathbf{Term}_\tau$  if  $\tau = \sigma \rightarrow \rho$  and  $x \in \mathbf{Var}_\sigma$  and  $\alpha \in \mathbf{Term}_\rho$

A term of the form  $\alpha(\beta)$  is called a functional application of  $\alpha$  to  $\beta$ . For example, if an expression  $walk(esther)$  is of the type  $Bool$ ,  $esther$  is of the type  $Ind$ , then  $walk$  will be of the type  $Ind \rightarrow Bool$ .

A term of the form  $\lambda x.(\alpha)$  is a functional abstraction. As explained in the previous paragraph, application always involve a functional type, while abstraction always produces a functional type. To illustrate this, lets consider the verb phrase *loves John* we have first order representation  $love(x, john)$ , assuming  $x$  is of type  $Ind$ , we can abstract  $x$  thus:  $\lambda x.love(x, john)$ .  $\lambda$  abstraction is governed by the following axiom schemes.

**DEFINITION 2.4.4** *Axioms for  $\lambda$ -calculus*

1.  $\vdash \lambda x.\alpha \Rightarrow \lambda y.(\alpha[x \mapsto y])$  ( $\alpha$ -reduction)
2.  $\vdash (\lambda x.\alpha)(\beta) \Rightarrow \alpha[x \mapsto \beta]$  ( $\beta$ -reduction)
3.  $\vdash \lambda x.(\alpha(x)) \Rightarrow \alpha$  ( $\eta$ -reduction)

Lets consider examples to express how the  $\lambda$  calculus works. Given a  $\lambda$  abstracted formula

$$\lambda Q[\forall x(girl(x) \rightarrow Q(x))]$$

In the formula above  $x$  is of type  $Ind$ ;  $girl(x)$  and  $Q(x)$  are of type  $Bool$  therefore  $girl$  and the  $\lambda$ -abstracted variable  $Q$  are of type  $Ind \rightarrow bool$ . For rule 2 to be applicable we need to apply a  $\lambda$ -term of the same type as  $Q$ .

$$\lambda Q[\forall x(girl(x) \rightarrow Q(x))](\lambda y[human(y)])$$

Applying the second axiom defined above, we have

$$[\forall x(girl(x) \rightarrow \lambda y[human(y)](x))]$$

We have another  $\lambda$  term of type  $Ind$  we can therefore apply the variable  $x$  thus

$$[\forall x(girl(x) \rightarrow human(x))]$$



## 2.4.2 Montague Semantics

Montague semantics is a tool that systematically enables us to assign semantic interpretations to natural language sentences from the semantic interpretation of their constituents. We have thus far shown how to represent the syntax of a simple English sentence with the aid of several grammars. Montague semantics puts together the interpretation of each syntactic category of a given sentence e.g. *John loves Mary*, and a set of productions:

|  |
|--|
| $S \rightarrow NP, VP$<br>$NP \rightarrow PN$<br>$VP \rightarrow TV, NP$<br>$PN \rightarrow \text{John} / \lambda P[P(\text{john})]$<br>$PN \rightarrow \text{Mary} / \lambda Q[Q(\text{mary})]$<br>$TV \rightarrow \text{loves} / \lambda x_3 \lambda x_4 [x_3(\lambda x_5 [\text{love}(x_4, x_5)])]$ |
|--|

Table 2.3: Simple CFG rules

We have the derivation tree:

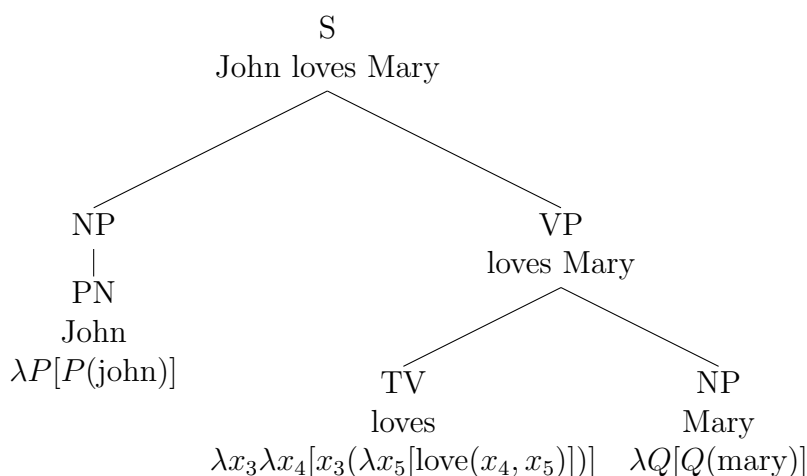


Figure 2.7: Semantic annotated parse tree

Blackburn and Bos [2005] discussed the systematic interpretation of natural language expressions. Chapter 2 of their book explains how we can systematically generate the semantic representation of expressions from their syntactic constituents. Although they showed this using context free grammar (see Figure 2.7), we attempt to show here that we can generate a semantic representation of an expression using categorial grammar. Note that we mentioned in section 2.2.2 that categorial grammars are weakly equivalent to context free grammars.

$$\frac{\frac{\textit{John}}{\lambda P[P(j)] : np} \quad \frac{\frac{\textit{loves}}{\lambda x_3 \lambda x_4 [x_3 (\lambda x_5 [\textit{love}(x_4, x_5)])]} : np \setminus s/np} \quad \frac{\textit{Mary}}{\lambda Q[Q(m)] : np}}{\lambda x_5 [\textit{love}(x_5, m)] : np \setminus s}}{\textit{love}(j, m) : s}$$

Figure 2.8: Semantic annotated categorial grammar

Employing  $\lambda$ -calculus, we can systematically derive natural language expression along with its syntactic derivation using any formal grammar we decide to choose, here we use the categorial grammar. Representing meaning in natural language however involves a lot of other complexities not expressed in the above example, some of these include plurals, number agreement, tense and aspects etc. We will discuss some of these in subsequent chapters of this thesis.

## 2.5 Conclusion

Languages in general whether formal or natural are governed by rules. Although as discussed over the course of this chapter we know that natural languages tend to have rather less strict rules at least when compared with formal or computer languages. However our aim of defining a fragment of English language that is computable requires us applying a grammar. In this chapter we discussed few grammars highlighting similarities between them and in some cases equivalence. We are therefore left with the choice of which of the grammars to apply in the definition of our language. Given the four Chomsky grammars, categorial grammars, LFGs and dependency grammars, we find the context free grammar to be the most intuitive and easily applicable to natural language. This might be the case as it was originally created for the purpose of defining natural language syntax as opposed to the categorial grammar which was originally designed for formal languages and was only later adapted for natural language by making it bi-directional.

We discussed three formal representation, namely – propositional logic, first order logic and Discourse representation theory. While propositional logic is quite simple to understand, its application to natural language interpretation is quite impractical as it does not consider the internal structure of the sentences of interest. As a result we are unable to generate the semantic interpretation a sentence

from the semantic interpretation of its constituents. We see in section 2.4.2 how we can generate our sentence interpretation in first order logic from a semantic annotated context free grammar parse tree. We can derive similar interpretations in DRSs as well. Considering the inclusion of temporal information in our semantics we will stick to generation our semantics in first order logic through Montague semantics.

# Chapter 3

## Temporality in English

### 3.1 Temporal Ontology

There has been a perpetual discussion of what is the most appropriate representation of time. Time is of immense relevance in many fields of study and hence their representation varies respectively. In this section we consider some of the existing representation of time with an attempt to make choices on which model best suits the development of a controlled natural language with temporal features.

#### 3.1.1 Time Flow

We often have time points ordered in sequence or on a line. This model of time can be represented formally as  $\Gamma = \langle T, < \rangle$ , where  $T$  are time points and  $<$  is an ordering relation on the set  $T$ . Therefore if  $s$  and  $t$  are time points in  $T$ , then  $s < t$  means  $s$  is *before*  $t$ . We refer to this structure as a flow of time if the relation  $<$  is irreflexive and transitive.

Flows of time are strictly partially ordered structures. Hence any given two time points must satisfy the first order sentence:

$$\forall x \forall y ((x < y) \vee (x = y) \vee (y > x))$$

This ensures flows of time are linear structures as every time point within a given flow of time is related. There are a few choices of properties that can be imposed on linear structure of time. For example, a fundamental choice will be between denseness and discreteness of time. A linear structure of time is dense if between

any two time points we can find a third point. That is,

$$\forall x \forall y ((x < y) \rightarrow \exists z ((x < z) \wedge (z < y))).$$

A flow of time can be modelled as discrete. This model unlike dense structures does not model the movement of time. One way to compare either view is a dense structure orders time as real or rational numbers are ordered. Discrete structure orders time like integers. That is,

$$\forall x \forall y ((x < y) \rightarrow \neg \exists z ((x < z) \wedge (z < y))).$$

Alternatively, time can be modelled as branching in the future. That is given a time point, there exists two unrelated time points in its future. The structure often permits the branching of time flow to the future and not the past. The past is considered determined hence a time flow can only be linear in the past and branched in the future.

### 3.1.2 Basic Tense Logic

Temporal Logic can be considered an extension of classical propositional logic. Formulas of classical propositional logic are interpreted as either true or false. Suppose a *valuation* is a function mapping propositional logic formulas to truth values, while the assigned truth value of a classical propositional formula is fixed, the valuation of formulas in temporal logics are time dependent. Given therefore a proposition  $q$ ,  $\delta$  is a valuation that assigns a truth value to the proposition at a given time point  $t$ . We represent this thus:

$$\delta(t)(q).$$

Prior [1957] therefore defined four temporal modal operators that assigns truth values to propositions dependent on time thus:

- **P**: "It has at some time been the case that..."
- **F**: "It will at some time be the case that..."
- **H**: "It has always been the case that..."
- **G**: "It will always be the case that..."

These operators can be combined to define more complex temporal functions. For example,  $\mathbf{GP}$ (John arrives) means "it will always be the case that it has at some time been the case John arrives".

Formally, the set of Prior tense logic as is defined as the smallest set containing the propositional variables that is closed under constructing new formulas using the boolean connectives  $\neg$  and  $\wedge$  and the temporal operators  $\mathbf{G}$  and  $\mathbf{H}$ . We can therefore define the notion of truth of a propositional formula  $q$  at a time point  $t$  in a model  $M = (T, <, \delta)$ :

- $M, t \Vdash q$  if  $\delta(t)(q) = 1$
- $M, t \Vdash \neg q$  if not  $M, t \Vdash q$
- $M, t \Vdash q \wedge p$  if  $M, t \Vdash q$  and  $M, t \Vdash p$
- $M, t \Vdash \mathbf{G}q$  if  $M, s \Vdash q$  for all  $s$  given that  $t < s$
- $M, t \Vdash \mathbf{H}q$  if  $M, s \Vdash q$  for all  $s$  given that  $s < t$

The Prior tense logic is however considered to be low in expressiveness and there exists a few extensions. Most popular amongst these extension is Kamp [1968] tense logic. This extension includes new two temporal operators –  $\mathbf{S}$  and  $\mathbf{U}$  which represent *since* and *until* respectively. These operators are formally defined thus:

- $M, t \Vdash \mathbf{U}qp$  if  $M, s \Vdash q$  for some  $s$  such that  $t < s$  and  $M, u \Vdash p$  for all  $u$  such that  $t < u < s$ ,
- $M, t \Vdash \mathbf{S}qp$  if  $M, s \Vdash q$  for some  $s$  such that  $s < t$  and  $M, u \Vdash p$  for all  $u$  where  $s < u < t$ .

Supposed we have flow of time with the discrete property, we can described an operator  $\mathbf{X}$  which represents *next* time. Where  $\mathbf{X}q$  means  $q$  is true at the next time point.

### 3.1.3 Branching Time Logic

We briefly discussed the a flow of time where time is linear in the past but branched in the future. Given this system, we require a special treatment for  $\mathbf{F}q$ . One way to interpret the branched time is to assume flows of time are trees. That is they are connected strictly partial orders that is linear in the past. Each

branch of the tree is defined as  $\Gamma = \langle T, < \rangle$ . Each branch has a common time point says  $t$ . If each branch represents a possible course of events,  $b$ , we say  $b$  passes through  $t$  or  $t$  lies on  $b$ . We therefore consider possible future of  $t$  as a set of time points on a fixed branch  $b$  which passed through  $t$ . We can therefore provide the semantics of a proposition within a given branch thus:

- $M, t, b \Vdash q$  if  $\delta(t)(q)$
- $M, t, b \Vdash \neg q$  if not  $M, t, b \Vdash q$
- $M, t, b \Vdash q \wedge p$  if  $M, t, b \Vdash q$  and  $M, t, b \Vdash p$
- $M, t, b \Vdash \mathbf{G}q$  if  $M, t, b \Vdash q$  for all  $s$  on  $b$  such that  $t < s$
- $M, t, b \Vdash \mathbf{H}q$  if  $M, t, b \Vdash q$  for all  $s$  on  $b$  such that  $s < t$
- $M, t, b \Vdash \Box q$  if  $M, t, c \Vdash q$  for all branches  $c$  through  $t$

Just as with the linear tense logic, branching time systems can be extended by including the *Since* and *Until* operator. This extension creates the language computation tree logic (CTL).

### 3.1.4 Interval Based Temporal Logic

All the systems of temporal representation we have considered thus far assumes the time instants as the primitive entity of time. An alternative way of representing time is treating time as intervals. Its been observed that some real life durative events are difficult to model with time instants. We are however able to define more complex relationships between temporal entities when they are model as time points. These relationships include *precedence*( $<$ ), *inclusion*( $\subseteq$ ), *overlap*( $\mathbf{O}$ ). We can therefore represent a flow of time in interval model thus:  $\Gamma = \langle T, \subseteq, <, \mathbf{O} \rangle$ . Some natural basic properties of such interval-based relations and models include:

- reflexivity of  $\subseteq$ :  $\forall x(x \subseteq x)$ ,
- anti-symmetry of  $\subseteq$ :  $\forall x \forall y(x \subseteq y \wedge y \subseteq x \rightarrow x = y)$
- atomicity of  $\subseteq$ :  $\forall x \exists y(y \subseteq x \wedge \forall z(z \subseteq y \rightarrow z = y))$
- downward monotonicity of  $<$  with respect to  $\subseteq$ :  $\forall x \forall y \forall z(x < y \wedge z \subseteq x \rightarrow z < y)$

- symmetry of  $\mathbf{O}$ :  $\forall x \forall y (x \mathbf{O} y \rightarrow y \mathbf{O} x)$ ,
- overlapping intervals intersect in sub-interval:  $\forall x \forall y (x \mathbf{O} y \rightarrow \exists z (z \subseteq x \wedge z \subseteq y \wedge \forall v ((v \subseteq x \wedge v \subseteq y) \rightarrow v \rightarrow z)))$
- monotonicity of  $\subseteq$  with respect to  $\mathbf{O}$ :  $\forall x \forall y \forall z (x \subseteq y \wedge x \mathbf{O} z \rightarrow (z \subseteq u \vee z \mathbf{O} y))$

Allen defined thirteen operators between two intervals in a time flow. These operators are mutually exclusive and jointly exhaustive. Halpern and Shoham [1991] define a set of equivalent modal operators. We list these operators and their Allen operator equivalent in the table below.

| Allens Notation | Halpern & Shoham's Notation |
|-----------------|-----------------------------|
| equals          |                             |
| before          | $\langle L \rangle$         |
| after           | $\langle \bar{L} \rangle$   |
| meets           | $\langle A \rangle$         |
| met by          | $\langle \bar{A} \rangle$   |
| overlaps        | $\langle O \rangle$         |
| overlapped by   | $\langle \bar{O} \rangle$   |
| ended by        | $\langle E \rangle$         |
| end             | $\langle \bar{E} \rangle$   |
| during          | $\langle D \rangle$         |
| contains        | $\langle \bar{D} \rangle$   |
| began by        | $\langle B \rangle$         |
| begin           | $\langle \bar{B} \rangle$   |

Table 3.1: Allen relations between pairs of intervals and Halpern-Shoham modal operators on them

Although its been argued which is the more appropriate model of temporal representation between instants and intervals. Both ontologies are closely related and reducible to each other. Temporal intervals can be bounded by pairs of instants – beginning and end. Time instants can be viewed as an interval whose endpoints coincide or with no duration.

## 3.2 TimeML

Setzer [2001] developed an annotation scheme for the identification of features in texts that enable a reader determine the temporal order and time of events



reported. TimeML (Pustejovsky et al. [2005]) extracts temporal information from natural language text. This is done by annotating a given natural language text with XML tags. TimeML (Time Markup Language) was designed to address specifically, four basic problems in event-temporal identification:

1. Time stamping of events (identifying an event and anchoring it in time);
2. Ordering events with respect to one another (lexical versus discourse properties of ordering);
3. Reasoning with contextually underspecified temporal expressions (temporal expressions such as last week and two weeks before);
4. Reasoning about the persistence of events (how long does an event or the outcome of an event last).

TimeML performs information extraction using XML-based tags, there are four major tags namely – EVENT, TIMEX3, SIGNAL, LINK Specifications of these tags are given below.

The Events tag `<EVENT>` is used for the extraction and annotation of situations. These situations could either be instantaneous or within intervals (punctual or occur over a period of time). Events are also used to describe states or circumstances in which something holds. Events are generally expressed by tensed and untensed verbs, normalizations, adjectives, predicate clauses or prepositional phrases.

For every tagged event in TimeML, an instance of that event is created using the `MAKEINSTANCE` tag. Instances of events participate in temporal relationships not just the events. `MAKEINSTANCE` is an example of a non-consuming tag in TimeML. This means unlike `TIMEX3` and `EVENT` tags that are inserted into documents and opened and closed hence surrounding the text they capture, the `MAKEINSTANCE` tag does not surround text. `MAKEINSTANCE` tags are used to capture multiple instances of an event. The following example illustrates the necessity of the `MAKEINSTANCE` tag in TimeML.

(15) John teaches on Monday and Wednesday.

This sentence contains more than one instance of the *teach* event, since it occurs on Monday and on Wednesday. Without the `MAKEINSTANCE` tag, annotation

of the above sentence will assume that there is only one instance of the event teaches. The MAKEINSTANCE tag allows a more accurate representation of the above sentence such that each occurrence of the event *teaches* is unique. Table 3.2 illustrates the annotation of events in TimeML as well as the selection of events instances.

|  |
|--|
| <pre> &lt; EVENT eid="e1" class="OCCURRENCE" &gt; teaches &lt;EVENT&gt; on Monday and Wednesday &lt;MAKEINSTANCE eiid="ei1" eventID="e1" tense="PRESENT" aspect="NONE"/&gt; &lt;MAKEINSTANCE eiid="e12" eventID="e1" tense="PRESENT" aspect="NONE"/&gt; </pre> |
|--|

Table 3.2: TimeML Event Tag

The TIMEX3 is used to mark up explicit temporal expressions like times, dates, duration, etc. The major types of TIMEX3 expressions: (a) Fully specified temporal expressions *June 11, 1989, Summer 2002*; (b) Unspecified temporal expressions, *Monday, Next month, Last year, Two day ago* (c) Durations, *Three months, Two years*.

The SIGNAL tag is used to annotate sections of the text, typically function words that indicate how temporal objects are to be related to each other. SIGNAL constitutes of several types of linguistic elements which serve as indicators of temporal relations e.g. temporal propositions, temporal connectives and subordinators. The SIGNAL tag also annotates polarity(not, no, none etc.) as well as indicators of temporal quantifications such as twice, three times etc. The specification is given as:

TIMEX3 and EVENT tags annotate time and events in a natural language text respectively, but for proper understanding and representation of natural language text and queries, TimeML is required to capture all possible temporal relationships. Given the following sentence

(16) John taught at 3:00p.m.

In sentence (16) *taught* can be stamped to the temporal expression 3:00p.m. Hence it gives an explicit event-time anchoring relationship. Representing these relationships, TimeML introduces LINKS, which is made of 3 different types: TLINK, SLINK, ALINK.

The TLINK represents the temporal relationship between events or between an event and a time, and establishes a link between the involved entities making explicit if they are: simultaneous identical, one before the other, one after the other, one immediately after the other one including the other, one being included in the other, one immediately before the other, one being the beginning of the other, one being begun by the other, one being the ending of the other, one being ended by the other.

The SLINK or the Subordination Link is used for context introduction relations between two events or an event and a signal. SLINK are of the following sort;

1. MODAL: relations that occur as a result of the presence of modal verbs (should, would, could etc.) and events that introduce a reference to a possibility
2. FACTIVE: these are verbs that introduce what an argument's veracity entails.
3. COUNTER FACTIVE: There are events that introduces a presupposition about non-veracity of its argument
4. EVIDENTIAL: these are relations introduced by REPORTING or PERCEPTION events
5. NEGATIVE EVIDENTIAL: these are introduced by REPORTING and PERCEPTION events but as opposed to EVIDENTIAL they convey negative polarity
6. NEGATIVE: these are introduced by negative particles (no, not, etc.)

The ALINK or the aspectual Link represents the relationship between an aspectual event and its argument event. Example of possible aspectual relationships—Initiation, Culmination, Termination, Continuation.

### 3.3 Tense

Speakers of English and indeed any other natural language describe situations holding within a temporal context which can either be in the *past*, *present* or, *future*. Consider the following simple English sentences.

(17) John loved Mary.

(18) John loves Mary.

(19) John will love Mary.

Sentences (17)-(19) relates the time of utterance with times *before*, *simultaneous* and *after* respectively. Relationships between the event time and speech time however, does not quite account for all the tenses in English. We will therefore discuss the existing tense theories as well as other related temporal phenomena required for appropriate semantic representation of natural language in this chapter.

### 3.3.1 Reichenbach's Theory of Tense

We have established that the tenses relate the time of speech to the time of event. Interestingly, tenses have been observed to involve quite a bit more complexity than that. Along with the obvious relationship between the event time and speech time, Reichenbach [1947] observed a third coordinate required for the representation of tenses in language. Reichenbach's theory serves as a basis for most other theories of tense. We will examine some of these theories in this chapter, but first we discuss Reichenbach's ideas on the semantics of tense.

*Reichenbach's Theory:* Reichenbach's Theory of Tense orders the time coordinates - event time ( $E$ ), speech time ( $S$ ) and reference time ( $R$ ) on a timeline depending on the tense of a given sentence.

The sentences given above show different forms of relationship between the event time and speech time. However there seem to be no explicit indication that there is a third coordinate. To observe this elusive third coordinate, consider the following sentences.

(20) John had gone.

(21) John had gone before Mary arrived.

