The Chinese Temporal Coverbs, Postpositions, Coverb-Postposition Pairs, and Their Temporal Logic

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Abstract

Some researches concerning the correspondence between the temporal features in English and other European languages have been done by Brée (1994). The subject of this paper is to collect and induce the temporal features of Chinese. The functionality of the Chinese temporal Coverbs, postpositions and Coverb-postposition pairs will be introduced. Meanwhile, simple logic representation forms for Chinese temporal sentences will be proposed. The temporal taxonomy of Chinese has been defined and these definitions are also ready to be coded into a program for translation purpose. We develop a temporal representation language into which Chinese sentences involving temporal Coverbs, postpositions and Coverb-postposition pairs can be naturally translated.

Keyword: Chinese Temporal Coverb, Chinese Temporal Postposition, Chinese Temporal Coverb-Postposition pair, Temporal Logic, Chinese Temporal Logic Representation.

1 Introduction

Intuitively, humans can exhibit their thought, intellect and mind using their mother tongue effortlessly, although human languages are extremely variant and of great complexity. People usually cannot be explicit about the rules of their own mother tongue of ambiguous words or phrase, whereas they can use their language appropriately in expression of their thought. Many linguists and psychologists have done numerous researches about this matter; however, it is still cannot be made explicit how such knowledge of language is stored in our brain and how we use it (J.B. Gleason, 1993). Therefore, in order to find out some useful rules about languages, it is necessary to be restricted in different subdomains. The purpose of this paper is to give an applicable model in a subdomain of natural language processing (NLP) by computers.

In this paper, we are going to submit the fundamental analyses of Chinese temporal Coverbs, postpositions and Coverb-postposition pairs. Many natural language processing between European languages and English with respect to temporals have been researched and implemented. For example, Brée (1992) defined the temporal subordinate conjunctions (SC) and prepositions as temporals. The temporals of European languages such as English, Dutch and German have been studied in detail. Brée, Smit & Werkhoven (1990) have compared English and Dutch temporals. Furthermore, Brée (1992) has discussed the temporals between English, Dutch and German. The completion of examining the temporals of the European languages does not entail the understanding of temporals of all languages over the world. As the result, in order to get a clearer picture of the use of temporals across languages, studies of the Chinese temporal representation is necessary. In this paper, we will study the temporals of Chinese and find some applicable rules in translation from Chinese temporals to logic symbols.

In Chinese, a special collection of verbs called Coverb, has the same function as English prepositions. The Coverbs approach was introduced by Francis (1946) who defined the approach as below:

Coverbs (CV) are transitive verbs which do not stand alone but precede and are secondary to the main verb of the sentence. Some Coverbs are sometimes used as full verbs; a few are never anything but Coverbs. All can be translated as prepositions in English.

Because we only concentrate on temporals, which mark a time clause or a time phrase, not all of Chinese Coverbs will be discussed in this paper, as will be explained in later sections. We are going to proceed in three steps in this paper. The first step is to make a description of an overview of English Temporals and in the way of English temporal logic representations. Secondly, we shall use semantic rules to represent the temporal Coverb, postposition and Coverb-postposition pair in Chinese. The semantics are categorised by means of diagrams and their usage will be illustrated by example. A table indicating Chinese temporals and English equivalents will be created in this stage. Finally, a constraint-based approach for Chinese temporals will be discussed.

2 The English Temporal Representation

We would be well advised to have a well-structured taxonomy of temporal prepositions and subordinating conjunction. These high frequency words are highly ambiguous, so it is essential to construct a good taxonomy for computerised natural language understanding or Machine Translation system. Brée (1987) described that the time of a Stevent, which means a state or an event, can be attached in two ways: by relating it to the time dimension, e.g. at 7 a.m., or by relating it to the time of another Stevent, e.g. during lunch. Also temporal prepositions can be considered as having either a durative or a non-durative use. One example of
Durative of the Stevent is something like: \textit{shave in five minutes}, but, on the other hand, the non-durative of the Stevent is something like: \textit{shave at 7:00 pm or shave during breakfast}. Brée et al (1993) marked the uses of duratives and non-duratives of English prepositions as:

\textbf{Durative:}

\begin{itemize}
  \item \textbf{Floating use:} to indicate the duration of a matrix event,
  \item \textbf{Relative to ToR:} to place the time of the matrix event within an interval adjoining the ToR (Time of Reference),
\end{itemize}

\textbf{Non-Durative:}

\begin{itemize}
  \item \textbf{Absolute use:} to place the time of the matrix event in the period specified directly by the prepositional noun phrase.
\end{itemize}

The floating use is that a temporal phrase is not fixed on a time axis and hence indicates an indefinite duration such as \textit{I run this circle in a minute}. In the case of English, Brée has already sorted out the \textit{for} and \textit{in} in the floating duration of the matrix event. Besides that, \textit{within} is also defined within the floating length of time. The relative to ToR use locates the time of reference (ToR) at one end of the duration given by the temporal duration to indicate an event that occurs either at the other side of duration (\textit{I will be back in a hour}), or once within the duration (\textit{This country will be destroyed within a week}), or continuously for the duration (\textit{I will be away for three days}). In the last one, the absolute use, a Stevent takes place in a definite time or event on the time axis such as in 1996, \textit{during the war}.

To category the temporal use in English, we can refer to a selection tree, which is a special kind of decision tree and is useful for analysing the use of temporals (Brée, 1992). The selection tree has a root node and many leaf nodes. Each branch of the tree has a particular meaning. First, we begin to take both the main clause and the subordinate phrase of a temporal sentence, and sort out the relationship between them to see which main category of relation the temporal phrase belongs to. For example, in the durative cases, three different meanings are considered. One of them is that the duration of the matrix Stevent is equal to the time of the subordinate temporal phrase. The second of the main categories is that the sub Stevent represents a time cycle, for example \textit{every} in English, of the main Stevent. The last main category is that the time of sub Stevent introduces a point on the time axis anchoring when the main Stevent occurs. Once the category of the temporal sentence is decided, further distinctions could be made among the sub-categories under the selected main category.

In the case of non-durative use of temporals, however, the sub-phrase specifies either a time point or period on the time axis. The major distinction in the non-durative use is between the sub-Stevent being used to indicate the time of the matrix Stevent versus indicating one (or more) end(s) of a time period in which the matrix Stevent falls. This corresponds to the distinction in the durative use between indicating the time of the matrix Stevent in relation to a time point some distance from the ToR (Time of Reference) versus the duration of the matrix Stevent itself. Moreover, there is no equivalent in the non-durative use of temporals that corresponds with the use to indicate the cycle time of the matrix Stevent. Figure-1 and Figure-2 show the selection trees for English durative use of temporals and the non-durative (absolute) use of temporals respectively.

\begin{center}
\textbf{Figure-1 Selection Tree for English Durative use of Temporals}
\end{center}
In this section, we are going to introduce a methodology of translation from temporal English to a temporal logic (TL). Logic was developed as a formal notation to capture the essential properties of natural language and reasoning. As a consequence, many of the structural properties have a parallel in natural language. For instance, an important distinction that can be made is between expressions that identify objects and expressions that assert properties of objects and identify relationships between objects. In particular many of the notations used in AI can be shown to be notational variants, or subsets, of the first-order predicate calculus (FOPC). The temporal properties, however, of the sentences implies by the use of this tense usually have, in fact, been completely absent from the interpretation. This means that really the model theory treats all formulas as universal truths or universal falsehoods, as if they were all of the same sort as sentence like All human are mortal, No bachelors are unmarried, Nobody likes taxes, and so on. The proposition expressed by such sentences have the same truth value at all times and so may be thought of as timeless. It is therefore necessary to construct a temporal logic system to present real living sentences.

We concern with the definitions of a theory, which enables the difference between timeless and temporally bound sentence to be captured. The approach for temporal logic representation has taken up by Pratt & Brée (1994, 1995, 1996, 1997) in terms of English prepositions. Before we discuss the Chinese temporals and their logic representations, the English part of logic form in temporals will be introduced as following first.

There are two English sentences:

(ex. 1) York ate his sandwich between 7 o'clock and 8 o'clock.  
(ex. 2) York ate his sandwich from 7 o'clock to 8 o'clock.

Sentence (ex.1) means that York has done an action eating his sandwich in a time point which locates within the interval [7:00, 8:00]. On the other hand, sentence (ex.2) obviously indicates the action continuously happening for whole the interval [7:00, 8:00]. We can define the truth condition of (ex.1) and (ex.2) as, respectively:

(def. 1) There exists an interval J wholly contained within the interval [7:00, 8:00], such that York eat his sandwich is true cover J.

(def. 2) For all interval J wholly contained within the interval [7:00, 8:00], such that York eat his sandwich is true cover J.

Thus we can present their logic symbols as (TL.1) and (TL 2):

(TL. 1) \( \exists J \subset [7:00, 8:00] \& (York\text{-}eat\text{-}his\text{-}sandwich) (J) \)

(TL. 2) \( \forall J \subset [7:00, 8:00] \rightarrow (York\text{-}eat\text{-}his\text{-}sandwich) (J) \)

If we indicate the tenseless sentence to be the symbol \( \phi \) and the two point of time of subStevent to be s1 and s2, we can have
Now the temporal logic of (TL. 3) and (TL. 4) represent the restricted existential and universal quantification over intervals. These two temporal logic can be generalised to:

(TL. 5) \( \exists J \in I \& \psi (J) \)

(TL. 6) \( \forall J \in I \rightarrow \psi (J) \)

where \( J \) is an interval of time when an event occurs, \( I \) is a reference interval which is determined by duration or a time given in a sentence, and \( \psi \) is an event (tenseless sentence) in the matrix. We propose if a temporal makes the predicate of sentence (TL. 5) true then we say that it has an existential meaning. Similarly, if a temporal makes sentence (TL. 6) true then it indicates a universal occurrence of the matrix Stevent. Sometimes a temporal can make both propositions true in this case we accept it captures both existential and universal meanings. Continuously, consider the following two sentences:

(ex. 3) York will eat his sandwich within twenty minutes.