Sentences such as (20) according Reichenbach refers to two events rather than one: (a)the moment of *John leaving* refers to the time of event, (b) a time between the event time and speech time - *reference time*. It is very difficult to still notice the existence of the reference point from sentence (20), but when modified by a

temporal prepositional phrase, it becomes a lot more obvious as we can see in sentence (21). We observe there exists between the time of event ie. *John leaving* and the speech time – a time when *Mary arrived*. This time is what Reichenbach refers to as the *reference time*.

Now that we have established the existence of the three time coordinates as defined by Reichenbach, we can therefore attempt to see how each tense in English language is represented on a timeline. The simple past tense is interpreted as the event time  $E$  and reference time  $R$  occurring simultaneously before the speech time  $S$  on the time line. The simple present tense is interpreted as the three coordinates occurring simultaneously (i.e. speech time, event time and reference time are on the same point on the time line). The future tense is interpreted as the event time occurring after the speech and reference time on a time line.  $E^{\rightarrow}$  represents extend time introduced by the progressive. Consider therefore in table 3.3 the ordering of these time coordinates for the twelve tense and aspect construction we have in English in .

| <b>Tense</b>                | <b>Timeline Coordinates</b>                               |
|-----------------------------|---|
| Past tense                  | $\rightarrow E, R \rightarrow S \rightarrow$              |
| Present Tense               | $\rightarrow S, R, E \rightarrow$                         |
| Future Tense                | $\rightarrow S \rightarrow R, E \rightarrow$              |
| Past Perfect                | $\rightarrow E \rightarrow R \rightarrow S \rightarrow$   |
| Present Perfect             | $\rightarrow E \rightarrow S, R \rightarrow$              |
| Future Perfect              |   |
| Past progressive            | $R, E^{\rightarrow} \rightarrow S \rightarrow$            |
| Present Progressive         | $E^{\rightarrow} \rightarrow S, R \rightarrow$            |
| Future Progressive          | $S, R \rightarrow E^{\rightarrow} \rightarrow$            |
| Past Perfect Progressive    | $E^{\rightarrow} \rightarrow R \rightarrow S$             |
| Present Perfect Progressive | $E^{\rightarrow} \rightarrow S, R \rightarrow$            |
| Future Perfect Progressive  | $S \rightarrow E^{\rightarrow} \rightarrow R \rightarrow$ |

Table 3.3: Time coordinates of Reichenbach’s tense

It might be worth mentioning that other theories of tense such as Comrie [1976] and Stowell [2012] considers the inclusion of reference time as a simple tense coordinate as redundant as they always coincide with the event time.

### 3.3.2 Syntax of English Tense

Having discussed the tense constructions in English, we attempt to provide syntactic representation of tense in English following the framework of generative

grammar as proposed by Chomsky [1957], Chomsky [1965].

Chomsky's syntactic theory of English tense and auxiliary was designed to generate the set of grammatical English sentences and their respective phrase structure representations. This theory accounts for the syntactic structure of finite clauses as opposed to infinitives and participials. Syntactic structure of tense according to Chomsky is based on certain production rules consisting of categories— *S* Sentence, *Aux* Auxiliary phrase, *VP* Verb Phrase etc. An example of Chomsky's grammar for English tense is given below

|   |   |
|---|---|
| 1 | $S \rightarrow NP, Aux, VP$                           |
| 2 | $Aux \rightarrow Tense, (Modal), (have+en), (be+ing)$ |
| 3 | $Tense \rightarrow past$                              |
| 4 | $Tense \rightarrow present$                           |
| 5 | $VP \rightarrow V, NP \dots$                          |

Table 3.4: Chomsky's CFG for English tense

Production (1) defines a three branch structure for all sentences. Rule (5) locates the verb *V* in the verb phrase as well as account for the linear ordering of the *V* relative to its noun phrase *NP* complement. Rule (2) tells us that depending on the what the tense is, we may choose zero or more of the parenthesized elements in the given order. The first symbol *Tense* is the mandatory morphosyntactic category with two possible values *past* or *present* defined by rule (3) and (4). Every finite clause can contain exactly one tense affix. When we have multiple auxiliary verbs in a sentence, their linear order relative to each other is determined by rule (2) as well.

(22) John Could have been reading a book

Using the production rules in Table 3.4, we have the fig(2.10) representing the deep structure.

### 3.3.3 Representation of Tenses with Temporal Intervals

Having discussed temporal intervals and how we can apply them in the representing temporal information a given English sentence, we have the tools to provide interpretation for tense. To do this we need to identify the temporal coordinates in Reichenbach's theory and represent them as temporal intervals the temporal

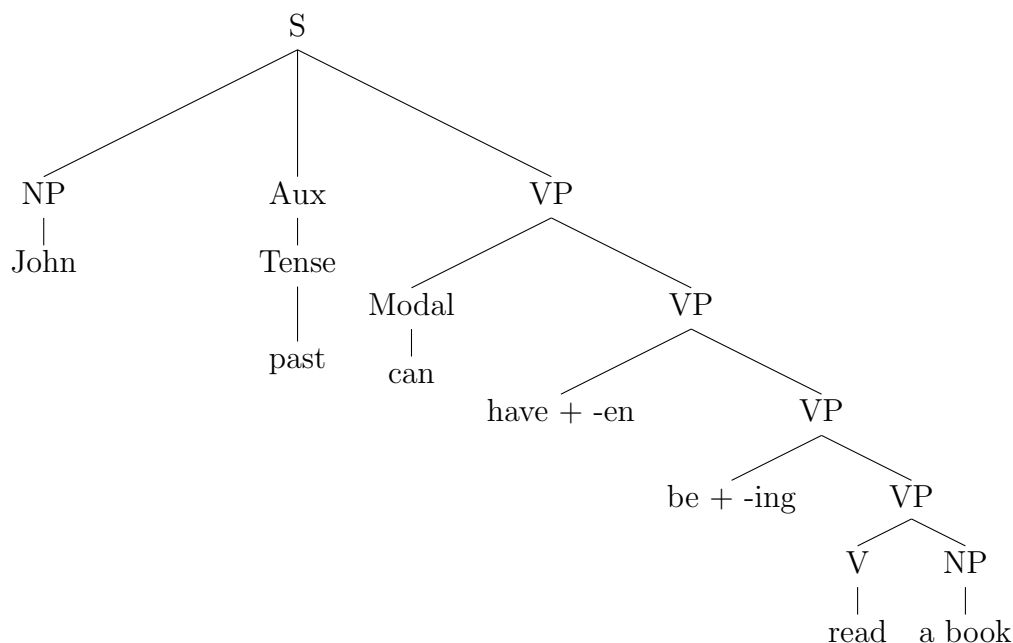


Figure 3.1: Deep Structure

ordering we place on these intervals will be dependent on the the tense of the sentence of interest.

(23) Mary kissed John.

(24)  $\lambda I[\exists i_0(\text{kiss}(\text{mary}, \text{john})(i_0) \wedge (i_0 < \text{now}) \wedge (i_0 \subseteq I))]$

Given a past-tensed sentence such (23), we interpret it as (24) where the interval  $i_0$  represents the temporal interval the with in which the event occurred, and the constant *now* represents the speech time. From Reichenbach's theory the past tense places the event time prior to the time of speech. We therefore represent temporal ordering with the precedence operator  $<$ . Hence the sentence above is interpreted as *there exists an interval where the event of Mary kissing John occurred, the said interval is before the time of speech and it is within a yet to be defined temporal context*. The future tense work similarly, to the past except for the temporal ordering of the event and speech time is reversed.

### 3.4 Grammatical Aspect

It is very difficult to separate the notion of tense from that of aspect. As a matter of fact all the theories of tense we have considered thus far include the

interaction of grammatical aspects with tenses. Comrie [1985] defines tense as the grammaticalization of location of time, Swart [2012] considered tense as deictic because it only requires reference to the speech time.

Aspects on the other hand according to Comrie [1976] are the different ways of viewing the internal temporal structure of a situation. We have two different grammatical aspects namely *the perfective aspect* and the *the imperfective aspect*. According to Binnick [1991] we have the following description for grammatical aspects:

### **Imperfective Aspect**

1. Concrete-processural: roughly the durational continuative situation of a single episode viewed in its extension. (*I am walking to the mall*)
2. Indefinite-iterative: Habitual, repetitive episodes distantly spaced in time and viewed as distinct (*Women are wearing fur coats this season*)
3. General-factual: Indefinite nonspecific episode

### **Perfective Aspect**

1. Concrete-factual: definite, specific episode viewed strictly as an occurrence (*John walked the Dog*)
2. Aggregate meaning: iterative, repetitive episodes closely spaced in time and viewed as unit (*He repeated the question to me several times*)

Referring back to the Riechenbach's theory of tense, we observed that the idea of aspect seems to be part of tense and is quite difficult to consider the two as separate concepts, however, there is much more to aspect than just the position of time coordinates on a timeline or in a predicate.

(25) I have eaten.

Syntactically when a verb is in the perfective, it is required to be preceded by the auxiliary verb *have*. For example sentence (25). When in the perfect, the main verb takes the participle inflection as in sentence (25) above. Note however that there are verbs that do not have participle inflection and just retain the past inflection for its perfective. The information of the tense of the perfect is therefore provided by the auxiliary verb *have*.



Semantically, the perfect in the present tense always locates the event time in the past such that there is a result state of the said event that is still of relevance till the time of speech. For example sentence (25) can be interpreted as the event *eating*, occurred at some past time as a result there has been a state of completion of the event which is true till the time of speech is in this case is also the time of reference. Prior's tense logic defines the present perfect as being similar to the past tense. In the past and future perfect the time of reference is not simultaneous with the speech time but rather coincides with some temporal modifier as in sentence (26).

(26) I had eaten before Mary arrived

(27) I will have eaten before Mary arrives.

Due to the deitic nature of the present tense we often do not have the present perfect with a temporal modifier providing information of the time of reference, as it just implies equality with the time of speech. The past and future tenses however require a temporal modifier.

The progressive or imperfective aspect syntactically requires the main verbs to have the suffix *-ing*. The main verb is also required to be preceded by the auxiliary verb *be*. Just like the perfect, given that the main verb does not carry information of the tense of the sentence, the *be* auxiliary verb provides information on the tense of the sentence.

The semantics of progressive is one that had been extensively studied. While we intuitively use the progressive to express continuous events, we observe the that its relationship with tense is an interesting one. A event therefore is observed as continuous from a given time of reference. Consider the following sentences.

(28) Jane was running.

(29) Jane was drawing a circle.

We can interpret sentence (28) as there exists a time in the past such that the event *running* began at a time prior to a time of reference and continued afterwards (Heny [1982]). Suppose we attempt to interpret sentence 29 similarly, we would say there exists a time in the past such the event drawing a circle began at a prior time and was completed as time afterwards. We making such a claim requires us to assume that the event of *drawing a circle* was complete. Suppose we

Jane was unfortunately struck by lightning before the completion of the event, sentence (29) will still be an appropriate statement, our interpretation will however not be correct. This is situation as observed by Dowty [1979] is called the imperfective paradox. To understand why our interpretation for sentence(28) is correct and (29) is not, we require an information of aspectual classification of verbs as given in the next section.

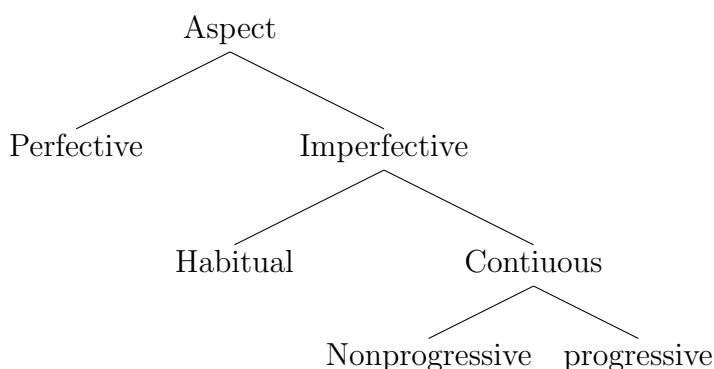


Figure 3.2: Hierarchy of Grammatical aspect

## 3.5 Aspectual Classification

Aspectual class is the classification of verbs according to the situation that the verb phrase describes. The aspectual class of a given verb phrase is determined by its internal and external structure. Vendler [1967] defined these classes first, after which more elaborate description were provided by Dowty [1979], Carlota [1983] etc. In this section we will discuss these aspectual classes and enumerate tests for distinguishing them.

### 3.5.1 States and Events

The most basic aspectual classes are the *states* and *events*. States describe static and homogeneous situations and have no internal structure. They hold over a period of time (can be judged at a moment in time) and they have no inherent end point or culmination (i.e. they can continue indefinitely except otherwise specified mostly by a temporal modifier). For example,

(30) Steve loves Kate.

*Events* on the other hand are heterogeneous and dynamic, meaning they contain phases. They can occur over a period of time (interval) or a particular point in time (moment), they may have inherent end point (not mandatory). For example,

(31) Ben is washing the dishes

.

There are a few factors that distinguish states from events. For example, states are not compatible with the progressive *be... - ing*

(32) \*John is owning the house.

(33) ?Kate is loving the summer.

(34) John is walking to the store

Sentence (32) is ungrammatical but there are certain readings where (33) is permissible where the verb *loving* is treated as an event. Sentence (34) illustrates the compatibility of the progressive with event.

States cannot be used in imperatives. Consider the sentences below.

(35) Hey you! come here

(36) \*Hey you! know English

Sentence (36) is clearly ungrammatical as opposed to sentence (35) which passes a command with an event verb.

Event verbs phrases in simple present tense have a habitual/repetitive interpretation. States in simple present tense is interpreted as holding at the present moment simultaneous with the time of speech.

(37) John washes the dishes

(38) John loves Mary

### Bounded and Unbounded Events

Eventives are further subdivided into *bounded* and *unbounded events*. Bounded events have an inherent endpoint after which the same event ceases to exist (i.e. the event culminates). This inherent termination or culmination is usually signified by a change in state of affairs. For example,

(39) The dog died last night.

We know the sentence verb *died* is bounded because its completion causes a change in the state of affairs from the dog being alive to being dead. Bounded events are also known as telic

*Unbounded event (Activities)* have no inherent end point or culmination. The same event can continue over an indefinite period of time. They are also referred to as the atelic

As proposed by Dowty, one way of distinguishing between these events is through their interaction with the temporal preposition *in*. An activities (unbounded events) cannot occur with *in*- phrase time adverbials, while bounded events can. Consider the sentences below.

(40) Walden finished the paper in 2 weeks

(41) \*Walden played the cards in 2 minutes

### Achievements and Accomplishments

The bounded event is subdivided to *accomplishments* and *achievements*. Accomplishments have two structures - a process which happens over a period of time leading to an *end point* or *culmination*

Achievement have no process preceding the endpoint. Instead they correspond to the transition point between states, or can be said to introduce a new state. It is expected to occur at a moment in time. For example,

(42) Linda's grandma passed away.

Test to distinguish between accomplishment and achievement:

Achievements cannot occur with the verbs finish or stop:

(43) The worker finished building the house

(44) \*Alex finished noticing the picture

(45) Michael stopped washing dishes

(46) \*Michael stopped passing away

A complete aspectual class test as proposed by Dowty is given in table 3.5

| Criterion   | States        | Activities    | Accomplishments | Achievements  |
|---|---------------|---------------|-----------------|---------------|
| meets nonstative tests  | no            | yes           | yes             | ?             |
| habitual interpretation in simple present tense                   | no            | yes           | yes             | yes           |
| $\phi$ for an hour, spend an hour $\phi$ ing:                     | Permitted     | Permitted     | Permitted       | not Permitted |
| $\phi$ in an hour, take an hour to $\phi$ :                       | nor permitted | not permitted | permitted       | permitted     |
| $\phi$ for an hour entails $\phi$ at all times in the hour        | yes           | yes           | no              | no            |
| x is $\phi$ ing entails x has $\phi$ ed:                          | no            | yes           | no              | no            |
| complement of stop  | permitted     | permitted     | permitted       | not permitted |
| complement of finish  | not permitted | not permitted | permitted       | not permitted |
| ambiguity with almost   | no            | no            | yes             | no            |
| x $\phi$ ed in an hour entails x was $\phi$ ing during that hour: | no            | no            | yes             | no            |
| occurs with studiously, attentively, carefully, etc.              | not permitted | permitted     | permitted       | not permitted |

Table 3.5: Dowty's aspectual class test

These classifications can be represented diagrammatically:

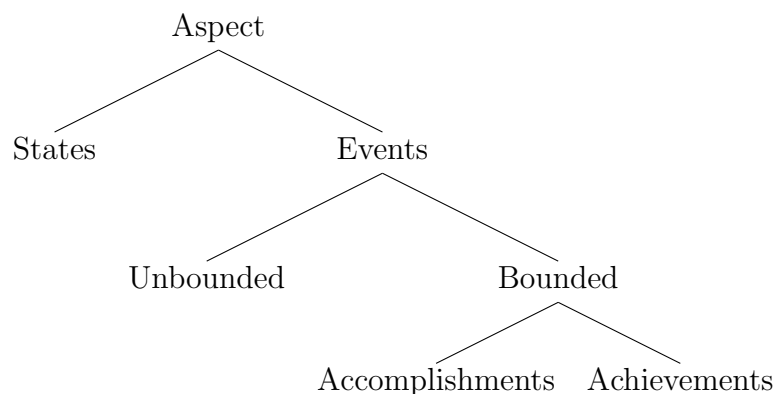


Figure 3.3: Diagrammatic representation of aspectual class (adopted from Carlota [1983])

## 3.6 Temporal Modifiers

There is one more temporal expression left for us to discuss— Temporal modifiers. These modifiers can also be considered as adverbials because of their semantic

roles on the state or event described in the main sentence. To illustrate better consider the following sentences.

(47) John kissed Mary

(48) John kissed Mary yesterday.

(49) John Kissed Mary before the meeting yesterday.

The above sentences describe the same event of *John kissing Mary*, there is however a difference due to the type of temporal context provided by the complements in sentences (48) and (49).

Some of the examples of temporal prepositions in English include *in, on, at, for, by, since, until, before, after, during, from, to, between, when, while etc.* One might have noticed that some of these prepositions have other linguistic uses other than temporal. For example locative prepositions like *in, on* and *at* can either be temporal or spatial. Consider the sentences below.

(50) Mark married Jane in Las Vegas.

(51) Mark married Jane on the rooftop.

(52) Mark married Jane at the galleria

(53) John arrived in January.

(54) John arrived on Monday.

(55) John arrived at noon.

Sentences(50)-(52) from our intuitive reading as English speakers illustrate the spatial use of the prepositions *in, on* and *at* as opposed to sentences (53)-(55) with temporal contexts. Amongst the topics of interest in the interpretation of prepositions includes syntactic markers for distinguishing between temporal and non-temporal uses of the prepositions of interest. Brée [1985a], Mittwoch [1988] amongst others provided syntactic markers for various prepositions. Bree in particular employed a very systematic procedure by analysing random sentences from an English corpus from which he was able to propose rules.

Temporal prepositions can be said to provide temporal context for the main event or state of a given sentence. We will notice from sentences(53)-(55) that

there are restrictions to the type of complements some prepositions permit. The preposition *in* for example will most likely permit years and months, *on* is most compatible with days and dates while *at* permits clock times. The syntactic structure of the main clause is also of huge importance in the correct use of temporal prepositions. Consider the following sentences.

(56) John did not return until Mary called.

(57) \*John did not return since Mary called.

(58) John has not returned since Mary called.

From the above sentences we observe that sentence(57) is ungrammatical, except it is in the perfect as in sentence(58). Other than the tense/aspect construction, of the main clause, an important factor in determining grammatical use of temporal preposition is the aspectual class of the main verbs. From the Dowty's study of the relation of aspectual classes and temporal prepositions we observe certain restrictions for example the preposition *for* only permits states or activities as main the verb.

Restrictions are also placed on the subordinate clause. As we have already observed above the different type of complement each of the locative prepositions permitted. But other than that, temporal prepositions can either have temporal nouns, events nouns or sentences as complements. The syntactic category selected by a given prepositions is often peculiar. Consider the following sentences.

(59) Marcos drank a cup of tea during the lecture.

(60) \*Marcos drank a cup of tea during noon.

(61) \*Marcos drank a cup of tea during Mary cooking.

It appears from sentences(59)-(61) that the preposition *during* will mostly permit event nouns and reject temporal proper nouns and sentential complements. Other temporal prepositions have their own peculiar restrictions as well.

The semantic purpose of temporal prepositions is primarily that of context provision, in our discussion of tense we observed tense provides a temporal ordering between the speech time and the event time. While aspects provides a location for the time of reference on the time line, temporal prepositions provides

a real context for the time of reference and in many cases, grammatical aspects require a temporal prepositions in order for us to have complete grammatical sentences. As a result there is a requirement of agreement between the tense aspects and temporal prepositions as observed by Partee [1973] and Hornstein [1977].

Syntactically, temporal adverbials can occur in two different positions, first after the main sentences, as in sentences like (59) or they can precede the main sentences as in (62).

(62) During the lecture, Marcos drank a cup of tea.

Most of the syntactic rules that govern the grammatical use of temporal prepositions in general are mostly governed by their semantic interpretation. Pratt-Hartmann and Francez [2001], Von Stechow [2002], Pratt-Hartmann [2005], provide a semantic interpretations for the commonly used temporal prepositions in first order logic or some of its variants like Interval Temporal Logic (ITL). We discuss in better detail the syntax and semantic interpretation of the temporal prepositions adopted in our proposed language, comparing it to existing theories.

### 3.7 Discussion

Expressing temporality in natural language requires the involvement of several linguistic and semantic phenomena, some of which we have discussed in this chapter. The most fundamental being: should time be represented as instants or intervals. From our discussion in the beginning of this chapter we see that instants are not well suited for the representation of events. Allen's theory appears to provide an extensive set of operators that can express relationship between intervals. We therefore adopt first order interval logic (a variant of interval temporal logic) for the representation of time in our language.

From a linguistic perspective, temporal expressions do not function in isolation there are a few rules that determine their compatibility. We have observed already that tense and grammatical aspects are rather inseparable, and Dowty showed verbs can be selective of their temporal complement depending on their aspectual class. There are quite a number of syntactic restrictions that determine correct use of these temporal expressions.

Other than the syntactic restrictions imposed on these temporal expressions and their interactions, there are semantic consequences as well. One of the most



obvious of these consequences is the effect of having an accomplishment in the progressive. Known as the imperfective paradox, the proper interpretation has been studied by many linguist such as Dowty [1977], Mittwoch [1988], Ben. This problem is due the inability represent an accomplishment as a culminating event given the progressive enforces it to be continuous.

Its has also been observed that although we attempt to apply Montague semantics in generating the interpretation of English sentences from the semantics of their constituents, we observe that temporal expressions do not always permit that method of interpretation generation. For example,

(63) John arrived before Mary left.

(64) John had arrived before Mary left.

Strictly based on truth conditions alone, sentences(63) and (205) have similar interpretations. We argue that such use of the perfect is to fulfill a pragmatic purpose rather than a semantic one . It therefore appears the grammatical aspect does not always have a semantic effect on the sentence. And in many cases the use of these grammatical aspects are selected by the aspectual class of the verb and temporal preposition complimenting the said sentence. We discuss in more detail temporal prepositions and their interactions with other temporal expressions in chapter 5.

# Chapter 4

## Controlled Natural languages

The term language is intuitively understood as the primary mode of communication amongst humans. This form of language as discussed in section 2.1 is more precisely known as natural language. It requires every party in the communication channel to have an intuitive understanding of the language grammar and meaning. Despite the intuitive property of natural languages, it appears to be difficult to parse by none native speakers and machines. As a result there has been numerous attempts to develop a language that is just as intuitive as the regular natural languages but also easy to parse by none native speakers and more importantly machines. This has led to the definition of a class of languages called Controlled Natural Languages.

### 4.1 What is a CNL?

Providing a definition for CNLs, is not very straight forward as various currently existing ones were developed in response to different problems ranging from strictly linguistic to software. But we will begin by stating a note worthy property of every CNL in existence as of today—they are each based on just one natural language. That is we do not have a CNL that is a composition of more than one base natural language. The level of restriction placed on a natural language in the process of developing a CNL is however dependent on various factors such as its users and industry of application etc.

The earliest known form of restriction placed on natural language syntax is the Aristotle's Syllogisms, after which many others have been defined. For example Basic English which is discussed later in this chapter is a language developed

to facilitate easier understanding and learning of English by none native speakers. More recently however controlled natural languages have been defined as the fragments of a given natural language that is computer processable. Hence enabling its application to software and hardware specification, ontology authoring, query systems etc. Having considered the wide variety of the motivation behind the development of the currently existing controlled natural languages, the most complete definition of a CNL is that proposed by Kuhn [2014];

**DEFINITION 4.1.1** *A language is called a controlled natural language if and only if it has all of the following four properties:*

1. *It is based on exactly one natural language (its “base language”).*
2. *The most important difference between it and its base language (but not necessarily the only one) is that it is more restrictive concerning lexicon, syntax, and/or semantics.*
3. *It preserves most of the natural properties of its base language, so that speakers of the base language can intuitively and correctly understand texts in the controlled natural language, at least to a substantial degree.*
4. *It is a constructed language, which means that it is explicitly and consciously defined, and is not the product of an implicit and natural process (even though it is based on a natural language that is the product of an implicit and natural process).*

Recognizing the huge disparity amongst the existing CNLs, Kuhn defined four criteria for classifying CNLs, namely– precision, expressiveness, naturalness and simplicity. *Precision* measures the languages ambiguity, predictability and formality of definition. *Expressiveness* just as the name implies measures the level of restriction of the languages syntax and semantics. *Naturalness* is based on the understandability and natural look and feel of the language. *Simplicity* how easy it is to learn, use and apply as required. These properties make up the Kuhn’s classification scheme –**PENS**. We do not explain here how Kuhn assign scores to CNLs based on these four criteria, the user can refer to Kuhn [2014] for a detailed report on assigning scores to languages.

## 4.2 CNL Applications

While having a regimented grammar that permits machine processing of language appears to be an interesting endeavour, one important question might be why will anyone care about developing such a language? In the early days of controlled natural languages, they were developed mostly to ease learning of a given natural language, enabling none speakers of the said language familiarize with its grammar and vocabulary. This use of controlled natural languages might be a quite redundant with the current level of technological advancement, particularly in software and the internet. Now that CNLs are essentially computer processable languages, the domain of application and potential users of these languages have significantly increased.

Although we have considered for the most part of this thesis Controlled English, there are other controlled languages with other base languages such as Mandarin (Zhang and Peng [2012]), Greek (Vassiliou et al. [2003]), Portuguese (Marrafa et al. [2012]) and even less popular languages such as isiZulu (Keet and Khumalo [2014]), Runyankore (Byamugisha et al. [2016]). We will however consider Controlled English in this section and the rest of this thesis.

Many controlled natural languages were designed to serve as an interface for formal languages. Attempto Controlled English, is one of such, which provides the DRT interpretation of English sentences this use of the language is proposed by Fuchs et al. [1999]. The ability to represent natural language sentences in some formal language has enabled their application in various domains. Attempto Controlled English can therefore be used for writing consistent system specification documents Fuchs et al. [1990]. Another popular area of application of CNLs as shown by Smart et al. [2010], Denaux et al. [2010], Ferré [2012], Power [2012] is ontology authoring, querying and editing

There have been more recent and relatively less popular areas of applications as well, this include business contract development (Pace and Rosner [2010]), tax fraud detection (Calafato et al. [2016]), proof checking mathematical text (Cramer et al. [2010]), speech recognition interfaces (Kaljurand and Alumäe [2012]).

Controlled natural languages have therefore over the last decade been an interesting area of study primarily because of its tendency to enhance ease of use of computer software and formal languages.

### 4.3 CNLs Survey

In this section we take a quick survey of some of the existing CNLs, discussing briefly some of their syntax and semantics.

#### 4.3.1 Sowa Syllogisms

We consider this language first because it probably has the simplest grammar of all the the CNLs in the section. Given that Aristotle's syllogisms were given in Greek, Sowa [2000] defined a similar language in English. Hence a form of controlled English. This language has four sentence patterns given thus;

Every  $X$  is a  $Y$ .      Some  $X$  is a  $Y$ .

No  $X$  is a  $Y$ .      Some  $X$  is not a  $Y$ .

Where  $X$  and  $Y$  is any common noun. Pratt-Hartmann [2004] extended this language by adding two sentence patterns to cater for proper nouns.

$S$  is a  $Y$ .       $S$  is not a  $Y$ .

Where  $S$  is a proper noun. We can of course represent this language with simple context free grammar.

The Semantics of this language is also fairly straight forward from the sentence patterns. We present the interpretation of these patterns in first order logic thus,

$$\forall\alpha(X(\alpha) \rightarrow Y(\alpha)) \quad \exists\alpha(X(\alpha) \wedge Y(\alpha))$$

$$\neg\exists\alpha(X(\alpha) \wedge Y(\alpha)) \quad \neg\forall\alpha(X(\alpha) \rightarrow Y(\alpha))$$

Although this is very simple language as observed from its syntatic and semantic representations. The sentences of the language are perfectly natural and precise, it is however not very expressive based on Kuhn's **PENS** classification.

### 4.3.2 Basic English

Basic English was developed by Ogden [1930] as an aid to teach English to none native speakers. Basic is indeed a fragment of regular English. Basic English as developed by Ogden is of course not build into a program there has however been more recently been computerized versions of it. For example, Simplified technical English.

Basic English has a lexicon of 850 common words, where 600 are nouns, 150 are adjectives, The last 100 are the words operation words, this includes 16 verbs. Basic English permits the use of a few inflections to expand its lexicon. For example, plurals expressed by appending "s" to common count nouns, verbs can have either "-ing", or "-ed" endings, we can form adverbs by adding "-ly" to qualifiers,"more" and "most" are used in comparing quantities. The "un-" prefix is used to negate adjectives. Questions are formed by having an opposite word order starting with the word "Do". There are more rules we do not discuss here.

Basic English according to Kuhn's criteria is a very natural and expressive language but not very precise and definitely not as simple as Sowa's syllogisms.

### 4.3.3 Attempto Controlled English(ACE)

Attempto is a formal language that avoids the ambiguity of natural language as well as offers easy understandability to users.

The Attempto Controlled English ACE is a controlled precisely defined subset of English that can automatically and unambiguously be translated into first-order logic.

Initially ACE was used for the disambiguation of requirement specification documents for software development, the system is now used in many other domains. However readable by both human and machine, the ACE converts ACE texts inputs into Discourse Representation Structure DRS, a variant of first order logic which is a knowledge representation of the input text.

This system has a lexicon containing predefined function words (articles, prepositions etc.), predefined phrases ('there is a ...', 'it is false that ...'), user-defined content-words (nouns, verbs ...), basic lexicon of 100'000 words. Users can however define domain specific content words as well. User defined words have precedence over the predefined content words. Sentences could be simple or composite, simple sentence have the structure; subject + verb + (complements)

+ adjuncts, they describe that something is the case—a fact, an event, a state. This simple sentences can however be combined with coordinators – and, or , subordinators, negation and quantifiers.

ACE uses the Attempto Parsing Engine (APE) in generating DRS interpretations, syntax tree as well as a paraphrase for the input text. The paraphrase represents the understanding of the ACE text by the machine and can hence be rephrased by the user in case of wrong interpretation. DRS are used in reasoning and can optionally be represented in OWL/SWRL and prolog.

With DRS representation of ACE text, DRS integrates discourse anaphora, first-order logic eases automated deduction and re-usability, possible quantification over "predicates" in first-order logic, plurals represent plurals in first-order logic, optional translation into other first-order languages e.g. standard or clausal form of first-order logic.

#### 4.3.4 PENG

PENG (Processable ENGLISH) Schwitter [2005] is a controlled natural language with a well defined grammar, it provides interpretation for its sentences in DRSS and first order logic. PENG's interface provides information that enables its users enter correct sentences. It does this by providing a look-ahead information of the correct options of the category of the next lexical item of the input sentence.

Simple sentences are of the form of noun phrases followed by the verb phrases where the noun phrases can have pre-modifiers or post-modifiers, and complex sentences such as conditional sentences can be constructed with the use of *if... then*. PENG has therefore been applied as an interface for OWL ontologies.

#### 4.3.5 FAA Air Traffic Control Phraseology

The Federal Aviation Administration (FAA) developed this controlled natural language for easy communication in air traffic coordination. Being in existence since the 80s, languages of this class that facilitates air traffic coordination are often calls air speak. There are about three hundred sentence fragments for example, TAXIING AIRCRAFT/VEHICLE LEFT/RIGHT OF RUNWAY, IN THE EVENT OF MISSED APPROACH.

It has a restricted vocabulary and semantics as it is a language designed for the specific domain. For example the use of the words gain and loss when describing

the the wind shear effect on air speed. The language includes grammar of simple English sentences although because of the requirement of quick communications, the grammar is very restricted.

### 4.3.6 E2V

Pratt-Hartmann [2003] proposes a slightly different approach in the definition of this controlled language. While other languages such as ACE provides semantic interpretations from a defined set of natural language sentence forms, E2V defines a controlled language that translates to the two variable fragments of first order logic. That is the first order interpretation of sentences of this language a member of the two variable fragment of first order logic. Pratt-Hartmann is therefore able to proof that the satisfiability of E2V is NEXPTIME complete.

The syntax of E2V as defined with context free grammar permits determiner quantified nouns, transitive and intransitive verbs. Unlike other most other languages, E2V also permits the used of relative clauses, reflexives and pronouns. Pratt-Hartmann however notes that the satisfiability problem of the language can easily become undecidable if the level restrictions on pronouns are slightly relaxed.

## 4.4 A CNL with Temporal Features

Having introduced several tools required for the development of a controlled natural language with temporal features over the course of this thesis. We also considered the landscape of already existing controlled natural languages, we can now discuss briefly what a controlled natural language with temporal features looks like. Our attempt to include the interpretation of temporal expression in our CNL, is expected to improve the expressiveness and naturalness of the language.

### 4.4.1 Syntax

Although we attempt to provide the temporal information in the sentences of our language, not all sentences are temporal particularly many sentences in the simple present tense, a simple sentence in our controlled language is therefore made up of a noun phrase followed by a verb phrase. Where noun phrase acts as the sentence



subject which can be a proper noun, or a common noun preceded by a determiner, singular or plural. The verb phrase can either have a transitive or intransitive verb head. When the verb is transitive it is followed by another noun phrase. We however majorly consider the interpretation of verbs with inflections that are of temporal significance for example past tensed verbs, past tensed sentences are signalled by the main verbs being in the past tense. Future tensed sentences have the auxiliary verb *will* before the main verb. Other inflection of temporal significance include the progressive and the perfect in their past, present and future tenses.

(65) John writes poems.

(66) John wrote a poem.

(67) John had written the poem.

Sentences (65)-(67) are examples of valid sentences of our language where sentence (65) is an atemporal sentence, different from 66 and 67 which are in the past and past perfect respectively.

Whats interesting about our controlled language is the ability to include temporal modifiers, these includes temporal prepositions, conjunctions and adverbials. Examples of some prepositions are *at, on, in, after, before* etc. Prepositions are specifically those temporal modifiers and have only nominal complements, for example *during*, while conjunctions permit sentential complement for example *while*. There are also those modifiers that function as both for example *before, after* etc. We should note that the class of nouns that complement temporal prepositions are specifically those that describes some time or event such as *a meeting, a lecture, 1988, January 2013* etc. We call these class of nouns temporal nouns. Temporal proper nouns like *12:45, noon* behave like proper nouns and are therefore not preceded by determiners. Common temporal nouns on the other hand act like common count nouns and are therefore precede by determiners.

Temporal adverbials are modifier such as *yesterday, today, last week, every monday* etc. They provide temporal context for sentences. They are syntactically nouns but act sentential modifiers. There are not preceded by any preposition or conjunction. In section 5.3 of the following chapter we discuss how words like *last* and *next* can be considered as temporal determiners.

(68) John writes poems every Monday.

(69) John wrote a poem during the lecture.

(70) John had written the poem before Mary arrived.

We see in the above sentences how temporal prepositions, conjunctions and adverbials modify sentences. We observe that an atemporal sentence such as 66 becomes temporal when modified as seen in sentence (68).

### 4.4.2 Semantics

We provide semantics for sentences of our language in first-order logic as we have discussed in chapter 2, we apply the use of context free grammars and simply typed  $\lambda$ -calculus ie. Montague semantics to generate semantics for sentences in our language. Hence each lexical item is of given grammatical category, where every grammatical category is assigned a semantic interpretation and the combination of the subparts of a sentence produces the interpretation of the main sentence.

Determiners often function as quantifiers for common count nouns. The subject or object noun phrases can also be proper nouns. What makes our language interesting are the temporal information provided by the tense construction of the verb phrases. Given an event described by a verb, it can be said to have occurred within a given interval, we existentially quantify over intervals, where the event occurred. Consider the sentence interpretation 71 for sentence 66 below;

(71)  $\exists i \exists x (\text{poem}(x) \wedge \text{write}(\text{john}, x)(i) \wedge (i < \mathbf{now}) \wedge (i \subseteq I))$

The variable  $i$  represents the interval within which the main event occurred, given this interval we are able to represent other temporal information provided by the verb such as the verb tense. Where  $<$  can be said to be a temporal ordering operator, the interval of the given event is ordered prior to the time of speech which is represented here as the constant **now**. And the free variable  $I$  is the context in which the event occurred. This variable can be lambda abstracted and combined with a temporal adverbial. We consider the behaviour of temporal prepositions and adverbials in the next chapter.

## 4.5 Summary

Controlled natural languages are essentially natural languages with syntax that have corresponding formal representations. From the linguistic perspective we are aware of the fact that the meaning of a given natural language text is subject to context or domain, as a result many controlled natural languages are domain specific in order to provide none ambiguous interpretations.

This research attempts however to include the meanings of temporal expressions to controlled natural languages. As we find that many of the information passed by controlled natural languages are of temporal significant for example event ordering, or weather reports. As with many other linguistic problems, the interpretation of temporal expressions is not without its challenges, we however apply a systematic research which provides us with a rather clear idea of how these temporal expressions behave in real life and can hence be applied in the development of our language. We discuss this and our results in the following chapter.

## Chapter 5

# Temporal Prepositions and Adverbials

Based on their syntactic structure, we identify three types of temporal modifiers – temporal prepositions, temporal conjunctions and temporal adverbials. Consider the following sentences.

(72) Mark arrived in January.

(73) Mark arrived while the VC was speaking

(74) Mark arrived last week

Temporal prepositions are those modifiers where a preposition is complemented by a noun phrase as in sentence (72). Examples include *in*, *during*, *at* etc. Temporal conjunctions are similar to prepositions but rather have sentential complements as in sentence (73). For example *while*, *when*. There are also a few modifiers that permit nominal and sentential complement, they therefore act as both prepositions as well as conjunctions. Examples of these include *before*, *after*, *since*, *until*. Lastly temporal adverbials are syntactically temporal nouns. They however semantically act as modifiers and they specifically provide temporal context for the event or state described by the main clause. Sentence (74) for instance, shows that the event of *Mark arriving* within a given temporal interval in this case *last week*. We attempt to understand how these temporal modifiers behave and how they interact with the temporal expressions we have thus far discussed.

In section 5.1 we describe the analysis of sentences that enables us develop rules for the temporal modifiers of interest in this chapter. Section 5.2 shows the semantic interpretation of main and subordinate clauses of the temporal modifiers we consider in this chapter. We discuss the syntactic representation and semantic interpretation of various temporal adverbials, temporal prepositions and temporal conjunctions in section 5.3, 5.4 and 5.5 respectively.

## 5.1 Corpus Analysis

English language has various temporal prepositions and conjunctions, each with its own syntactic and semantic characteristics. When these modifiers interact with other temporal expressions – that is, *tense* and *aspects* in a given sentence, they generate varied interpretations. As a result there is a need to understand in the best possible way how these modifiers behave and why they should be assigned a particular interpretation in a given sentence. We therefore need to consider these temporal modifiers in the different sentences construction they could occur and observe their syntactic structure as well as their semantic interpretation.

Vendler [1967] defined four aspectual classes of verbs based on their behaviour in relation to the temporal context. These are states, achievements, accomplishments and activities. Based on the theory of tense as defined by Reichenbach [1947] we have three tenses in English – past, present and future. These combine with English aspects – the perfect and progressive to produce twelve tense and aspect constructions. We therefore examine various configuration of these temporal expressions by systematically generating sentences by first having the possible aspectual class combination between the main and subordinate clause. These produces sixteen possible combinations. For each of these sixteen possible aspectual class combination, we generate every possible tense/aspect construction between the main and subordinate clause. This produces one hundred and forty four construction for each of the aspectual class combination, giving us a total of 2,304 sentences of every possible aspectual class, tense and aspect configuration. The last linguistic factor we consider is verbal negation. Having every possible verbal polarity between the main and subordinate clause generates 9,216 sentences. For temporal prepositions, the combination of aspectual classes, tense and aspect in the main clause produces sixty possible constructions given they are complemented by temporal nouns rather than sentences.

Our generated sentences provides an overview of how the various temporal modifiers behave in different situations. We however cannot assume that all possible scenarios are catered for from our generated dataset . We therefore extract two hundred sentences for each preposition and conjunction which we analyze with the aim of finding patterns such as tense agreement, syntactic structure of nominal and sentential complements, distinguishing between temporal instances and other uses of the modifier (e.g. spatial) and a few other observations not apparent from the data we have generated. These analyses are similar to that carried out by Brée [1985b].

## 5.2 Main and Subordinate clauses

Before we present our findings from the analysis of temporal modifiers, we present first the interpretation of simple tensed and untensed sentences and how we generate their semantics with the aid of Montague semantics. Given therefore a sentence such as:

(75) Mary kissed John,

from our discussion in chapter 2, we assign a semantic interpretation to each lexical item in the sentence from which the sentential interpretation can be generated. Figure 5.1<sup>1</sup> shows how we apply Montague semantics. The eventual sentence interpretation assigns a temporal interval when the event described by the sentence takes place. This interval is within a temporal context represented by the free variable  $I$ , this interval enables us to attach temporal modifiers to simple sentences by lambda abstracting it, we would have the type  $(i, t)$ . That is a type of function from intervals to truth values.

From our the parse tree in figure 5.1, we observe that tense does have defined syntactic and semantic functions. That it provides temporal ordering of the event time relative to the time of speech. We however observe from our generated set of sentences as well as Brown corpus extracts that grammatical aspects do not have specific behaviours as tenses do. In many cases their syntactic roles and semantic interpretations are dependent on the temporal modifier they interact with or the tense of the sentence. Consider the following sentences.

(76) ?John had arrived during the meeting.

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<sup>1</sup>We show how the generation of future tensed sentences in A.1 in the Appendix

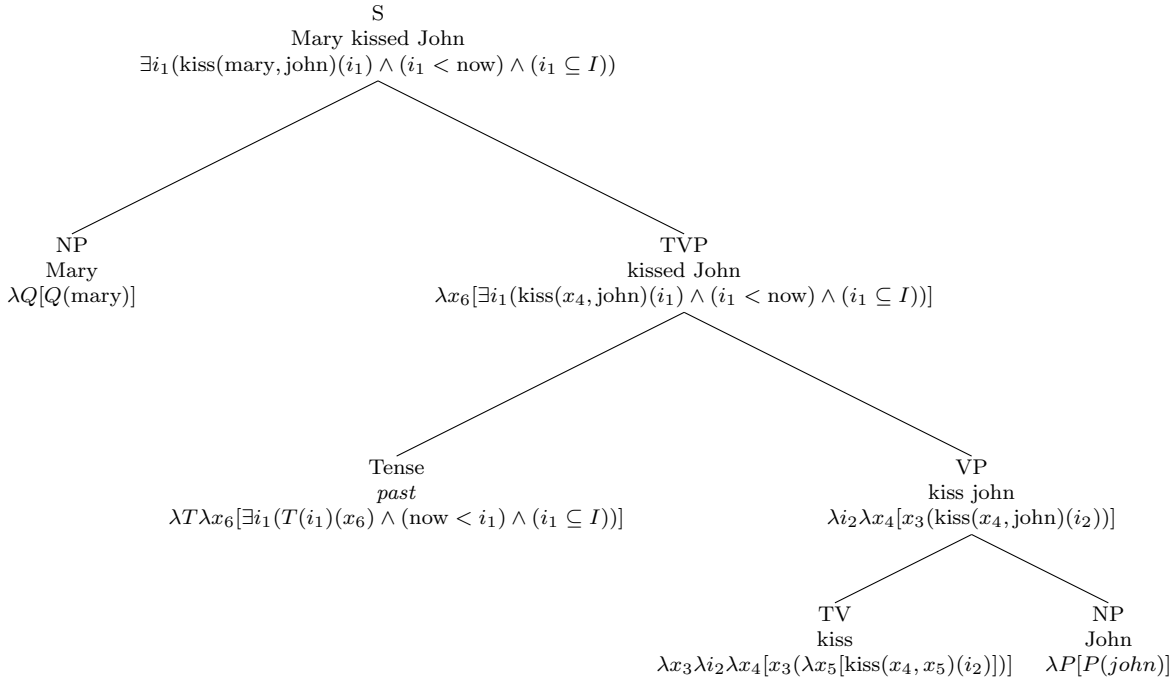


Figure 5.1: Parse Tree of a simple past tensed sentence

(77) John has been sleeping since noon.

(78) John is arriving today.

From literature the perfect is said to place some sort of focus on the result state of a given culminated or terminated event. While this view of the perfective is not incorrect, the perfective does not always have the same interpretation in all cases. This can be observed in sentence (77), the perfect is more of a syntactic marker required to distinguish between temporal and non-temporal uses of the preposition *since* and is not necessarily of any semantic consequence. The progressive also tends to behave differently in different situations. Sentence (78) does not describe an on going event, but rather an event to occur in the future. We therefore do not have an interpretation for the perfect and progressive that can be used in the generation of the semantics of the main clauses as we do for tense, but rather provide interpretations for the various interactions of tense, aspects and temporal modifiers.

Although subordinate clauses of temporal conjunctions have very similar syntactic structure to the main clauses, they require a different semantic interpretation. One of the primary reason for this difference in interpretation is tense

agreement. In many cases, there is a tense agreement between the main and subordinate clause verb. Providing an interpretation for the tense of the subordinate clause will result some sort of redundancy in the eventual generated interpretation considering interpretation of our main clause already provides tense information. We therefore omit interpretation from the subordinate clause verb.

(79) John left before Mary arrived.

Given sentence (79), we therefore interpret the subordinate clause thus;

(80)  $[\lambda Q[\exists i_0(\text{arrive}(\text{mary})(i_0) \wedge Q(i_0))]]$

Where the lambda abstracted variable  $Q$  enables us apply the interpretation of the temporal modifier to the subordinate clause. We show in the rest of the chapter how we generate the interpretation of modified sentences .

The interpretation of temporal nouns is quite similar to those of regular object nouns. We will introduce their interpretations as required as we apply them to the various temporal modifiers of interest.

## 5.3 Temporal Adverbials

This class of temporal modifiers refers exclusively to those that are not preceded by any temporal preposition. For example

(81) Maurice went to the hospital yesterday.

(82) Coldplay is performing tonight.

Both sentences above are complemented by temporal modifiers, these temporal modifiers are not prepositional phrases but are syntactically noun phrases even though they function as adverbs in these cases. We are therefore attempt in this section to provide an analysis of these temporal adverbials' syntactic structures as well as their interpretation and how they combine with simple sentences.

### 5.3.1 Temporal Determiners

There are certain common nouns that represent temporal intervals, for example *day*, *week*, *hour* etc. or event nouns like *meeting*, *match*, *lecture* etc. Just as we quantify over individuals, we can quantify over the intervals represented by these temporal nouns. We can therefore have sentences such as (83) and (84).



(83) Every student writes an exam every year.

(84) Every student writes an exam every semester.

We notice from the above sentences that temporal adverbials have similar syntactic structures to regular noun phrases, that is the noun head is preceded by a determiner. Other than the regular determiners such as *every, a, an, the* etc. Temporal nouns have two other commonly used determiners – *last, next*.

(85) Every student wrote an exam last semester.

(86) Every student will write an exam next month.

Although the words *last* and *next* in sentences (85) and (86) are syntactically adjectives, in this case their role is similar to determiners. As they help provide information on the specific interval of interest from a given set of intervals.

There is also a syntactic restriction on these two temporal determiners, because *last* refers to a temporal interval before the current interval, the main clauses of the *last* adverbials are often past tensed. When the temporal adverbial is a *next* adverbial, then we are required to have future tensed main clause, as observed in sentences (85) and (86).

Semantically, temporal adverbs provide temporal context for the main event or state of a given sentence as seen in sentences (83)-(86). It is important to note however at this point that providing an interpretation for the sentences such as those above, sentence complements out-scope the main clause. This seems intuitive as the main clause is within the context of the complement.

We therefore need to provide interpretations for these temporal determiners. Determiners such as *every, a* have the same interpretations as those for the common noun phrases, in order to be able to distinguish when they precede temporal nouns as opposed to common nouns, we change the type of variables they quantify over.

(87)  $[\text{det every}] = \lambda P \lambda Q [\forall x (P(x) \rightarrow Q(x))]$

(88)  $[\text{tempDet every}] = \lambda P \lambda Q [\forall i (P(i) \rightarrow Q(i))]$

While interpretations (87) and (88) are essentially the same we differentiate in order to distinguish their roles. Given that (87) is of type  $(e, t, t)$  but (88) is  $(i, t, t)$  where  $e$  represents individuals and  $i$  represents temporal intervals. Similarly noun phrases are assigned different variables from temporal nouns.

$$(89) \text{ [}_{\text{noun}} \text{ student]} = \lambda x_1[\text{student}(x_1)]$$

$$(90) \text{ [}_{\text{tempNoun}} \text{ year]} = \lambda i_1[\text{year}(i_1)]$$

By applying the lambda calculus beta rule we generate (91)

$$(91) \text{ [}_{\text{tNP}} \text{ every year]} = \text{[}_{\text{tempDet}} \text{ every]}(\text{[}_{\text{tN}} \text{ year}]) = \lambda Q[\forall i(\text{year}(i) \rightarrow Q(i))]$$

Supposed we have an unmodified sentence (92) interpreted as (93)

(92) Every student wrote an exam.

$$(93) \forall x(\text{student}(x) \rightarrow \exists i_1 \exists y(\text{exam}(y) \wedge \text{write}(x, y)(i_1) \wedge (i_1 < \text{now}) \wedge (i_1 \subseteq I)))$$

We can therefore attach a temporal modifier to (93) by lambda abstracting the sentence the free variable  $I$  and applying it to the (91) as we have done below;

$$(94) \forall i(\text{year}(i) \rightarrow \forall x(\text{student}(x) \rightarrow \exists i_1 \exists y(\text{exam}(y) \wedge \text{write}(x, y)(i_1) \wedge (i_1 < \text{now}) \wedge (i_1 \subseteq i))))$$

We are of course able to generate the sentence interpretation (264) by applying Montague semantics as discussed in section 2.4.2.

We can now turn our attention to the other two temporal determiners of interest in this section— *last* and *next*. All we require is finding an interpretation for these two temporal determiners that are of the same lambda type as the interpretation of the *every* in (88).

Suppose we are to provide the semantic interpretation for (85), we need to know what the translation of the lexical item *last* is. In this context, *last* presupposes the existence of a current semester. From the current semester we need to select specifically the semester exactly before it, suppose we quantify over the semesters *before* the current semester, it would mean that four or five semesters before will be relevant. We are however interested in the semester just before, which means there are no semesters between the current and the semester of interest. Therefore the most appropriate operator to express this relationship is the *meets* operator. Hence there are no interval between these two intervals that can be described as a semester. We hence assign the following interpretation to the temporal determiner *last*.

$$(95) \text{ [}_{\text{tempDet}} \text{ last]} = \lambda P \lambda Q[\exists i_0 \exists i_1(P(i_0) \wedge P(i_1) \wedge \text{meets}(i_0, i_1) \wedge Q(i_0))]$$

We can therefore apply our interpretation of temporal nouns above to (95) thus;

$$(96) \text{ [tempDet last]}([\text{tN semester}]) = \\ \lambda P \lambda Q [\exists i_0 \exists i_1 (P(i_0) \wedge P(i_1) \wedge \text{meets}(i_0, i_1) \wedge Q(i_0))] (\lambda i [\text{semester}(i)]) = \\ \lambda Q [\exists i_0 \exists i_1 (\text{semester}(i_0) \wedge \text{semester}(i_1) \wedge \text{meets}(i_0, i_1) \wedge Q(i_0))]$$

The temporal determiner *next* can be considered as the inverse to *last*. It selects the interval following the current interval. *Next* is therefore assigned a similar interpretation to *last* except for the inverse in the temporal ordering. That is while the determiner *last* has the *meets* relationship between the current and previous interval, we use the inverse of the operator – *meetBy* for selecting the following interval.

$$(97) \text{ [tempDet next]} = \lambda P \lambda Q [\exists i_0 \exists i_1 (P(i_0) \wedge P(i_1) \wedge \text{meetBy}(i_0, i_1) \wedge Q(i_0))]$$

Temporal adverbials can be said to be temporal containers for the intervals where the main event occurred, they have similar semantic interpretations as the preposition *during* to be considered later in this chapter. There are however other temporal relationships that can be expressed in natural language . We are therefore required to consider the behaviour of temporal prepositions and conjunctions.

Note that at the beginning of this section we included temporal nouns such as *tomorrow*, *yesterday* as examples of temporal adverbials. We can observe that *tomorrow* can be assigned the meaning such as *next day* and *yesterday* can be interpreted as *last day*. We can therefore treat these modifiers and any of those preceded by the temporal determiners *last* and *next*.

## 5.4 Temporal Prepositions

Temporal prepositions refer to those temporal modifiers that are complemented by noun phrases. There are quite a number of them considered in this section—*during*, *in*, *on*, *at*, *for* and *by*. Over the course of this section we divide temporal nouns into event nouns, interval nouns and proper temporal nouns. Event nouns are those nouns that describe occurrences such as *the lecture*, *the meeting* etc. Interval nouns on the other hand are those that refer to time intervals such as *every hour*, *every Monday*. Proper temporal nouns are similar to proper names, examples of these include *noon*, *midnight*, 1954 etc.

In many cases these prepositions do not always provide temporal contexts, we however attempt in this section to provide possible syntactic marker that distinguished their temporal uses from non-temporal ones. We also consider how these temporal prepositions interact with various tense and aspect constructions in the main clause.

### 5.4.1 During

Like temporal adverbials, *during* provides a temporal interval within which the main clause verb is contained. Consider the following sentences.

- (98) Mark left during the meeting.
- (99) Mary spoke during the conference
- (100) Jake wrote a novel during the war
- (101) Peter owned industries during the depression.

The above sentences are examples of each aspectual class in interaction with the *during* phrase. Although we see that it is possible to have all the Vendler aspectual class produce grammatical sentences when in the context of a *during* phrase, varying the sentence tense/aspect construction might affect the correctness of the *during* sentence. Lets consider therefore the syntactic structure of *during* phrases.

#### Syntactic Analysis

We attempt to understand what makes up a felicitous *during* phrase complement. Temporal prepositions and indeed prepositions in general permit nominal complements. Usually these complements determine what kind of context the preposition provides (temporal, spatial etc.). The *during* preposition however provides strictly only the temporal context and therefore permits only temporal nouns as complement.

Just as we have proper nouns and common count nouns for regular nouns naming individuals, the same is the case for temporal nouns. It is mostly the case that the preposition *during* is complemented by interval and event nouns and not temporal proper nouns. Consider the following *during* sentences.

(102) Lily ate a cupcake during the party.

(103) John lost his keys during a riot.

(104) Mark kissed Mary during every meeting.

The above sentences illustrate the *during* phrase complemented by event noun phrases with various determiners. Sentence (105) and (106) illustrates the use of interval nouns as the *during* preposition complement.

(105) Lily ate a cupcake during the night.

(106) John lost his keys during the week.

(107) David kissed Mary during meetings.

As we have seen in previous examples we can also have an undetermined temporal noun phrase complement as in sentence (107). When the complement is an explicit temporal noun similar to proper nouns, we often have unnatural *during* sentences.

(108) \*David Kissed Mary during 9:30.

(109) ?David kissed Mary during January.

(110) ?David kissed Mary during 2015.

One will not intuitively utter sentences (108) - (110). This is evident in the study of about two hundred sentences extracted from the Brown corpus, where only 2% of those sentences have an explicit year as a complement and 4% had months as complements. Where as there were 53% with interval nouns and 34% with event nouns. The combination of temporal nouns, 59% of them were had definite quantifiers which illustrates how *during* attempts to select specific temporal intervals as just 6% had indefinite determiners, 2% had universal determiners. Others either had possessives, deitic determiners or no determiners.

The behaviour of the main clause in *during* sentences is not quite as straight forward. This is because we consider the interaction of several linguistic factors. Given a *during* sentence in the past tense for instance, the *during* phrase provides a temporal context within which the main clause event occurred. *During* has a

similar behaviour given a future-tense main clause. The present tense on the other hand describes many episodes of the described event. The *during* phrase must therefore imply multiple intervals for each of the instances of the event described by the main clause verb. The tables below show the behaviour of the main clause of *during* sentences.

| Aspectual Class | Past |      |          |      |
|-----------------|------|------|----------|------|
|                 | Perf | Prog | PerfProg | None |
| Activity        | ?    | +    | ?        | +    |
| Achievement     | -    | -    | -        | +    |
| Accomplishment  | ?    | +    | ?        | +    |
| State           | +    | -    | -        | ?    |

Table 5.1: During in the past tense

| Aspectual Class | Present |      |          |      |
|-----------------|---------|------|----------|------|
|                 | Perf    | Prog | PerfProg | None |
| Activity        | -       | +    | +        | +    |
| Achievement     | +       | +    | -        | +    |
| Accomplishment  | +       | +    | -        | +    |
| State           | ?       | -    | -        | ?    |

Table 5.2: During in the present tense

| Aspectual Class | Future |      |          |      |
|-----------------|--------|------|----------|------|
|                 | Perf   | Prog | PerfProg | None |
| Activity        | ?      | +    | ?        | +    |
| Achievement     | -      | -    | -        | +    |
| Accomplishment  | ?      | +    | ?        | +    |
| State           | +      | -    | -        | ?    |

Table 5.3: During in the future tense

Tables 5.1, 5.2, 5.3 describe various configurations of tense, aspect and aspectual class of the main clause of *during* sentences. Where the + represent grammatical constructions, - are for configurations that are not absolutely ungrammatical and ? is used when the construction is not very natural.

### Interpretation of *During*

From the examples of *during* sentences we have encountered thus far we see it permits only interval and event nouns as complements. These temporal nouns are

like regular count nouns can be preceded by determiners as in the following sentences.

(111) John kissed Mary during the meeting.

(112) John kissed Mary during a meeting.

(113) John kissed Mary during every meeting.

Before we consider the interpretation of the preposition *during*, we consider first the behaviour its complements. The sentences (111), (112), (113) are examples of the during phrase with the possible complement noun phrase determiner. We treat these determiners similarly to how we interpreted the temporal determiner *every* in (88) therefore the indefinite determiner *a* will be interpreted as 114<sup>2</sup>;

(114)  $[\text{tempDet } a] = \lambda P \lambda Q [\exists i (P(i) \wedge Q(i))]$

(115)  $[\text{tnp } a \text{ meeting}] = [\text{det } a]([\text{tn meeting}]) =$   
 $\lambda P \lambda Q [\exists i_0 (P(i_0) \wedge Q(i_0))] (\lambda i [\text{meeting}(i)]) =$   
 $\lambda Q [\exists i_0 (\text{meeting}(i_0) \wedge Q(i_0))]$

We present therefore our interpretation of temporal nouns as seen in (115). Although we require a temporal constraint the temporal nouns occur in, we do not include it in their interpretation. We place this temporal context instead in the interpretation of the temporal preposition it will be concatenated with.

The temporal preposition *during* provides a temporal constraint  $I$  within which the subordinate event occurred.

(116)  $[\text{tp during}] = \lambda z_3 \lambda \Phi [z_3 (\lambda i_4 [\Phi(i_4) \wedge (i_4 \subseteq I)])]$

Considering the interpretation in (116), the proposition  $\Phi$  occurs within the temporal interval  $i_4$  and  $i_4$  is within the temporal constraint  $I$ . Application of the interpretation of temporal nouns to the interpretation of the temporal preposition *during* is presented below.

(117)  $[\text{tpp during a meeting}] =$   
 $\lambda z_3 \lambda \Phi [z_3 (\lambda i_4 [\Phi(i_4) \wedge (i_4 \subseteq I)])] (\lambda Q [\exists i_0 (\text{meeting}(i_0) \wedge Q(i_0))]) =$   
 $\lambda \Phi [\exists i_0 (\text{meeting}(i_0) \wedge \Phi(i_0) \wedge (i_0 \subseteq I))]$

---

<sup>2</sup>The interpretation for other determiners like *the* is given in the appendix 294

Interpretation (117) illustrates the result of applying a temporal noun phrase to the interpretation of the temporal preposition *during*<sup>3</sup>.

Having considered the interpretation of the temporal preposition *during* and observed how it combines with complement temporal nouns to form temporal prepositional phrases, we next attempt to apply temporal prepositional phrase interpretations to sentences which we have considered . We lambda abstract the free variable  $I$  which acts as a temporal constraint. In our interpretation the main clause is actually applied to the temporal prepositional phrase. Since the main clause is within the context of the prepositional phrase in order to achieve this we place the main clause within the context of a new lambda abstracted variable.

$$\begin{aligned}
 (118) \quad & [_s \text{John kissed Mary during a meeting} ] = \\
 & [_s \text{John Kissed Mary}]([_{tpp} \text{during a meeting}]) = \\
 & \lambda M[M(\lambda I[\exists i_1(\text{kiss}(\text{john}, \text{mary})(i_1) \wedge (i_1 < \text{now}) \wedge (i_1 \subseteq I))])] \\
 & (\lambda \Phi[\exists i_0(\text{meeting}(i_0) \wedge \Phi(i_0) \wedge (i_0 \subseteq I))]) = \\
 & \exists i_0(\text{meeting}(i_0) \wedge \exists i_1(\text{kiss}(\text{john}, \text{mary})(i_1) \wedge (i_1 < \text{now}) \wedge (i_1 \subseteq i_0) \wedge (i_0 \subseteq I))
 \end{aligned}$$

We generate an interpretation for a *during* sentence in (118) (see figure A.2 for the its semantic annotated parse tree). While we still retain a temporal constraint  $I$  which enables us to place this sentence in another context that is we are able to have nested prepositional phrases.

### 5.4.2 In, On & At

This group of prepositions have a common property of providing the temporal location for a given event. When used in the spatial context, they describe quite specifically the position of a given object.

(119) The space shuttle will land at 15:00.

(120) The space shuttle will land in January.

(121) The space shuttle will land on Tuesday.

---

<sup>3</sup>We can similarly have corresponding interpretations for other forms of temporal noun phrases (295) and (296)



Sentences (119), (120), (121) all described the time when the main clause event occurs. But we know intuitively as English speakers that these prepositions cannot be used interchangeably. We therefore need to identify syntactic markers that help determine which of the prepositions is appropriate in a given sentence.

These three prepositions tend to permit explicit times as complements, we observe that what this prepositions attempt to do is select exactly one identifiable interval in which the sentence event occurs as in the sentences below,

(122) John arrived at noon.

(123) John arrived at the meeting.

Unlike the *during* phrase where the main clause can occur within an event noun, given an event noun as complement of a locative preposition as in sentence (123), *at* and indeed all the locative prepositions we consider in this section provides a spatial context. This also applies to interval nouns as in sentence (124). We would only get a temporal context if the preposition is complemented by and temporal proper noun as in sentence (122).

(124) ?John arrived at the semester.

*In* and *On* behave similarly, hence in order to have these prepositions provide temporal contexts in simple sentences, we require them to be complemented by temporal proper nouns.

We have noted however that despite the similarity in their functions in providing temporal information of when a given event occurs, we intuitively know that these locative prepositions cannot be used interchangeably. We know their complements are required to be temporal proper nouns. However different temporal proper nouns describe different sizes of intervals. For example, a temporal noun such as *1956* describes a whole year as opposed to *14:45:34* which describes a given time accurate to the second. These two explicit times complement two different types of locative prepositions.

*In* is adapted for temporal proper nouns that describe larger intervals ranging from months to millenniums. The reason for this might be observed from its spatial use. *In* when used to convey the spatial context is used to describe an object within a larger container, hence in the temporal context, the preposition tends to choose intervals large enough to act as temporal containers within which a given event occurred as in (125) and (126)

(125) Russia will host the world cup in 2018.

(126) Terrence's graduated in December.

(127) Dudley plays golf on Sunday.

(128) The train departs at 19:43

*On* although similar in meaning to *in*, it has been adapted to permit days of the week as in sentence (127). *At* selects relatively very small granules of time , ranging from hours to seconds as in sentence (128).

There are however some exceptions where locative prepositons permit common temporal nouns. Consider the following sentences.

(129) Christianity became popular in the fourteenth century.

(130) In the first year of Obama's presidency, the hope of an improved economy was high

*In* can be used when we want to select a particular interval in a set with a count like *the first century, the fourth minute* etc. *At* can be use to select subintervals as in sentences below;

(131) Jose arrived at the end of the match.

| Aspectual Class | Past |      |          |      |
|-----------------|------|------|----------|------|
|                 | Perf | Prog | PerfProg | None |
| Activity        | +    | +    | -        | +    |
| Achievement     | +    | ?    | -        | +    |
| Accomplishment  | +    | +    | -        | +    |
| State           | +    | -    | -        | +    |

Table 5.4: *In* in the past tense

Tables 5.4, 5.5 and 5.6 show the various configuration of *in* sentences, showing which configurations are grammatical, ungrammatical and unnatural. We present similar tables for *on* and *at* in tables A.7 - A.12 in the appendix.

The preposition *in* has another use different from its locative use. Consider the sentence below,

(132) Joshua finished his thesis in 2 months.

We consider this use in more detain in section 5.4.3.

| Aspectual Class | Present |      |          |      |
|-----------------|---------|------|----------|------|
|                 | Perf    | Prog | PerfProg | None |
| Activity        | -       | +    | -        | ?    |
| Achievement     | -       | +    | -        | ?    |
| Accomplishment  | -       | +    | -        | ?    |
| State           | -       | -    | -        | ?    |

Table 5.5: *In* in the present tense

| Aspectual Class | Future |      |          |      |
|-----------------|--------|------|----------|------|
|                 | Perf   | Prog | PerfProg | None |
| Activity        | ?      | +    | -        | +    |
| Achievement     | ?      | +    | -        | +    |
| Accomplishment  | ?      | +    | -        | +    |
| State           | ?      | -    | -        | +    |

Table 5.6: *In* in the Future tense

### Interpretation of *In*, *On* & *At*

The interpretations of the locative temporal prepositions appear to be similar to *during*'s. The function of these preposition is provide temporal identity for the interval the sentence event occurs, for we need to consider the event time as equal or a subset of the time of reference as provided by the preposition complement. Since we mostly have explicit times as complements of locative prepositions, we interpret then similarly to proper nouns as in (134) Other explicit times like years, days of the week are interpreted similarly.

$$(133) [\text{PNMary}] = \lambda P[P(\text{mary})]$$

$$(134) [\text{TNnoon}] = \lambda P[P(\text{noon})]$$

We then assign interpretation (135) to each of the locative prepositions. Considering we have already noted the difference between them is the complement they permit and not necessarily their interpretation.

$$(135) \lambda z_3 \lambda \Phi [z_3 (\lambda i_4 [\Phi(i_4) \wedge (i_4 \subseteq I)])]$$

$$(136) \lambda z_3 \lambda \Phi [z_3 (\lambda i_4 [\Phi(i_4) \wedge (i_4 \subseteq I)])] (\lambda P [P(\text{noon})]) = \\ \lambda \Phi [\Phi(\text{noon}) \wedge (\text{noon} \subseteq I)]$$

Just as we have done for the previous temporal modifiers, given an unmodified sentences, we apply our the semantics of locative prepositions. We derive an interpretation similar what we get for *during*.

### 5.4.3 Durative Prepositions *For* & *In*

We have already discussed the locative use of *in* in section 5.4.2. We however consider *in* yet again as there is a different type of temporal context it can provide – durative use. Like many other temporal prepositions, *for* and *in* can provide other contexts not necessarily temporal. We however observe that to have these prepositions produce a temporal context (in this case durative), they require a durative temporal nouns as complements as in sentences (137) and (138) below.

(137) Mark finished the puzzle in 3 minutes.

(138) The Bishop spoke for 2 hours.

(139) Chris left early for the airport

We observe that the difference between the temporal and non-temporal use of the preposition *for* from sentences(138) and (139) is the prepositional phrase complement. The durative nouns that complement the *for* and *in* are of a particular syntactic structure. We often have these temporal noun have numerical determiners as in the above sentences. From the Brown corpus extracted sentences, we observe that when a durative noun has an indefinite determiner preceding it, then it refers to a singular unit of the interval represented by the durative noun.

(140) The Bishop spoke for an hour.

(141) Mark finished the puzzle in a minute.

The main difference between these durative prepositions is the aspectual class of their main clause this was observed by Dowty [1979] where he in fact used these prepositions as a test to determine the aspectual class of a sentence verb. Similarly we observe that the durative *in* is compatible with culminating main verbs, while *for* permits only non-culminating main verbs and accomplishment, but reject achievements as main verbs.

When we have the past progressive in the main clause of the *for* sentence, we often get an unnatural reading. A more felicitous construction will be the simple past tense seen in sentence (142) in comparison to (138).

(142) ?The bishop was speaking for an hour

The progressive in the present and future tense is however compatible with the *for* preposition. One will observe that these two constructions have similar interpretation as the present progressive has a future reading. Consider the sentences below.

(143) The Bishop is speaking for an hour.

(144) The Bishop will be speaking for an hour.

The *in* preposition with the past progressive is not a grammatical as observed in the sentence below.

(145) \*The Bishop was speaking in an hour.

This is because the progressive in the main clause of the *in* sentence is does not give the duration of the event, but rather the duration from the speech time to the beginning of the event time. Therefore when in the past tense, we cannot locate the event time from the speech time as it is in the past. However in the present and future tense the progressive provides information of the amount of time required for the event interval to commence from the time of speech as seen in sentences (146) and (147). Note that a similar interpretation is assigned to simple present and future tensed *in* sentences, particularly if the sentence verb is a non culminating verb.

(146) Bishop is speaking in an hour.

(147) The Bishop will be speaking in an hour.

*In* only permits the perfect when in the future as seen in sentence (150).

(148) \*The Bishop had spoken in an hour.

(149) \*The Bishop has spoken in an hour.

(150) The Bishop will have spoken in an hour.

The future perfect as in sentence (150) is compatible with *in* because it is interpreted as the main clause being completed within the duration specified by the *in* phrase. *For* on the other hand provides the duration of a given event as of a time of reference, as a result when *for* is in the perfect, the sentence complement is usually an embedded preposition except in the present tense where the time for reference is the time of speech.

(151) The Bishop has spoken for an hour.

Tables 5.7, 5.8 and 5.9 show the configuration of tense, aspect and aspectual class of the main clause of *for* sentences. We provide a similar syntactic analysis for the durative *in* in tables A.19, A.20 and A.21.

| Aspectual Class | Past |      |          |      |
|-----------------|------|------|----------|------|
|                 | Perf | Prog | PerfProg | None |
| Activity        | +    | +    | +        | +    |
| Achievement     | -    | -    | -        | -    |
| Accomplishment  | -    | +    | +        | ?    |
| State           | ?    | -    | -        | +    |

Table 5.7: For in the past tense

| Aspectual Class | Present |      |          |      |
|-----------------|---------|------|----------|------|
|                 | Perf    | Prog | PerfProg | None |
| Activity        | +       | +    | +        | +    |
| Achievement     | -       | -    | -        | -    |
| Accomplishment  | ?       | +    | +        | ?    |
| State           | -       | -    | -        | ?    |

Table 5.8: For in the present tense

| Aspectual Class | Future |      |          |      |
|-----------------|--------|------|----------|------|
|                 | Perf   | Prog | PerfProg | None |
| Activity        | ?      | +    | ?        | +    |
| Achievement     | -      | -    | -        | -    |
| Accomplishment  | ?      | +    | +        | ?    |
| State           | -      | -    | -        | +    |

Table 5.9: For in the Future tense

### Semantic Interpretation

Due to the common occurrence of numerical determiners of the complements of durative prepositions we will require the use of counting quantifiers. Given a sentences such (152).

(152) Doug spoke for 15 minutes

(153) Doug wrote the essay in 5 hours

Applying counting quantifiers, we interpret sentences (152) and (153) in (154) and (155) respectively

$$(154) \exists_{=15} j(\text{minute}(j) \wedge \exists i(\text{speak}(\text{doug})(i) \wedge (i < \text{now}) \wedge (i \subseteq j)))$$

$$(155) \exists_{=5} j(\text{hour}(j) \wedge \exists i \exists x(\text{essay}(x) \wedge \text{write}(\text{doug}, x)(i) \wedge (i < \text{now}) \wedge (i \subseteq j)))$$

Where the quantifiers in the above sentence interpretation provides the quantity of the given temporal noun. This is with the assumption that each of the temporal intervals quantified by these temporal counting quantifiers are joined. That is the last subinterval of the given temporal noun is the first subinterval of the next.

Generating the interpretations (152) and (153) with the aid of Montague semantics does not seem obvious, we will require a way of assigning the a numerical value to the counting existential quantifiers. We therefore apply the set function – cardinality, which returns the number of elements in given set as seen in (156) and (157).

$$(156) \exists j(\text{minute}(j) \wedge (|j| = 15) \wedge \exists i(\text{speak}(\text{doug})(i) \wedge (i < \text{now}) \wedge (i \subseteq j)))$$

$$(157) \exists j(\text{hour}(j) \wedge (|j| = 5) \wedge \exists i(\text{return}(\text{doug})(i) \wedge (i < \text{now}) \wedge (i \subseteq j)))$$

Given that counting quantifiers enables us apply other equating operators such as  $\leq$  and  $\geq$ , we are able to provide interpretations for sentences such as (158) and (159) as in (160) and (161) respectively.

$$(158) \text{Doug spoke for less than 15 minutes.}$$

$$(159) \text{Doug returned in less than 5 hours.}$$

$$(160) \exists j(\text{minute}(j) \wedge (|j| < 15) \wedge \exists i(\text{speak}(\text{doug})(i) \wedge (i < \text{now}) \wedge (i \subseteq j)))$$

$$(161) \exists j(\text{hour}(j) \wedge (|j| < 5) \wedge \exists i(\text{return}(\text{doug})(i) \wedge (i < \text{now}) \wedge (i \subseteq j)))$$

#### 5.4.4 By

The preposition *by* is somewhat similar in interpretation to *before*. A major difference between them however is that *before* generally asserts that a given event or state holds prior to the time of reference, *by* on the other hand tends to claim the the event occurred prior to the time of reference or at the time of reference.

### Syntactic Analysis

The complements of *by* phrases are usually explicit times as in sentence (162). But just like *for* and *in*, *by* also allows complements that describe subintervals as in sentences (163) and (164). Regular event nouns produce ungrammatical constructions as in sentence (165) or spatial contexts at best .

(162) The President will meet the delegates by noon.

(163) The president will meet the delegates by the end of the conference.

(164) The opposing team will equalise by the second half

(165) \*The President will meet the delegates by the meeting.

*By* is quite selective on the main clause tense it permits. Given a past tense in the main clause, we tend to have a somewhat unnatural reading and the preposition will be more appropriate for such a configuration as in sentence (167).

(166) ?The president met the delegates by noon.

(167) The president had met the delegates by noon.

In the past tense, we get a more appropriate reading for *by* sentences if the verb is in the perfective as in sentence (167). This is because the preposition *by* tends to claim the completion of the main event at a given time. This behaviour of *by* is similar to the behaviour of the perfect which claims an event has been completed at a given time of reference.

The past progressive is ungrammatical in *by* sentences. When in the present tense it tends to provide a future reading. Consider the sentences below:

(168) The train departs by midnight.

(169) \* The train has departed by midnight.

(170) The train is departing by midnight.

As observed in sentence (169) the present perfect is completely ungrammatical whilst the simple present tense is not very natural and would rather be complemented by a locative preposition or be in the progressive as in sentence (170).

The future tense is a lot more compatible with *by* consider the following sentences.



(171) The train will depart by midnight.

(172) The train will be departing by midnight.

(173) The train will have departed by midnight.

When we are given the future and the future progressive as in sentences (171) and (172) we have similar interpretation of be main event occurring before or at the time reference. In the future perfect on the other hand, *by* has a similar interpretation with *before*. That is the main clause event is said to have occurred prior to the time of reference.

| Aspectual Class | Past |      |          |      |
|-----------------|------|------|----------|------|
|                 | Perf | Prog | PerfProg | None |
| Activity        | -    | -    | -        | ?    |
| Achievement     | +    | -    | -        | ?    |
| Accomplishment  | +    | -    | -        | ?    |
| State           | ?    | -    | -        | ?    |

Table 5.10: By in the past tense

| Aspectual Class | Present |      |          |      |
|-----------------|---------|------|----------|------|
|                 | Perf    | Prog | PerfProg | None |
| Activity        | -       | +    | ?        | ?    |
| Achievement     | -       | +    | ?        | ?    |
| Accomplishment  | -       | +    | ?        | ?    |
| State           | -       | -    | ?        | ?    |

Table 5.11: By in the Present tense

| Aspectual Class | Present |      |          |      |
|-----------------|---------|------|----------|------|
|                 | Perf    | Prog | PerfProg | None |
| Activity        | -       | +    | -        | +    |
| Achievement     | -       | +    | -        | +    |
| Accomplishment  | -       | +    | -        | +    |
| State           | -       | +    | -        | +    |

Table 5.12: By in the future tense

See tables 5.10, 5.11 and 5.12 for the syntactic analysis of the main clause of *by* sentences.

### Semantic interpretation

From the syntactic analysis we observe that *by* has an interpretation similar to *before* when the main clause is the perfect, and when it is not, we interpret then main event as occurring on or before the time of reference. We therefore provide semantics for *by* given a perfect main clause in (174) and (176) is the interpretation of *by* given a simple tensed main clause.

$$(174) [\text{TPby}] = \lambda z_3 \lambda \Phi [z_3 (\lambda i_0 [\Phi(j_0) \wedge (j_0 < i_0)])]$$

$$(175) [\text{TPby}] = \lambda z_3 \lambda \Phi [z_3 (\lambda i_0 [\Phi(j_0) \wedge ((j_0 \leq i_0))])]$$

The present progressive has a future reading however the progressive in the present and future tense is read as the main event occurring in at the time of reference similar to the interpretation of the locative prepositions.

$$(176) [\text{TPby}] = \lambda z_3 \lambda \Phi [z_3 (\lambda i_0 [\Phi(j_0) \wedge (j_0 \leq i_0)])]$$

Given therefore a sentences such as (171) and (173), we assign interpretation (177) and (178) respectively.

$$(177) \exists i_0 \exists x (\text{train}(x) \wedge \forall y (\text{train}(y) \rightarrow y = x) \wedge \text{depart}(x)(i_0) \wedge (\text{now} < i_0) \wedge (i_0 \leq \text{midnight}))$$

$$(178) \exists i_0 \exists x (\text{train}(x) \wedge \forall y (\text{train}(y) \rightarrow y = x) \wedge \text{depart}(x)(i_0) \wedge (\text{now} < i_0) \wedge (i_0 < \text{midnight}))$$

## 5.5 Temporal Conjunctions

Temporal conjunctions refer to temporal modifiers that permit sentential complements, the interval within which these sentential events occur provide the the time of reference for the main clause of the sentence. In this section we consider some of the syntactic behaviours of these temporal conjunction as well as their interpretations.

### 5.5.1 Before & After

There are situations where events occur in sequence, we can describe these sequential events using the modifiers *before* and *after*. These prepositions are mostly temporal but there are instances where they can be used to provide spatial contexts. For example,

(179) The defendant was allowed to testify before the grand jury.

(180) The defendant was allowed to testify before the recess.

We observe that while the prepositional phrase in sentence(179) provides a spatial context, sentence(180) is temporal, the difference between these sentences and the type of context their complement provides is in the type of noun phrase that complements the prepositional phrase. The noun phrase complement in sentence (179) is an individual while the sentence (180) is an event which represents a temporal interval.

*After* can also be used to provide spatial context, although in a different manner from *before*.

(181) Turn right after 200yards.

The spatial use of *after* is mostly used in imperative statements similar to one given by a vehicle navigator. The temporal instances of *before* and *after* requires temporal noun or sentential complement. The sentential complements will always provide a temporal context. Given two hundred *before* sentences from the Brown corpus, we find that 21% illustrates the spatial use of *before*, while the remaining 79% is temporal. We will study the behaviour of this 79% temporal instances of *before*. Due to general imperative structure of spatial instance of *after*, our extracted sentences from the Brown corpus only included temporal instances of *after*.

#### Syntactic Analysis

There are three possible syntactic structures permitted in the temporal instances of *before*. These include—sentential complements, event nouns, temporal proper nouns and deictic references. Consider the following sentences.

(182) John had cleaned the windows before Mary arrived.

(183) Messi said a prayer before the kick-off.

(184) The guests arrived before noon.

(185) Luke had never met Joe before.

Sentences (182)-(185) all express the temporal instances of *before*. Note however the differences amongst the subordinate phrase/clause. Sentence (182) has a sentential complement, sentence(183) has a event noun as the subordinate phrase, Sentence (184) has a temporal proper noun in its subordinate phrase and sentence(185) implies some deitic temporal reference which in this case coincides with the time of speech.

Amongst 158 temporal instances of *before* extracted from the Brown corpus, we find that 54.4% of the sentences have sentences as complements, 16.5% are event nouns, 15.2% are explicit times and 13.9% have deitic temporal references.

(186) Mike spoke before Mary arrived.

(187) Mike speaks before the meeting begins

(188) Mike will speak before Mary arrives.

Sentences (186), (187) and (188) show the subordinate clause of *before* sentences in the past, present and future tense respectively. We observe the requirement of tense agreement between the main and subordinate clauses. Given a main clause in the future tense however we see the subordinate clause remains in the present tense. We observe also that *before* sentences do not permit the perfect in the subordinate clause. There is only one instance where the progressive is permitted. Consider sentence (189) below

(189) Mike left before hearing the announcement.

In the above sentence, the subject of the subordinate clause is can be said to be reflexive pronoun. We can say that there is a parasitic gap between the preposition and the subordinate clause subject.

*After* on the other hand permits similar syntactic structures in its subordinate phrase as *before*. Deitic references are however less common as *after* complements.

From two hundred Brown corpus *after* sentences, we observe that 48% has sentential complements, 28% are temporal nouns, and 24% are explicit times.

While *before* and *after* are similar in the syntactic structures of their main clause and subordinate clause, one obvious difference between them is *after* permits the perfective in its subordinate clause as opposed to *before*. As seen in the sentence below,

(190) John arrived after Mary had left.

Tables 5.13, 5.14 and 5.15, provides a summary of the syntactic structure of grammatical *before* sentence main clauses. A similar structure for *after* is given in A.25, A.26 and A.27 in the appendix.

| Aspectual Class | Past |      |          |      |
|-----------------|------|------|----------|------|
|                 | Perf | Prog | PerfProg | None |
| Activity        | +    | +    | -        | +    |
| Achievement     | +    | ?    | -        | +    |
| Accomplishment  | +    | ?    | -        | +    |
| State           | +    | -    | -        | +    |

Table 5.13: Before in the past tense

| Aspectual Class | Present |      |          |      |
|-----------------|---------|------|----------|------|
|                 | Perf    | Prog | PerfProg | None |
| Activity        | -       | +    | -        | +    |
| Achievement     | -       | +    | -        | +    |
| Accomplishment  | -       | +    | -        | +    |
| State           | -       | -    | -        | ?    |

Table 5.14: Before in the present tense

| Aspectual Class | Future |      |          |      |
|-----------------|--------|------|----------|------|
|                 | Perf   | Prog | PerfProg | None |
| Activity        | +      | +    | -        | +    |
| Achievement     | +      | +    | -        | +    |
| Accomplishment  | +      | +    | -        | +    |
| State           | +      | -    | -        | ?    |

Table 5.15: Before in the future tense

### Semantic Interpretation

We provided the semantic interpretation of the main clause and subordinate clauses of the preposition *before* and *after* in section 5.2. We attempt in this section to provide interpretations for the prepositions of interest.

$$(191) \text{ [}_{\text{TP}}\text{before]} = \lambda z_3 \lambda \Phi [z_3 (\lambda i_0 [\Phi(I_1) \wedge (I_1 < i_0)])]$$

$$(192) \text{ [}_{\text{TP}}\text{after]} = \lambda z_3 \lambda \Phi [z_3 (\lambda i_0 [\Phi(I_1) \wedge (I_1 > i_0)])]$$

The interpretation (191) and (192) presents the interpretation of *before* and *after* respectively. Given a sentence such as (193), we attempt to provide a semantic interpretation by combining the interpretation of their various constituent syntactic categories.

(193) John arrived before the meeting.

$$(194) \text{ [}_{\text{TPP}}\text{before the meeting]} = \text{[}_{\text{TP}}\text{before]}(\text{[}_{\text{TNP}}\text{the meeting]}) = \\ \lambda z_3 \lambda \Phi [z_3 (\lambda i_0 [\Phi(I_1) \wedge (I_1 < i_0)])] (\lambda Q [\exists i_i (\text{meeting}(i_1) \wedge \forall j (\text{meeting}(j) \rightarrow (j = i_1)) \wedge Q(i_1))]) = \\ \lambda \Phi [\exists i_1 (\text{meeting}(i_1) \wedge \forall j (\text{meeting}(j) \rightarrow (j = i_1)) \wedge \Phi(I_1) \wedge (I_1 < i_1))]$$

The interpretation in (194) shows the combination of the temporal preposition *before* and its complement noun phrase *the meeting*. Similar application is used for *after*.

$$(195) \text{ [}_{\text{S}}\text{John arrived before the meeting]} = \\ \lambda \Psi [\Psi (\lambda I [\exists i_0 \exists x (\text{arrive}(\text{john})(i_0) \wedge (i_0 < \text{now}) \wedge (i_0 \subseteq I))])] \\ (\lambda \Phi [\exists i_1 (\text{meeting}(i_1) \wedge \forall j (\text{meeting}(j) \rightarrow (j = i_1)) \wedge \Phi(I_1) \wedge (I_1 < i_1))]) = \\ \exists i_1 (\text{meeting}(i_1) \wedge \forall j (\text{meeting}(j) \rightarrow (j = i_1)) \wedge \\ \exists i_0 \exists x (\text{arrive}(\text{john})(i_0) \wedge (i_0 < \text{now}) \wedge (i_0 \subseteq I_1) \wedge (I_1 < i_1)))$$

Although we have not shown how these combinations works suppose the complement of the *before* phrase is a sentences. Note however that the interpretation of the sentential complement in (80) is of the same type as our interpretation of the nominal complements for example (195). We therefore apply the *before* phrases with sentential complements similarly as we have done for those with nominal complements.

### 5.5.2 Until

*Until* is a modifier that can behave as a preposition as well as a conjunction. That is it can be complemented either by a temporal noun or by a sentence. *Until* has only a temporal use. We consider the behaviour of *until* and *till* in this section as they both have similar syntactic behaviours and semantic interpretations. *Until* is indeed a very interesting prepositions and has this been studied by many linguists such as Karttunen [1973], Brée [1985a], Brée [1985b], Pratt-Hartmann and Francez [2001] etc.

#### Syntactic Analysis

We have already established that the complements of *until* can either be nominal or sentential. *Until* permits a wide range of syntactic structures as complement. Common ones include temporal proper nouns as in sentence (196), premodified temporal nouns as in sentence (197), and sentences as in sentence (198);

(196) John slept until 5:45pm.

(197) Mark continued composing until the last year of his life

(198) John slept until Mary arrived.

| Aspectual Class | Past |      |          |      |
|-----------------|------|------|----------|------|
|                 | Perf | Prog | PerfProg | None |
| Activity        | -    | +    | ?        | +    |
| Achievement     | -    | -    | -        | -    |
| Accomplishment  | -    | +    | ?        | -    |
| State           | -    | -    | -        | +    |

Table 5.16: *Until* in the past tense

| Aspectual Class | Present |      |          |      |
|-----------------|---------|------|----------|------|
|                 | Perf    | Prog | PerfProg | None |
| Activity        | -       | +    | -        | ?    |
| Achievement     | -       | -    | -        | -    |
| Accomplishment  | -       | +    | -        | -    |
| State           | -       | -    | -        | +    |

Table 5.17: *Until* in the present tense

| Aspectual Class | Future |      |          |      |
|-----------------|--------|------|----------|------|
|                 | Perf   | Prog | PerfProg | None |
| Activity        | ?      | +    | ?        | +    |
| Achievement     | -      | -    | -        | -    |
| Accomplishment  | ?      | +    | ?        | ?    |
| State           | -      | -    | -        | +    |

Table 5.18: *Until* in the future tense

In the case of sentential complements, there is a requirement of tense agreement between the main and subordinate clause verbs. The subordinate clause can however not be in the progressive or negative.

The main clause requires a durative verb in the main clause. This is because *until* is interpreted as an event beginning at a time of reference and continuing till its terminated at the interval provided by the temporal preposition complement. Given a culminating verb, we get an unnatural sentence as in sentence (199) below.

(199) ?Job drank a pint of beer until midnight.

Based on this observation one would tend to conclude that the perfect will not be permitted in an *until* sentence main clause considering that the perfect coerces culmination. The progressive on the other hand when in interaction with an accomplishment, it strips it of its culmination, making it resemble an activity as in sentence (200).

(200) Job was drinking a pint of beer until midnight.

Tables 5.16, 5.17 and 5.18 shows a summary of the grammaticality of various configurations of the main clause of *until* sentences.

### Semantic interpretation

We have discussed thus far that *until* and *till* requires a durative verb that is activities and states in the main clause, while the subordinate clause or phrase is complemented by temporal nouns, explicit times and sentences, we observe the reason there is a constraint on having a durative verb in the main clause is *until* tends to enforce a termination on the main event or state. For example, it is can be implied from sentence (196), that *John* did not remain in the state of sleeping



beyond 5:45pm. Brée [1985b], observes that *until*, provides more than the temporal context and in many cases it also includes a causal information. This is more obvious in sentences such as (198) where it appears John would have continued sleeping if Mary did not arrive. We therefore take the time complementing the *until* phrase or clause as the time of termination of the main clause verb.

We interpret *until* as the main clause verb occurring from a time of reference and continuing till the *until* time. We therefore interpret sentence (198) thus,

$$(201) \exists i_1(\text{arrive}(\text{mary})(i_1) \wedge \exists i \exists i_0(\text{beganBY}(i_0, i) \wedge \forall j((j \subset i_0) \wedge \text{endedBY}(i_0, i_1) \rightarrow \exists j(\text{sleep}(\text{john})(j) \wedge (j < \text{now}) \wedge (j \subseteq I))))))$$

*Until* is therefore interpreted as (202)

$$(202) \lambda \Phi \lambda \Psi [\Phi(\lambda i [\exists i_1 \exists i_0(\text{beganBY}(i_0, i_1) \wedge \text{endedBY}(i_0, i) \forall j((j \subset i_0) \rightarrow \Psi(j)))])]$$

Given that we assign the same lambda types to nominal complements to sentential complements, we can easily provide interpretation for *until* phrases as we did in interpretation (201).

### 5.5.3 Since

*Since* is amongst well studied temporal prepositions/conjunctions. There are two uses of *since* – the temporal as in sentence (203) and inferential instances as in sentence (204);

(203) Yolanda has lived in London since the 1980s

(204) Since Yolanda lives in London Adam will have a place to sleep.

Brée [1985b] rightly observed the syntactic marker that distinguished these two uses of *since*. The temporal *since* usually have its main clause in the perfect, while the inferential *since* is not. Given a main clause event, *since*, provides information on the starting point of the interval the main clause occurred.

#### Syntactic Analysis

Although the temporal *since* often has a perfective verb in the main clause, the main clause verbs are often states or achievements as in sentences (205) and (206) respectively. We can have the activities and accomplishments in the perfect progressive, and passive voiced main clause as in sentence (208)

(205) Rose had arrived since 16:30.

(206) Dudley has been a boxer since 2012.

(207) John has been sleeping since Mary left.

(208) The constitution had been writing since the beginning of the 19th century.

*Since* like *before*, *after* and *until* can be complemented by either a temporal noun or a sentence. When the main clause is in present perfect the, subordinate clause is often in the past tense as in sentence (207). We do not often encounter *since* sentences in the future tense. When in the past tense the sentence described the event time and the reference time as being prior to the time of speech as in sentence (205).

| Aspectual Class | Past |      |          |      |
|-----------------|------|------|----------|------|
|                 | Perf | Prog | PerfProg | None |
| Activity        | +    | -    | ?        | -    |
| Achievement     | ?    | -    | ?        | -    |
| Accomplishment  | ?    | -    | ?        | -    |
| State           | ?    | -    | ?        | -    |

Table 5.19: Since in the past tense

| Aspectual Class | Present |      |          |      |
|-----------------|---------|------|----------|------|
|                 | Perf    | Prog | PerfProg | None |
| Activity        | ?       | -    | +        | -    |
| Achievement     | +       | -    | -        | -    |
| Accomplishment  | +       | -    | +        | -    |
| State           | +       | -    | -        | -    |

Table 5.20: Since in the present tense

| Aspectual Class | Future |      |          |      |
|-----------------|--------|------|----------|------|
|                 | Perf   | Prog | PerfProg | None |
| Activity        | ?      | -    | ?        | -    |
| Achievement     | ?      | -    | -        | -    |
| Accomplishment  | ?      | -    | -        | -    |
| State           | ?      | -    | -        | -    |

Table 5.21: Since in the future tense

Tables 5.19, 5.20 and 5.21 summarized the the syntactic configurations of the *since* sentence.

### Semantic Interpretation

*Since* is often regarded as a durative preposition as its main clause verbs are required to be durative verbs. Although the perfect is often known to enforce a culmination on events, it appears in the case of *since* it converts achievements to states that is directly referring to the result state of the event described by the verb. Therefore making the main clause verb durative. *Since* however describes the beginning of the temporal interval the main event or state holds, Allen's *begins* temporal operator describes the relationship between the main clause interval and the subordinates clause interval. For example (209) is interpreted as the interval where the main clause – *John waiting* was began by the interval of *Mary leaving*. That is the subordinate clause interval is the first subinterval of the main clause interval. Sentence (209) is therefore interpreted as (210).

(209) John has been waiting since Mary left.

(210)  $\exists i_0(\text{leave}(\text{mary})(i) \wedge \exists i(\text{wait}(\text{john})(i) \wedge (i < \text{now}) \wedge (i \subseteq I) \wedge \text{beganBy}(I, i_0)))$

*Since* is therefore interpreted thus;

(211)  $\lambda\Phi\lambda\Psi[\Phi(\lambda i(\Psi(i_0) \wedge \text{beganBy}(i, i_0)))]$

### 5.5.4 While

*While* is strictly a temporal conjunction, that is it can only permit sentential complements. *While* can be said to be similar to *during* in that the main clause state or event holds within the subordinate interval.

#### Syntactic Analysis

The subordinate clause of *while* is expected to be durative since we expect it to contain the main clause event or state. Achievements are therefore not permitted as the subordinate clause verb. Activities are permitted as they inherently imply an extended interval in which they occur as in sentence(212).

(212) Vince played the guitar while Gabriel sang.

Accomplishments can be viewed as activities with an eventual culmination. When we have an accomplishment in the subordinate clause the interval of interest is the activity without necessarily including the culmination. Consider the following sentence.

(213) Vince played the guitar while Gabriel drank a glass of wine.

We know the event *drink a glass of wine* is true only when the glass has been emptied by Gabriel, however as a *while* complement, we are more interested in the interval before the culmination.

Because the subordinate clause requires a durative verb, we often have progressive but never the perfect. Stative verbs mostly seem unnatural in the subordinate clause as well.

Main clause of *while* sentences do not have many restrictions. The only obvious ones are that the perfective are unnatural. This is because the perfect refers to the interval after the termination of the event. Therefore having the perfect in the main clause of *while* sentences means the interval after the main event is within the subordinate clause interval. Which really is not the temporal relationship *while* provides.

| Aspectual Class | Past |      |          |      |
|-----------------|------|------|----------|------|
|                 | Perf | Prog | PerfProg | None |
| Activity        | ?    | +    | +        | +    |
| Achievement     | ?    | -    | -        | +    |
| Accomplishment  | ?    | +    | +        | +    |
| State           | ?    | -    | -        | +    |

Table 5.22: *while* in the past tense

| Aspectual Class | Present |      |          |      |
|-----------------|---------|------|----------|------|
|                 | Perf    | Prog | PerfProg | None |
| Activity        | -       | +    | ?        | +    |
| Achievement     | -       | -    | -        | +    |
| Accomplishment  | -       | +    | ?        | +    |
| State           | -       | -    | -        | ?    |

Table 5.23: *while* in the present tense

### Semantic Interpretation

Just like *during*, *while* acts as some sort of temporal container within which the main clause event or states holds. A more pragmatic way to look at *while* is that the main event occurred simultaneous to the subordinate clause event. There is however the impression that the interval of the main clause event is completely

| Aspectual Class | Future |      |          |      |
|-----------------|--------|------|----------|------|
|                 | Perf   | Prog | PerfProg | None |
| Activity        | ?      | +    | -        | +    |
| Achievement     | ?      | -    | -        | +    |
| Accomplishment  | ?      | +    | -        | +    |
| State           | ?      | -    | -        | +    |

Table 5.24: While in the future tense

contained in the subordinate clause event. We therefore interpret *while* as in 214

$$(214) \ [_{tp} \text{while}] = \lambda \Psi \lambda \Phi [\Psi (\lambda i_4 [\Phi (i_4) \wedge (i_4 \subseteq I)])]$$

Given therefore a sentences such as (212), we interpret the subordinate clause as we did in (80);

$$(215) \ [_{s} \text{Gabriel sang}] = \\ \lambda Q [\exists i_0 (\text{sing}(\text{gabriel})(i_0) \wedge Q(i_0))]$$

$$(216) \ [_{\text{TPP} \text{while}} \text{Gabriel sang}] = \\ \lambda \Phi [\exists i_0 (\text{sing}(\text{gabriel})(i_0) \wedge \Phi(i_0) \wedge (i_0 \subseteq I))]$$

Sentence (212) is therefore interpreted as follows

$$(217) \ \exists i_0 (\text{sing}(\text{gabriel})(i_0) \wedge \\ \exists i_1 \exists x (\text{guitar}(x) \wedge \forall (\text{guitar}(x) \rightarrow (x = y) \wedge \\ \text{play}(\text{vince}, x)(i_1) \wedge (i_1 < \text{now}) \wedge (i_1 \subseteq i_0) \wedge (i_0 \subseteq I)))$$

## 5.6 Temporal Prepositions and Verbal Negation

We have thus far not considered the effect of verbal negation on the interpretation temporal prepositions. From literature and our study, we observe that verbal negation does in fact affect the interpretation of some of the prepositions we have discussed thus far. Given the temporal prepositions we have studied that is , *during*, *in*, *on*, *at*, a negated main clause asserts that there does not exists an interval where the event occurred. For example,

$$(218) \ \text{John did not arrive during the meeting}$$

(219) John did not arrive at midnight

Sentence (218) is interpreted as (220) below, sentence (219) is interpreted similarly

(220)  $\exists i_0(\text{meeting}(i_0) \wedge \forall j_0(\text{meeting}(j_0) \rightarrow (i_0 = j_0) \wedge \neg \exists i(\text{arrive}(\text{john})(i) \wedge (i < \text{now}) \wedge (i \subseteq i_0))))$

We see that the sentence interpretation (220) simply denies the existence of an interval in which the event of interest occurs.

Durative prepositions *for* and *in* with negated main clauses do not equate the duration of provided by prepositional complement with the cardinality of the main clause interval. The following sentence interpretation illustrates what we mean.

(221) Doug did not speak for 15 minutes

We interpret sentence (221) the duration of the interval of main clause is not equal to the duration specified by the prepositional phrase complement.

(222)  $\exists j(\text{minutes}(j) \wedge (|j| \neq 15) \wedge \exists i(\text{speak}(\text{doug})(i) \wedge (i < \text{now}) \wedge (i \subseteq j)))$

Similar treatment is applied for the durative use of *in*.

Similarly, *before* and *after* prepositions with negated main clause verbs asserts that event did not occur *before* and *after* the time of reference respectively as observed in the following sentence.

(223) John did not arrive before the meeting.

Sentence (218) is therefore interpreted as:

(224)  $\exists i_1(\text{meeting}(i_1) \wedge \forall j(\text{meeting}(j) \rightarrow (j = i_1)) \wedge \exists i_0 \exists x(\text{arrive}(\text{john})(i_0) \wedge (i_0 < \text{now}) \wedge (i_0 \subseteq I_1) \wedge (I_1 \not\subseteq i_1)))$

The preposition *until* with a negated main clause verb has however being a topic of discussion in linguistics for a few decades. There are two popular theories for the interpretation of the *until* phrase with a negated main clause verb. The first as proposed by Brée [1985a] claims that verbal negation like grammatical aspects is capable of causing an aspectual class coercion. That is negation creates a state where the described event does not occur. For example, sentence (225) describes the interval where the stated of affairs is *John not arriving*

(225) John did not arrive.

Given therefore an *until* sentence with a negated main clause verb, Bree claims there is a state that denies the occurrence of the main clause event, from a time of reference to the temporal interval given by the *until* phrase or clause. Consider the following sentence.

(226) John did not wake up until Mary arrived.

According to Bree's interpretation of *until*, there is an interval where the state of affairs is such that *John was not awake*, this said interval terminates at the time *Mary arrived*.

The alternative theory of *until* with a negated main clause verb as proposed by Karttunen [1973], denies that negation causes an aspectual class coercion but rather considers *until* as a negative polarity item such that there is no denial of the occurrence of the main clause event but rather asserts its. For example, sentence(226) does not deny the event of *John waking up* but rather asserts that he does at the time indicated by the *until* complement.

(227)  $\exists j(\text{arrive}(\text{mary})(j) \wedge \exists i_o \exists i(\text{beganBy}(i, i_o) \wedge \text{endedBy}(i, j) \wedge \neg \text{wake}(\text{john})(i) \wedge (i < \text{now}) \wedge (j \subseteq I)))$

(228)  $\exists j(\text{arrive}(\text{mary})(j) \wedge \exists i(\text{wake}(\text{john})(i) \wedge (i < \text{now}) \wedge (i \subseteq j) \wedge (j \subseteq I)))$

Both Bree's and Kattunen's theories appear reasonable, considering however that we have always treated *until* as a modifier that terminates a given durative event, it appear's Bree's interpretation is the more appropriate theory for our controlled natural language.

## 5.7 Conclusion

In the chapter we discussed the interpretation of temporal modifiers quite extensively. The syntactic analysis and interpretation of these temporal modifiers are important because as we have observed in many cases, they determine the behaviour of other temporal expressions, particularly grammatical aspects.

In developing a controlled natural language with temporal features, we require a proper understanding of the interaction of these temporal expressions, their syntactic compatibility and effect of their interaction on the interaction on the sentence interpretation.

## Chapter 6

# Design of a CNL with Temporal Features

Just as we discussed in section 2.1, a language is made up of a vocabulary and a set of rules that determine how the words in the said vocabulary combine to form sentences of the language. We also considered formal interpretation for sentences of a given language and how these interpretations can possibly be automatically derived from the sentence's syntactic representation – Montague semantics.

We are concerned with developing a controlled natural language, which has English as its base language able to parse and provide interpretations for temporal expressions. And just like every language, this said language has a vocabulary or lexicon and a set of grammar rules. With the aid of these grammar rules and annotated semantic interpretation of terminal and non-terminal symbols, we automatically generate interpretations for sentences in first order logic. For example, given sentence (229), we consider what a language requires to provide its first order interpretation as given in (230).

(229) Every student will write an exam every semester.

(230)  $\forall i(\text{semester}(i) \rightarrow$   
 $\quad \forall x(\text{student}(x) \rightarrow$   
 $\quad \exists j \exists y(\text{exam}(y) \wedge \text{write}(x, y)(j) \wedge (\text{now} < j) \wedge (j \subseteq i) \wedge (i \subseteq I))))$

Achieving this interpretation requires the application of a grammar in this case context free grammar to a lexicon and applying Montague semantics for the automatic translation to its formal representation in first order logic. We therefore



describe the lexicon of our language in section 6.1, the grammar 6.2 and in section 6.3 we discuss the semantic interpretation of our controlled natural language with temporal features.

## 6.1 Lexicon

The lexicon or vocabulary refers to the set of terminal symbols of a given language where each member of the set is of a syntactic category. In the case of a controlled natural language, a vocabulary or more appropriately a lexicon is the set of words used by the language grammar to form sentences. Each member word (otherwise called lexical item) of the lexicon is assigned a syntactic category or a part of speech (POS). This enables the grammar understand the behavior of the lexical item.

We can say members of our lexicon are divided into function and content words. The most observable difference between these two classes is that the semantic representation of function words are relations, while content words are either interpreted as variables or predicates. In general we define a lexical item as

(231)  $\text{lexentry}(\text{POS}, [X]),$

where POS is the part of speech of the lexical item and X is a list of its parameters. We describe each of the parts of speech in our language and the various parameters we assign that helps describe the behaviour of a given lexical item

### 6.1.1 Nouns

In our language we have two major types of nouns that is objects and temporal nouns. As suggested by their names, an object noun names objects or individuals while temporal nouns name temporal intervals. Object nouns can either be common countable nouns, or proper nouns. Countable nouns can be singular or plural.

Temporal nouns are those that name intervals. They can either be interval nouns, event nouns or temporal proper nouns. Interval nouns refer to those nouns that name common intervals. For example *day*, *hour*. Event nouns name events like *meeting*, *lecture* etc. Interval and event nouns behave as common countable nouns do and can be singular or plural. Temporal proper nouns are similar to

proper nouns and describe specific times like clock times, years, months etc. For example *1978*, *16:45*, *January* etc. We therefore define lexical entries with the POS nouns thus:

(232) `lexentry(noun, [symbol:Q, syntax:[X], num:Y, type:Z])`

Where the symbol (Q) is the used in representing the lexical entry in the eventual semantic interpretation of the lexical item. The value of syntax (X) is the lexical item itself. And the value of type (Z) states whether the lexical entry is an interval noun, an event noun, a countable noun, a proper noun or temporal proper noun. Therefore nouns *boys* and *april* are defined as in (233) and (234) respectively.

(233) `lexentry(noun, [symbol:boy, syntax:[boys], num:pl, type:countable])`

(234) `lexentry(noun,[symbol:april, syntax:[April], num:sgl, type:tmpPrNoun])`

### 6.1.2 Determiners

Determiners are function words that behave like quantifiers. In our language we distinguish four types— indefinite determiners, definite determiners, nominal negation and universal determiners. Examples of indefinite determiners include *a*, *an* and *some*. Indefinite determiners *a* and *an* are considered singular determiners because they preceded only singular nouns, *some* can however be singular or plural. Definite determiner refer to *the*, it can either be singular or plural. Examples of universal determiner include *every*, *all* and *each*. *All* is always plural, *each* and *every* are always singular. Finally nominal negation *no* is always singular. We therefore define determiners thus:

(235) `lexentry(Det, [syntax:[X],num:Y, type:Z])`

Where type ranges between indefinite , definite, universal and nominal negation. Determiners *every* and *the* can therefore be defined as (236) and (237) respectively

(236) `lexentry(Det, [syntax:[every], num:sgl, type:uni])`

(237) `lexentry(Det, [syntax:[the], num:sgl, type:indef])`

Note that the lexicon definition for *the* in (237) can also be assign plural value.

### 6.1.3 Verbs

Verbs are content words, that describe events and states. Verbs just as nouns can either be in singular or plural forms. Where the number of a verb must agree with the number of its subject noun.

Our language attempts to parse temporal expressions, therefore there are some inflections on verbs that are of temporal significance. In our lexicon every verb has a corresponding past, participle and progressive inflection. Every verb hence possesses the following properties – number, tense, and type. Verbs are represented in our lexicon in the format:

(238) `lexentry(verb, [symbol:X, syntax:[Y], num:Z, tense:T, type:R])`

As usual the symbol (X) and syntax and number as defined as in section 6.1.1, tense is tense inflection on verb which can either be past, present, nil, participle, or progressive. The type can either be transitive or intransitive. We therefore define verbs like *written* in our lexicon as in (239) below.

(239) `lexentry(verb, [symbol:written, syntax:[written], num:sgl, tense:participle, type:transitive])`.

### 6.1.4 Temporal Prepositions/Conjunctions

In chapter 5, we discussed in quite some detail the syntactic behaviour and interpretations of temporal prepositions and conjunctions. We however show here how we include them in our language. Because of the very varied behaviours of these temporal prepositions, each preposition is assigned its own type. We are therefore interested only in the interpretations of lexical item and its type. Temporal prepositions and conjunctions are therefore defined as (240) in our lexicon.

(240) `lexEntry(tempPrep, [syntax:[X], type:Y])`

Given a preposition such as *during*, we therefore define it as:

(241) `lexEntry(tempPrep, [syntax:[during], type:before])`

### 6.1.5 Auxiliary verbs

Examples of auxiliary verbs include *have*, its past and plural inflections which indicates the perfective aspect, the copula *be* and its various tensed inflections etc. Semantic functions of these auxiliary verbs are reasonably varied we therefore have many varied types. For example, the auxiliary verb *is* precedes the progressive we therefore define it thus:

(242) `lexentry(aux,[syntax:[is], num:sgl tense:present, type:be])`

### 6.1.6 Tense

Although these are not lexical items in the regular sense, they are however of semantic importance. In section 6.3, where we discuss the semantic interpretations of the structures in our language, we will observe the need to have tense represented as a syntactic category as its semantic interpretation is combined with those of untensed verb phrases to provide temporal ordering between event time and speech time, and also provide a temporal context which enables interaction with temporal modifiers. There are two types in our language – past and future tenses. The past tense is syntactically represented by an empty string. The future tense on the other hand is represented by the auxiliary verb *will*. The past tense is therefore interpreted thus:

(243) `lexentry(tense,[syntax:[], type:past])`

## 6.2 Grammar

In chapter 2.2 we discussed various formalisms for representing the syntactic structure of languages. We were able to see that amongst the many existing grammars, context free grammar appears to be the most suitable for the definition of a controlled natural language. As a result we will attempt to present context free grammars production rules for various syntactic structure in our language .

In the previous section we showed how lexical items are being defined in our lexicon. We know that these items make up terminal symbols of our language. Therefore production rules for terminal symbols have the lexical items as the body of the rule while the POS which serves a syntactic category is the head of the production rule. Therefore given a sentence as

(244) Every boy loves some girl.

We represent the production rules for the lexical items in the sentence (244) in figure 6.1

|                    |
|--------------------|
| <b>Det</b> → every |
| <b>N</b> →boy      |
| <b>V</b> →loves    |
| <b>Det</b> →some   |
| <b>N</b> →girl     |

Figure 6.1: Terminal Symbols

Where **Det** represents determiners, **N** represents nouns, **V** represents verbs. The rules in the above table is of course incomplete and do not quite show how the said sentence can be generated from these lexical items. We therefore consider in the rest of this section the syntactic representation of non-terminal symbols.

Before introducing the various non-terminal syntactic categories of our language, we need to highlight the importance of the parameters defined on each lexical item. While the production rules define the word order of the lexical item, these parameters decide the appropriate type, inflection, number, tense etc. of a particular lexical item in order for a given production rule to be applicable. An obvious instance is the number agreement required between noun phrases and verb phrases before they can be concatenated to form a sentence. We attempt to describe the settings of some these parameters as required by the various productions rules for our non-terminal symbols.

### 6.2.1 Noun Phrases

In section 6.1.1 we observed that there are two different types of nouns in our language – object and temporal nouns. Object nouns can be common countable nouns or proper nouns. A common noun is often preceded by a determiner to form a noun phrase (noun phrases are represented by NP in our production rules). Therefore a common count noun is of the syntactic representation

(245) **NP**→Det, N

A given noun phrase possesses a few parameters – number which can either be singular or plural and type which can either be interval, event, proper noun or temporal proper noun. The values of these parameters are inherited from the

noun head of the noun phrase. That is if the noun head is a plural event noun then the noun phrase has the same parameters set.

In order to have rule 245 produce correct noun phrases, there are certain criteria to be met. For example, there is a number agreement requirement between the determiner and the noun head. Therefore suppose we have a noun phrase such as

(246) The trucks,

Rule (245) will produce 246 only if the determiner is defined as (247) and the noun as (248) where the appropriate parameters are assigned to both lexical items.

(247) `lexentry(Det, [syntax:[the], num:pl, type:def])`

(248) `lexentrynoun,[symbol:truck,syntax:[trucks], num:pl, type:countable].`

Proper nouns (represented as PN) on the other hand are not required to be preceded by a determiner to form a noun phrase therefore a proper noun is simply rewritten as a noun phrase as seen below

(249) **NP**→PN

Temporal noun phrases behave similarly to object noun phrases, such that interval and event nouns behave like common count nouns hence requiring a determiner. We however distinguish between temporal and non temporal determiners as discussed in chapter 5. Although the difference between temporal and non-temporal is not particular syntactic but rather semantic, because we eventually provide semantic annotation to our production rules we distinguish temporal from non-temporal determiners. Therefore a temporal noun phrase(TNP) is represented thus:

(250) **TNP**→Det, TN

Just as we have discussed for countable nouns, there is also a requirement of number agreement between the determiner and the temporal noun head in order to avoid generating ungrammatical noun phrases such as

(251) \*Every days.

Similar to proper nouns are temporal proper nouns, they are simply rewritten as temporal noun phrases.

(252) **TNP**  $\rightarrow$  TPN

Just as we have assigned parameters to our lexical items, non-terminal symbols also have parameters inherited from their constituent lexical items. For example, the noun phrase 246, retains the number that is in this case plural, and the type of noun in this case countable. These parameters help define the syntactic behaviour of the given noun phrase.

### 6.2.2 Verb Phrases

We described two types of verbs in our lexicon that is transitive and intransitive verbs. Transitive verbs are those verbs that have nominal objects. That is they are followed by a noun phrase. A verb phrase formed by combining transitive verbs with noun phrases is therefore syntactically represented as seen below

(253) **VP**  $\rightarrow$  V, NP

Again as we we did with noun phrases, the parameters must be of the appropriate type in order for rule (253) to be applicable. In most cases, transitive verbs accept countable nouns as object, therefore, in this case the object NP is required to be of the type *countable*. We can therefore generate verb phrases such as (254) as opposed to unnatural once like (255).

(254) drive the trucks

(255) ?drive the hours.

Intransitive verbs on the other hand are not followed by noun phrases. Therefore an intransitive verb can be rewritten as a verb phrase as shown below.

(256) **VP**  $\rightarrow$  V

The syntactic structure for verb phrases described in (253) and (256) define syntactic structures for bare verbs. Given a verb with the past, perfect and progressive inflection. Each of these inflection require being preceded by an auxiliary verb of appropriate type to produce verb phrases. For example, the verb *written* is the participle inflection of *write*. Which requires the *have* auxiliary verb preceding it. We therefore require an intermediate category that is concatenated to the *have* auxiliary verb and a tense to produce a verb phrase. Note that this

|  |
|--|
| $V \rightarrow \text{written}$<br>$V\text{Bar} \rightarrow V, NP$<br>$V\text{Bar} \rightarrow \text{Aux}, V\text{Bar}$<br>$VP \rightarrow \text{Tense}, V\text{Bar}$ |
|--|

Figure 6.2: Syntactic Representation of Verb Phrases

intermediate category with the syntactic category **VBar** inherits the tense parameter from the verb head in this case – participle . We can therefore set the auxiliary verb *have* to be concatenated only with a *VBar* with the tense parameter set to participle. The auxiliary verb *have* has tense and number parameters as well and we would require a number agreement. The tense parameter of the resultant verb phrase from the concatenation of the auxiliary verb and the *VBar* is assigned the concatenation of both tense parameters. Given therefore the verb phrase

(257) had written an essay,

we assign the tense parameter *past participle* given that the auxiliary verb is assigned then tense parameter – past. We can hence correctly assign the tense/aspect construction to verb phrases, given the tense parameters of the main clause and the auxiliary verb if any.

### 6.2.3 Temporal Prepositions

In chapter 5, we discussed the syntactic structure of several temporal modifiers and their corresponding semantic interpretations. We observed that temporal modifiers are of three different structures – temporal adverbials are syntactically temporal nouns just as shown in (250), temporal prepositions phrases have the structure such that the preposition heads are followed by temporal nouns and temporal conjunctions which are complemented by sentences. We therefore define temporal prepositional phrases as

(258)  $TPP \rightarrow TP, TNP$ .

Temporal conjunctions on the other hand permit just sentential complement. Therefore we define temporal conjunctions as

(259)  $TPP \rightarrow TC, S$ .



From our discussion of the syntactic behaviours of these temporal modifiers in the previous chapter, we know that temporal prepositions vary in the structure of temporal noun phrase they permit as complements. There are also specific configurations of sentences that complements temporal conjunctions. For example, the temporal prepositions *in*, *on* and *at* are known as discussed in the previous chapter to permit only temporal proper nouns as complement. Given the temporal preposition *in*, rule 258 is only applicable provided the type of the complement noun phrase is of the type *TmpPrNoun* that is a temporal proper noun. Temporal conjunctions like temporal prepositions each have defined syn-

| Prepsition/Conjunction | Complement structure  |
|------------------------|---|
| During                 | Determined and undetermined interval and event noun phrases   |
| In                     | Temporal proper nouns   |
| On                     | Temporal proper nouns   |
| At                     | Temporal proper nouns   |
| For                    | Numerically determined interval noun phrases  |
| In(durative)           | Numerically determined interval noun phrases  |
| By                     | Temporal proper nouns   |
| Before                 | Temporal proper nouns, inteval and event noun phrases, simple past and present tensed sentences                           |
| After                  | Temporal proper nouns, inteval and event noun phrases, simple past and present tensed sentences, Past perfective sentence |
| Since                  | Temporal proper nouns, inteval and event noun phrases, simple past and present tensed sentences                           |
| Until                  | Temporal proper nouns, inteval and event noun phrases, simple past and present tensed sentences                           |
| While                  | simple past and present tensed sentences  |

Table 6.1: Summary of Temporal Prepositions complement structure

tactic criteria required of their complements. For example, *before* does not permit the perfective sentence as complement but *after* does. We therefore have to consider the tense/aspect construction of the complement sentence in order to have

the appropriate syntactic configuration for the complement sentence. Table 6.1 provides a summary of the syntactic structures of the complements of temporal prepositions and conjunctions.

Temporal adverbials are syntactically temporal nouns. But there are of course certain structures that are permitted. Temporal nouns such as *yesterday*, *today*, *tomorrow* are defined as temporal adverbials. Other structures defined as adverbials include universally quantified interval and temporal nouns.

### 6.2.4 Sentences

Simple sentences in English are produced by noun phrases followed by verb phrases. Having defined the syntactic structure of noun and verb phrases, simple sentences are defined therefore as:

(260)  $S \rightarrow NP, VP$

A major requirement for the production rule (260) to be applicable is the number agreement between the subject noun phrase and verb phrase. For example, given a noun phrase such as

(261) All students,

which is assigned the *plural* number parameter, it can only be concatenated with a verb phrase with a *plural* number parameter like

(262) write exams

Given that noun phrase (261) and verb phrase (262) meet the required number agreement, we can therefore apply the production rule (260) to produce

(263) All students write exams.

The above defined production rule produces unmodified sentences we therefore assign the type *unmodified* to such a construction. A sentence has the parameters number, tense and type. Where number is inherited from the verb phrase number that is it can either be singular or plural. Due to the derivation of tense/aspect construction through the concatenation of the tense parameters of auxiliary verbs and main verbs, we are able to assign twelve possible values for tense.

From our discussion in chapter 5, we described sentences that are complemented by temporal modifiers. Therefore in our language, given a simple unmodified sentence such as (261), we can produce a modified sentence by concatenating

an unmodified sentence with a temporal prepositional phrase. As discussed in chapter 5 we described the grammatical structure of the complements and main clause of each preposition. Tables A.1-A.36 in the appendix, show the felicitous grammatical constructions of the main clause of each of the prepositions discussed in the previous chapter. Table 6.1 shows a summary of the syntactic structure. For example, from our discussion on temporal prepositions we know that the preposition *since* is expected to have a perfective main clause and past tensed subordinate clause. Supposed a modified sentence is produced with rule

(264)  $\mathbf{S} \rightarrow \mathbf{S}, \text{TPP}$ ,

where the TPP is a *since* clause, we will require the tense of the main clause (S) to have the tense parameter set to a past or present perfective for rule 264 to be applicable. A temporally modified sentence has its type parameter set to *modified*.

## 6.3 Semantics

By annotating our grammar rules with semantic interpretations we are able to apply Montague semantics, there by automatically generating the semantic interpretation of sentences in our language. In this section we discuss the semantic interpretation of the syntactic categories our language as discussed above and show how we generate interpretation for sentences.

### 6.3.1 Noun and Noun Phrases

We already established that our language has two types of nouns – object and temporal nouns. Since temporal proper nouns and proper nouns are rewritten as noun phrases lets consider their interpretation both structures first. Given a proper noun as *Mary*, we assign the following interpretation;

(265)  $[_{\text{PN}}\text{mary}] = \lambda P[P(\text{mary})]$ ,

where  $P$  is of the type  $(e, t)$  that is a function from individuals to truth value.

Similarly, temporal proper nouns are rewritten as temporal noun phrases and are assigned similar interpretation as proper nouns. We however have their lambda types as  $(i, t)$  that is function from intervals to truth values. A temporal proper noun such as *noon* is therefore interpreted as:

$$(266) \quad [_{\text{ET noon}}] = \lambda P[P(\text{noon})]$$

Count nouns are preceded by determiners. A determiner such as *every* is interpreted<sup>1</sup> (267). A countable noun is interpreted thus

$$(267) \quad [_{\text{Det every}}] = \lambda P \lambda Q [\forall x (P(x) \rightarrow Q(x))]$$

$$(268) \quad [_{\text{N boy}}] = \lambda y [\text{boy}(y)]$$

A noun phrase as defined in (245) is therefore assigned the interpretation (269) such that the interpretations of determiners are applied to the nouns'

$$(269) \quad [_{\text{NP every boy}}] = \\ \lambda P \lambda Q [\forall x (P(x) \rightarrow Q(x))] (\lambda y [\text{boy}(y)]) = \\ \lambda Q [\forall x (\text{boy}(x) \rightarrow Q(x))]$$

Temporal nouns that is interval and event nouns, are interpreted similarly to countable nouns. However as we stated in section 5.3 temporal nouns are preceded by temporal determiners which are of the type ((i,t),t). In our language the difference is in the type of variable we quantify over in the determiner interpretation. The temporal noun phrase is therefore interpreted as in (270)

$$(270) \quad [_{\text{TMP every day}}] = \\ \lambda P \lambda Q [\forall i (P(i) \rightarrow Q(i))] (\lambda j [\text{day}(j)]) = \\ \lambda Q [\forall i (\text{day}(i) \rightarrow Q(i))]$$

### 6.3.2 Verb Phrase

Designing a controlled natural language with temporal feature will require a special treatment of verbs. This is because we are required to consider the temporal context within which the events or states described by the verbs hold. Before considering interpretation of verb phrases with the inclusion of the interval they occur in, lets consider non-temporal verb phrases.

From our definition of the syntactic structure of verbs, we distinguished two types of verbs – transitive and intransitive verb, where transitive verbs are those that are concatenated with noun phrases to produce a verb phrase while intransitive verbs are not followed by noun phrases. There for intransitive verbs can be rewritten as verb phrase, a verb phrase with an intransitive verb head such as *run* is therefore interpreted as gicen below

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<sup>1</sup>the semantics of other determiners as given in the appentix

$$(271) \text{ [}_{\text{VP}}\text{run]} = \lambda x[\text{run}(x)]$$

Verbs phrases with transitive verbs heads for example *write* on the other hand are required to be followed by noun phrases. Therefore require an interpretation that enables us provide subject and object noun phrases. This is given in (272) below.

$$(272) \text{ [}_{\text{TV}}\text{write]} = \lambda x_3 \lambda x_4 [x_3(\lambda x_5 [\text{write}(x_4, x_5)])]$$

From our interpretation of transitive verbs and of noun phrases, we can generate the interpretation of verb phrases thus;

$$(273) \text{ [}_{\text{VP}}\text{write a letter]} = \\ \lambda x_3 \lambda x_4 [x_3(\lambda x_5 [\text{write}(x_4, x_5)])](\lambda Q[\exists x(\text{letter}(x) \wedge Q(x))]) = \\ \lambda x_4 [\exists x_1(\text{letter}(x_1) \wedge \text{write}(x_4, x_1))]$$

$$(274) \text{ [}_{\text{VP}}\text{kiss Mary]} = \\ \lambda x_3 \lambda x_4 [x_3(\lambda x_5 [\text{kiss}(x_4, x_5)])](\lambda P[P(\text{mary}))]) = \\ \lambda x_4 [\text{kiss}(x_4, \text{mary})]$$

In order to provide interpretations for the various tense and aspect constructions we discussed in chapter 3, we make a few adjustments to the interpretation of non-temporal instances of verbs phrases to cater for the temporal context.

$$(275) \text{ [}_{\text{V}}\text{kissed]} = \lambda x_3 \lambda i_1 \lambda x_4 [x_3(\lambda x_5 [\text{kiss}(x_4, x_5)(i_1)])]$$

Where  $i_1$  is the interval the event of state described by the verb holds.

$$(276) \text{ [}_{\text{VBar}}\text{kissed mary]} = \\ \lambda x_3 \lambda i_1 \lambda x_4 [x_3(\lambda x_5 [\text{kiss}(x_4, x_5)(i_1)])](\lambda P[P(\text{mary}))]) = \\ \lambda i_1 \lambda x_4 [\text{kiss}(x_4, \text{mary})(i_1)]$$

Note that we do not have an interpretation of the verb phrase until we have an interaction with the tense. Given that the verb head is syntactically a past tense, we can apply the semantics of the past tense to the interpretation in (276). We therefore require an interpretation for tense. Consider the interpretation in (277) for past tense<sup>2</sup>.

$$(277) \text{ [}_{\text{tense}}\text{past]} = \lambda \Phi \lambda x_6 [\exists i_0(\Phi(i_0)(x_6) \wedge (i_0 < \text{now}) \wedge (i_0 \subseteq I))]$$

<sup>2</sup>The interpretation for the future tense is simply the reverse as given in (297) in the appendix

$$(278) \text{ [}_{\text{VP}}\text{kissed mary]} = \lambda x_6 [\exists i_0 (\text{kiss}(x_6, \text{mary})(i_0) \wedge (i_0 < \text{now}) \wedge (i_0 \subseteq I))]$$

Where  $i_0$  is the event time, **now** is the time of speech, and  $I$  is a free variable representing the temporal context, this can be lambda abstracted in order to allow interaction with temporal modifiers.

We however have other forms inflections on verbs in our lexicon such as the participle and the progressive. These inflections have varied interpretations which are largely determined by the type of temporal modifiers they interact with. We discuss this in better detail in section (6.3.3) below.

### 6.3.3 Temporal Modifiers

We presented the semantics for various temporal modifiers in chapter 5. We however show in this section how temporal prepositions combine with temporal noun phrases to form temporal prepositional phrases and how temporal conjunctions interact with their complement sentences. Given a temporal preposition such as *during* interpreted as (279). We can produce the interpretation of temporal prepositional phrase by applying it to the a temporal noun phrase.

$$(279) \text{ [}_{\text{TP}}\text{during]} = \lambda z_3 \lambda \Phi [z_3 (\lambda i_4 [\Phi(i_4) \wedge (i_4 \subseteq I)])]$$

$$(280) \text{ [}_{\text{TPP}}\text{during every meeting]} = \lambda z_3 \lambda \Phi [z_3 (\lambda i_4 [\Phi(i_4) \wedge (i_4 \subseteq I)])] (\lambda Q [\forall i (\text{meeting}(i) \rightarrow Q(i))]) = \lambda \Phi [\forall i (\text{meeting}(i) \rightarrow \Phi(i) \wedge (i \subseteq I))]$$

Temporal conjunctions are treated similarly, because of the sentential complement they possess, we discuss temporal conjunctions and their complements better in section 6.3.4

### 6.3.4 Sentences

Syntactically simple sentences are defined as noun phrases concatenated with verb phrases. Having discussed the interpretation of verb phrases (274) and noun phrases (265) we can therefore interpret an untense sentence such as;

$$(281) \text{ John kisses Mary}$$

$$(282) \text{ [}_s\text{John kisses Mary]} = \\ \lambda P[P(\text{john})](\lambda x_4[\text{kiss}(x_4, \text{mary})]) = \\ \text{kiss}(\text{john}, \text{mary})$$

Suppose we are given a past tensed sentence as given below;

$$(283) \text{ John kissed Mary}$$

$$(284) \text{ [}_s\text{John kissed Mary]} = \\ \lambda P[P(\text{john})](\lambda x_6[\exists i_0(\text{kiss}(x_6, \text{mary})(i_0) \wedge (i_0 < \text{now}) \wedge (i_0 \subseteq I))]) = \\ \exists i_0(\text{kiss}(\text{john}, \text{mary})(i_0) \wedge (i_0 < \text{now}) \wedge (i_0 \subseteq I))$$

In our language tense sentences can be modified by temporal modifiers. We have three forms of temporal modifier – temporal adverbials, temporal prepositions and temporal conjunctions. Supposed we are given the sentence (285) we lambda abstract the free variable  $I$  enabling us apply the sentence to temporal prepositional phrases.

$$(285) \text{ John kissed Mary during every meeting.}$$

$$(286) \lambda \Phi[\forall i(\text{meeting}(i) \rightarrow \Phi(i) \wedge (i \subseteq I_0))](\lambda I[\exists i_0(\text{kiss}(\text{john}, \text{mary})(i_0) \wedge (i_0 < \text{now}) \wedge (i_0 \subseteq I))]) = \\ \forall i(\text{meeting}(i) \rightarrow \exists i_0(\text{kiss}(\text{john}, \text{mary})(i_0) \wedge (i_0 < \text{now}) \wedge (i_0 \subseteq i)) \wedge (i \subseteq I_0))$$

Temporal conjunctions as we discussed in chapter 5 have sentential quantifiers, we showed in section 5.2 that sentential complements do have a different interpretation as main clause such as (284). Consider the following sentence.

$$(287) \text{ John kissed Mary before Tim arrived.}$$

The subordinate clause in sentence (287) is interpreted is assigned the interpretation to

$$(288) \text{ [}_s\text{Tim arrived]} = \lambda Q[\exists i_1(\text{arrive}(\text{tim})(i_1) \wedge Q(i_1))]$$

$$(289) \text{ [}_{\text{TPP}}\text{before Tim arrived]} = \\ \lambda z_3 \lambda \Phi[z_3(\lambda i_0[\Phi(I_1) \wedge (I_1 < i_0)])](\lambda Q[\exists i_1(\text{arrive}(\text{tim})(i_1) \wedge Q(i_1))]) = \\ \lambda \Phi[\exists i_1(\text{arrive}(\text{tim})(i_1) \wedge \Phi(I_1) \wedge (I_1 < i_1))](\lambda I[\exists i_0(\text{kiss}(\text{john}, \text{mary})(i_0) \wedge (i_0 < \text{now}) \wedge (i_0 \subseteq I))])$$

$$\begin{aligned}
(290) \quad & [\text{sJohn kissed Mary before Tim arrived}] = \\
& \lambda\Phi[\exists i_1(\text{arrive}(\text{tim})(i_1) \wedge \Phi(I_1) \wedge (I_1 < i_1))](\lambda I[\exists i_0(\text{kiss}(\text{john}, \text{mary})(i_0) \wedge \\
& (i_0 < \text{now}) \wedge (i_0 \subseteq I))]) = \\
& \exists i_1(\text{arrive}(\text{tim})(i_1) \wedge \exists i_0(\text{kiss}(\text{john}, \text{mary})(i_0) \wedge (i_0 < \text{now}) \wedge (i_0 \subseteq I_1) \wedge \\
& (I_1 < i_1))
\end{aligned}$$

Note that there is a requirement of tense agreement between the main and subordinate clauses. Hence we do not need to provide a tense information for both the main and subordinate verbs.

Other verb inflections are interpreted based on the temporal modifier complementing the sentence. For example, *before* sentences with a present progressive main clause verb has a future reading. We therefore simply interpret the sentence as a future tense rather than combining the interpretation of the present tense with the progressive as suggested by standard Montague semantics.

## 6.4 Conclusion

A language is of numerously stated over the course of this thesis, a language is defined by some grammar. We observe in this chapter however that defining a controlled natural language will require very many rules. The best of of minimizing and managing these rules is by assigning parameters to the various syntactic categories in our language.

We have therefore shown a summary of the design of a controlled natural language with temporal features. We show how we distinguish between the various various sub-types within a category. Our semantics also reflects this difference particularly syntactic structures with temporal expressions and non temporal structures.



# Chapter 7

## Conclusion and Future work

We have presented in this thesis the design of a controlled natural language with temporal features. In chapter 2 we introduced grammars which are formalisms for defining the syntactic structure of sentences of a language. We also discussed the automatic generation of the semantic interpretation of natural language sentences from their syntactic structures with the aid of a semantic annotated syntactic representation. These technical tools serve as a background in the definition of a controlled natural language.

Our aim was however to define a controlled natural language with temporal features. We are therefore required to make a decision on how temporal information will be represented in the semantic interpretation of our sentences given the options – temporal instants and temporal interval. From observation of how unsuitable temporal instants are at representing information about events, the intuitive choice seemed to be temporal intervals. Chapter 3 therefore shows the representation of Reichenbach’s tense theory in temporal interval model.

In chapter 5 we observe that aspects unlike simple tense do not always retain a defined interpretation. This led to a detailed analysis of temporal modifiers, taking into account what tense, aspect and aspectual class configuration each modifier requires in their main clause to produce grammatical English sentences. We also take into consideration the syntactic structures of the modifiers complement. Equally important to these syntactic structures are the semantic interpretations of the temporal modifiers of interest.

The results of our analysis facilitates the design of a controlled natural language with temporal features as presented in chapter 6. We observe that primitive

syntactic categories do not provide sufficient restrictions. We therefore assign parameters to our lexical items such as tense inflection, number, type etc. Rules such as tense/aspect configuration, tense and number agreement can be applied before the production rules can generate a the appropriate syntactic structure. Alongside the production rules, we define semantic interpretations for each lexical item, which combine to generate interpretation for sentences.

## 7.1 Future Work

We have defined in this thesis a controlled natural language with temporal features such that we are able to provide semantic interpretations for untensed and tensed sentences, modified and unmodified sentences. We can however in the future make this language more robust by considering how our semantics will handle complex sentences.

Throughout this thesis we considered the effect of the interaction of temporal expressions – tense, aspects, aspectual classes and temporal modifiers, in the future we need to consider the co-interaction of temporal modifiers. That is the effect embedded modifiers can have on the interpretation of our sentences.

# Appendix A

## Temporal Modifiers

| Aspectual Class | Past |      |          |      |
|-----------------|------|------|----------|------|
|                 | Perf | Prog | PerfProg | None |
| Activity        | ?    | +    | ?        | +    |
| Achievement     | -    | -    | -        | +    |
| Accomplishment  | ?    | +    | ?        | +    |
| State           | +    | -    | -        | ?    |

Table A.1: During in the past tense

| Aspectual Class | Present |      |          |      |
|-----------------|---------|------|----------|------|
|                 | Perf    | Prog | PerfProg | None |
| Activity        | -       | +    | +        | +    |
| Achievement     | +       | +    | -        | +    |
| Accomplishment  | +       | +    | -        | +    |
| State           | ?       | -    | -        | ?    |

Table A.2: During in the present tense

| Aspectual Class | Future |      |          |      |
|-----------------|--------|------|----------|------|
|                 | Perf   | Prog | PerfProg | None |
| Activity        | ?      | +    | ?        | +    |
| Achievement     | -      | -    | -        | +    |
| Accomplishment  | ?      | +    | ?        | +    |
| State           | +      | -    | -        | ?    |

Table A.3: During in the future tense

| Aspectual Class | Past |      |          |      |
|-----------------|------|------|----------|------|
|                 | Perf | Prog | PerfProg | None |
| Activity        | +    | +    | -        | +    |
| Achievement     | +    | ?    | -        | +    |
| Accomplishment  | +    | +    | -        | +    |
| State           | +    | -    | -        | +    |

Table A.4: *In* in the past tense

| Aspectual Class | Present |      |          |      |
|-----------------|---------|------|----------|------|
|                 | Perf    | Prog | PerfProg | None |
| Activity        | -       | +    | -        | ?    |
| Achievement     | -       | +    | -        | ?    |
| Accomplishment  | -       | +    | -        | ?    |
| State           | -       | -    | -        | ?    |

Table A.5: *In* in the present tense

| Aspectual Class | Future |      |          |      |
|-----------------|--------|------|----------|------|
|                 | Perf   | Prog | PerfProg | None |
| Activity        | ?      | +    | -        | +    |
| Achievement     | ?      | +    | -        | +    |
| Accomplishment  | ?      | +    | -        | +    |
| State           | ?      | -    | -        | +    |

Table A.6: *In* in the Future tense

| Aspectual Class | Past |      |          |      |
|-----------------|------|------|----------|------|
|                 | Perf | Prog | PerfProg | None |
| Activity        | +    | ?    | -        | +    |
| Achievement     | +    | ?    | -        | +    |
| Accomplishment  | +    | ?    | -        | +    |
| State           | +    | -    | -        | ?    |

Table A.7: *On* in the past tense

| Aspectual Class | Present |      |          |      |
|-----------------|---------|------|----------|------|
|                 | Perf    | Prog | PerfProg | None |
| Activity        | -       | +    | -        | +    |
| Achievement     | -       | +    | -        | +    |
| Accomplishment  | -       | +    | -        | +    |
| State           | -       | -    | -        | +    |

Table A.8: *On* in the present tense

| Aspectual Class | Future |      |          |      |
|-----------------|--------|------|----------|------|
|                 | Perf   | Prog | PerfProg | None |
| Activity        | -      | +    | -        | +    |
| Achievement     | -      | +    | -        | +    |
| Accomplishment  | -      | +    | -        | +    |
| State           | -      | -    | -        | ?    |

Table A.9: *On* in the future tense

| Aspectual Class | Past |      |          |      |
|-----------------|------|------|----------|------|
|                 | Perf | Prog | PerfProg | None |
| Activity        | +    | ?    | -        | +    |
| Achievement     | +    | ?    | -        | +    |
| Accomplishment  | +    | ?    | -        | +    |
| State           | +    | -    | -        | +    |

Table A.10: *At* in the past tense

| Aspectual Class | Present |      |          |      |
|-----------------|---------|------|----------|------|
|                 | Perf    | Prog | PerfProg | None |
| Activity        | -       | +    | -        | +    |
| Achievement     | -       | +    | -        | +    |
| Accomplishment  | -       | +    | -        | +    |
| State           | -       | -    | -        | +    |

Table A.11: *At* in the present tense

| Aspectual Class | future |      |          |      |
|-----------------|--------|------|----------|------|
|                 | Perf   | Prog | PerfProg | None |
| Activity        | ?      | +    | -        | +    |
| Achievement     | ?      | +    | -        | +    |
| Accomplishment  | ?      | +    | -        | +    |
| State           | -      | -    | -        | +    |

Table A.12: *At* in the future tense

| Aspectual Class | Past |      |          |      |
|-----------------|------|------|----------|------|
|                 | Perf | Prog | PerfProg | None |
| Activity        | +    | +    | +        | +    |
| Achievement     | -    | -    | -        | -    |
| Accomplishment  | -    | +    | +        | ?    |
| State           | ?    | -    | -        | +    |

Table A.13: *For* in the past tense

| Aspectual Class | Present |      |          |      |
|-----------------|---------|------|----------|------|
|                 | Perf    | Prog | PerfProg | None |
| Activity        | +       | +    | +        | +    |
| Achievement     | -       | -    | -        | -    |
| Accomplishment  | ?       | +    | +        | ?    |
| State           | -       | -    | -        | ?    |

Table A.14: For in the present tense

| Aspectual Class | Future |      |          |      |
|-----------------|--------|------|----------|------|
|                 | Perf   | Prog | PerfProg | None |
| Activity        | ?      | +    | ?        | +    |
| Achievement     | -      | -    | -        | -    |
| Accomplishment  | ?      | +    | +        | ?    |
| State           | -      | -    | -        | +    |

Table A.15: For in the Future tense

| Aspectual Class | Past |      |          |      |
|-----------------|------|------|----------|------|
|                 | Perf | Prog | PerfProg | None |
| Activity        | -    | -    | -        | ?    |
| Achievement     | +    | -    | -        | ?    |
| Accomplishment  | +    | -    | -        | ?    |
| State           | ?    | -    | -        | ?    |

Table A.16: By in the past tense

| Aspectual Class | Present |      |          |      |
|-----------------|---------|------|----------|------|
|                 | Perf    | Prog | PerfProg | None |
| Activity        | -       | +    | ?        | ?    |
| Achievement     | -       | +    | ?        | ?    |
| Accomplishment  | -       | +    | ?        | ?    |
| State           | -       | -    | ?        | ?    |

Table A.17: By in the Present tense

| Aspectual Class | Present |      |          |      |
|-----------------|---------|------|----------|------|
|                 | Perf    | Prog | PerfProg | None |
| Activity        | -       | +    | -        | +    |
| Achievement     | -       | +    | -        | +    |
| Accomplishment  | -       | +    | -        | +    |
| State           | -       | +    | -        | +    |

Table A.18: By in the future tense

| Aspectual Class | Past |      |          |      |
|-----------------|------|------|----------|------|
|                 | Perf | Prog | PerfProg | None |
| Activity        | ?    | ?    | -        | ?    |
| Achievement     | +    | ?    | -        | +    |
| Accomplishment  | -    | -    | -        | +    |
| State           | -    | ?    | -        | +    |

Table A.19: Durative *in* in the Past tense

| Aspectual Class | Present |      |          |      |
|-----------------|---------|------|----------|------|
|                 | Perf    | Prog | PerfProg | None |
| Activity        | -       | +    | -        | +    |
| Achievement     | -       | +    | -        | +    |
| Accomplishment  | -       | +    | -        | +    |
| State           | -       | -    | -        | +    |

Table A.20: Durative *in* in the present tense

| Aspectual Class | Future |      |          |      |
|-----------------|--------|------|----------|------|
|                 | Perf   | Prog | PerfProg | None |
| Activity        | ?      | +    | -        | +    |
| Achievement     | +      | +    | -        | +    |
| Accomplishment  | +      | +    | -        | +    |
| State           | -      | -    | -        | +    |

Table A.21: Durative *in* in the future tense

| Aspectual Class | Past |      |          |      |
|-----------------|------|------|----------|------|
|                 | Perf | Prog | PerfProg | None |
| Activity        | +    | +    | -        | +    |
| Achievement     | +    | ?    | -        | +    |
| Accomplishment  | +    | ?    | -        | +    |
| State           | +    | -    | -        | +    |

Table A.22: Before in the past tense

| Aspectual Class | Present |      |          |      |
|-----------------|---------|------|----------|------|
|                 | Perf    | Prog | PerfProg | None |
| Activity        | -       | +    | -        | +    |
| Achievement     | -       | +    | -        | +    |
| Accomplishment  | -       | +    | -        | +    |
| State           | -       | -    | -        | ?    |

Table A.23: Before in the present tense

| Aspectual Class | Future |      |          |      |
|-----------------|--------|------|----------|------|
|                 | Perf   | Prog | PerfProg | None |
| Activity        | +      | +    | -        | +    |
| Achievement     | +      | +    | -        | +    |
| Accomplishment  | +      | +    | -        | +    |
| State           | +      | -    | -        | ?    |

Table A.24: Before in the future tense

| Aspectual Class | Past |      |          |      |
|-----------------|------|------|----------|------|
|                 | Perf | Prog | PerfProg | None |
| Activity        | ?    | ?    | ?        | +    |
| Achievement     | ?    | ?    | -        | +    |
| Accomplishment  | ?    | -    | -        | +    |
| State           | ?    | -    | -        | +    |

Table A.25: After in the past tense

| Aspectual Class | Present |      |          |      |
|-----------------|---------|------|----------|------|
|                 | Perf    | Prog | PerfProg | None |
| Activity        | ?       | +    | -        | +    |
| Achievement     | ?       | +    | -        | +    |
| Accomplishment  | ?       | +    | -        | +    |
| State           | ?       | -    | -        | -    |

Table A.26: After in the present tense

| Aspectual Class | Future |      |          |      |
|-----------------|--------|------|----------|------|
|                 | Perf   | Prog | PerfProg | None |
| Activity        | ?      | +    | -        | +    |
| Achievement     | ?      | +    | -        | +    |
| Accomplishment  | ?      | +    | -        | +    |
| State           | -      | -    | -        | +    |

Table A.27: After in the future tense

| Aspectual Class | Past |      |          |      |
|-----------------|------|------|----------|------|
|                 | Perf | Prog | PerfProg | None |
| Activity        | +    | -    | ?        | -    |
| Achievement     | ?    | -    | ?        | -    |
| Accomplishment  | ?    | -    | ?        | -    |
| State           | ?    | -    | ?        | -    |

Table A.28: Since in the past tense



| Aspectual Class | Present |      |          |      |
|-----------------|---------|------|----------|------|
|                 | Perf    | Prog | PerfProg | None |
| Activity        | ?       | -    | +        | -    |
| Achievement     | +       | -    | -        | -    |
| Accomplishment  | +       | -    | +        | -    |
| State           | +       | -    | -        | -    |

Table A.29: *Since* in the present tense

| Aspectual Class | Future |      |          |      |
|-----------------|--------|------|----------|------|
|                 | Perf   | Prog | PerfProg | None |
| Activity        | ?      | -    | ?        | -    |
| Achievement     | ?      | -    | -        | -    |
| Accomplishment  | ?      | -    | -        | -    |
| State           | ?      | -    | -        | -    |

Table A.30: *Since* in the future tense

| Aspectual Class | Past |      |          |      |
|-----------------|------|------|----------|------|
|                 | Perf | Prog | PerfProg | None |
| Activity        | -    | +    | ?        | +    |
| Achievement     | -    | -    | -        | -    |
| Accomplishment  | -    | +    | ?        | -    |
| State           | -    | -    | -        | +    |

Table A.31: *Until* in the past tense

| Aspectual Class | Present |      |          |      |
|-----------------|---------|------|----------|------|
|                 | Perf    | Prog | PerfProg | None |
| Activity        | -       | +    | -        | ?    |
| Achievement     | -       | -    | -        | -    |
| Accomplishment  | -       | +    | -        | -    |
| State           | -       | -    | -        | +    |

Table A.32: *Until* in the present tense

| Aspectual Class | Future |      |          |      |
|-----------------|--------|------|----------|------|
|                 | Perf   | Prog | PerfProg | None |
| Activity        | ?      | +    | ?        | +    |
| Achievement     | -      | -    | -        | -    |
| Accomplishment  | ?      | +    | ?        | ?    |
| State           | -      | -    | -        | +    |

Table A.33: *Until* in the future tense

| Aspectual Class | Past |      |          |      |
|-----------------|------|------|----------|------|
|                 | Perf | Prog | PerfProg | None |
| Activity        | ?    | +    | +        | +    |
| Achievement     | ?    | -    | -        | +    |
| Accomplishment  | ?    | +    | +        | +    |
| State           | ?    | -    | -        | +    |

Table A.34: *while* in the past tense

| Aspectual Class | Present |      |          |      |
|-----------------|---------|------|----------|------|
|                 | Perf    | Prog | PerfProg | None |
| Activity        | -       | +    | ?        | +    |
| Achievement     | -       | -    | -        | +    |
| Accomplishment  | -       | +    | ?        | +    |
| State           | -       | -    | -        | ?    |

Table A.35: *while* in the present tense

| Aspectual Class | Future |      |          |      |
|-----------------|--------|------|----------|------|
|                 | Perf   | Prog | PerfProg | None |
| Activity        | ?      | +    | -        | +    |
| Achievement     | ?      | -    | -        | +    |
| Accomplishment  | ?      | +    | -        | +    |
| State           | ?      | -    | -        | +    |

Table A.36: *While* in the future tense

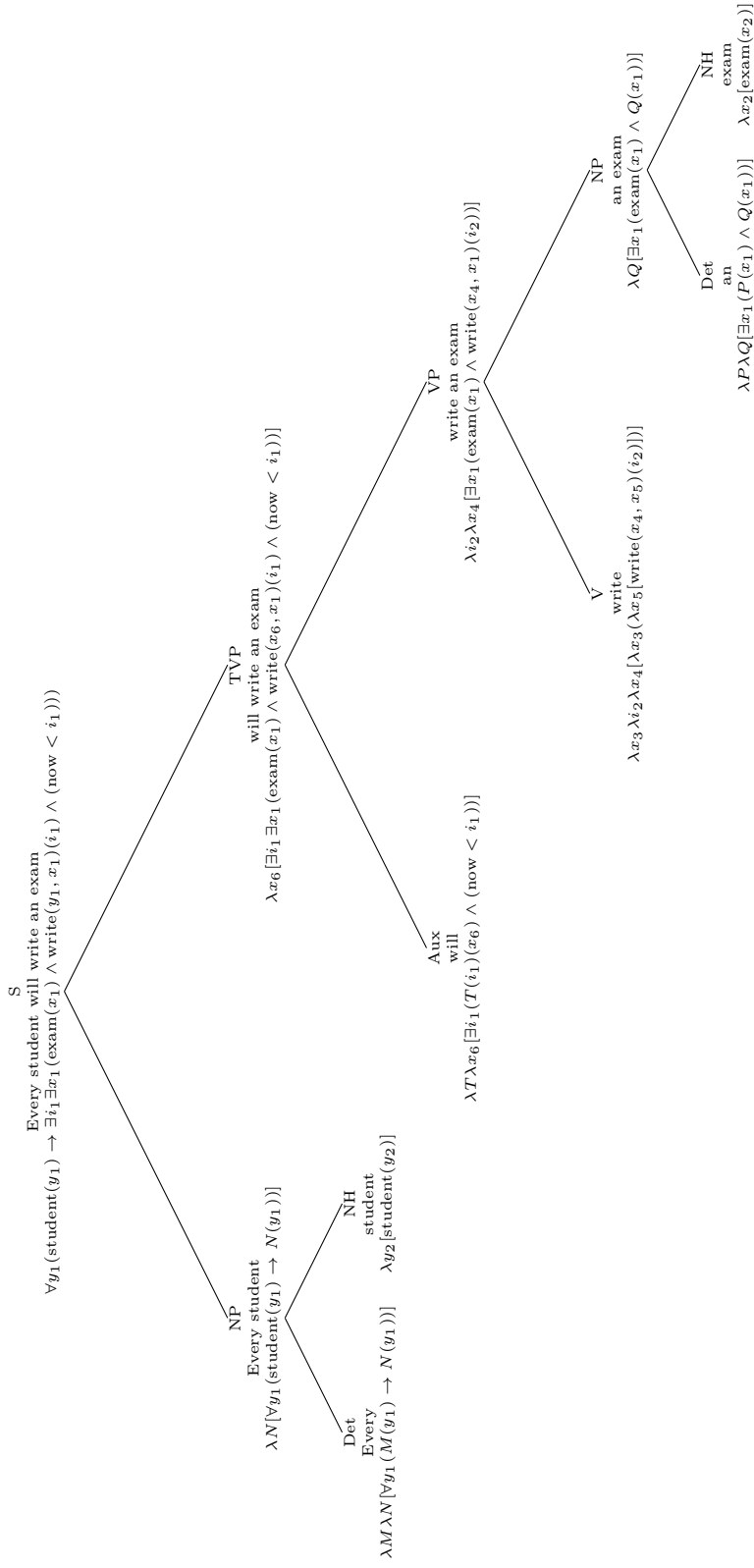


Figure A.1: Large parse tree

$$(291) \quad [_{\text{Det}}\text{the}] = \lambda P \lambda Q [\exists x (P(x) \wedge \forall y (P(y) \rightarrow (x = y)) \wedge Q(x))]$$

$$(292) \quad [_{\text{Det}}\text{every}] = \lambda P \lambda Q [\forall x (P(x) \rightarrow Q(x))]$$

$$(293) \quad [_{\text{Det}}\text{a}] = \lambda P \lambda Q [\exists x (P(x) \wedge Q(x))]$$

$$(294) \quad [_{\text{tempDet}}\text{the}] = \lambda P \lambda Q [\exists i (P(i) \wedge \forall j (P(j) \rightarrow (i = j)) \wedge Q(i))]$$

$$(295) \quad [_{\text{tnp}}\text{every meeting}] = [_{\text{det}}\text{every}]([_{\text{tn}}\text{meeting}]) = \\ \lambda P \lambda Q [\forall i_0 (P(i_0) \wedge Q(i_0))] (\lambda i [\text{meeting}(i)]) = \\ \lambda Q [\forall i_0 (\text{meeting}(i_0) \rightarrow Q(i_0))]$$

$$(296) \quad [_{\text{tnp}}\text{the meeting}] = [_{\text{det}}\text{the}]([_{\text{tn}}\text{meeting}]) = \\ \lambda P \lambda Q [\exists i_0 (P(i_0) \wedge \forall j (P(j) \rightarrow (j = i_0)) \wedge Q(i_0))] (\lambda i [\text{meeting}(i)]) = \\ \lambda Q [\exists i_0 (\text{meeting}(i_0) \wedge \forall j (\text{meeting}(j) \rightarrow (j = i_0)) \wedge Q(i_0))]$$

$$(297) \quad [_{\text{tense}}\text{future}] = \lambda \Phi \lambda x_6 [\exists i_1 (\Phi(i_1)(x_6) \wedge (i_1 < \text{now}))]$$

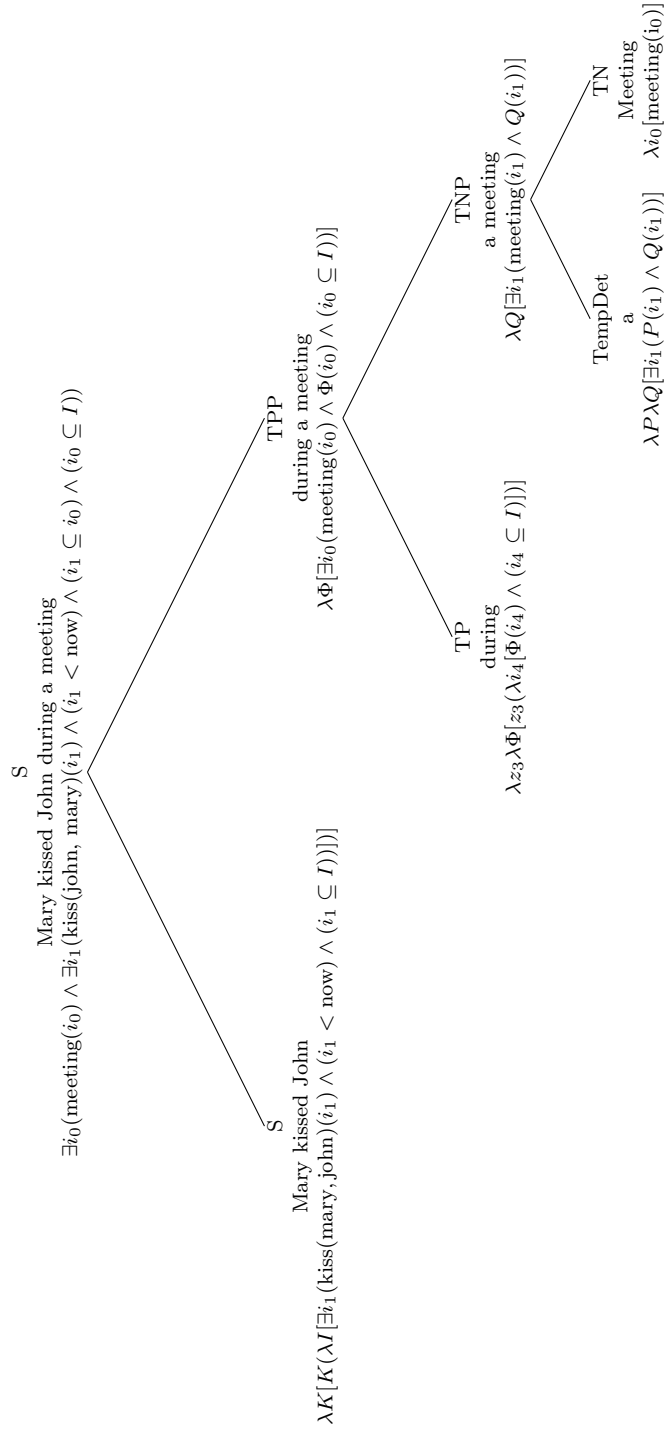


Figure A.2: Parse Tree for a *during* sentence

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