(ex. 4) York has eaten his sandwich for twenty minutes.

As we discussed in last section, for indicates a universal floating use whereas within and in indicate existential floating use. Floating use is a duration of matrix Stevent such as twenty minutes, five days, one month and so on. Thus we now define the truth condition of (ex. 3) and (ex. 4) as, respectively:

(def. 3) There exists an interval \( J \) wholly contained within the duration \( K \) and \( K=20\) minutes, such that (York eat his sandwich) is true cover \( K \).

(def. 4) For all interval \( J \) wholly contained within the duration \( K \) and \( K=20\) minutes, such that (York be eating his sandwich) is true cover \( J \).

As the result, we can explicate their logic symbols as (TL. 7) and (TL. 8):

(TL. 7) \( \exists K \subseteq [\text{START}, \text{ToR}] \& \& \text{dur}(K)=20\text{ minutes} \)

(TL. 8) \( \exists K \subseteq [\text{START}, \text{ToR}] \& \& \text{dur}(K)=20\text{ minutes} \)

In these two functions, (TL. 7) indicates a static event: York eat his sandwich but (TL. 8) marks a dynamic event: York be eating his sandwich. A static event describes an event occurrence which happens in an existential time of point whereas a dynamic event points out an event occurrence which occupies whole the duration. Consequently, these two temporal functions can be generalised as, respectively:

(TL. 9) \( \exists K \subseteq [\text{le}, \text{ToR}] \& \& \text{dur}(K)=\text{twenty minutes} \)

(TL. 10) \( \exists K \subseteq [\text{le}, \text{ToR}] \& \& \text{dur}(K)=\text{twenty minutes} \)

where \( le \) is the interval [ToR, END], \( le \) is [START, ToR] and \( s \) is a duration of sub Stevent such as 2 hours, 30 seconds and so on. Similarly, Chinese temporal systems also can be presented using these logic forms which will be explicated in the later section.

4 The Chinese Temporal Representation

Almost all the English temporals are prepositions, but the Chinese temporals can be consisted by Coverbs, postpositions, and Coverb-postposition pairs. The features of Chinese Coverb enable us to select a set of Chinese verbs and classify them as prepositions of Chinese. In this paper, we are going to concentrate on a subset of Chinese temporal Coverbs, postpositions and Coverb-postposition pairs.

In Chinese we use the Coverb 在 to specify a definite point of time, for example, 在5点 (at 5 o'clock), 在早上 (in the morning) and 在星期五 (on Friday). However, in English, three prepositions in, at and on are used to do this, for instance, at 6:00 am, in the morning, and on Friday. On the other hand, Chinese postpositions, in grammatical uses, are more flexible than Chinese Coverbs. A same sense of postposition can be stated by one Chinese character, two Chinese characters and even three. For instance, the postposition phrase 的时候:deshiho can be interpreted as while, as and when. This Chinese phrase 的时候:deshiho can also be represented by only one character 当:shi. That is, the word 当:shi is the short form for the phrase 的时候:deshiho. Moreover, many of the Chinese postpositions the first syllable is optional, such as 在:zi, 从:zi and 以:yi. For example, in Chinese 从5点到:zi to:yi when:yi the time:shihuo can be interpreted as while (or when, a). We construct the Chinese temporals with their corresponding meaning in English in the Table-1 as below.

| PostPosition / English Coverb | Ø | (的)时候: (de) shi (hou) | * 该: *gei | 起: qi | * 时: *qmian | 时间: shi | * 再: 再 | & 来: &lai | 时刻/时: jian/zhong |
|-----------------------------|---|------------------------|-----|---|------|---|---|---|-----|
| Ø                           | for, at, as, in, while, when | as, at, while, when | After | Ago, before | for |
| 在:zi, yu                   | at, in, on | As, at, while, when | After | Ago, before, by | between, within | During |
| 由: dian                    | When | when | After |

Table-1 Chinese Temporal Coverbs and Postpositions
As with the English analysis, we also divide Chinese temporals as durative and non-durative. With durative use, as mentioned in the section two, there are two types of use, namely the floating and relative to ToR. The distinctions will be discussed below.

**Floating Use:**

We now concentrate on the Chinese floating temporal phrases which no particular interval is indicated. In the floating use, for instance, we use the Chinese words *...* zai...nei to indicate a duration of the main Stevent when it is an accomplishment. Sometimes, alternative postpositions which are optional, are found; for example, in... zai...ye or in... zai...zhinei. The phrase *...* zai...nei here means in or within. (ex. 5) shows the example.

(ex. 5) 他 在 一個月內 花了五個 磅

He spends 500 pounds within one month.

An example of the use of English for to indicate a pure duration is given in (ex. 6). (ex. 6) shows that no temporal (Ø) or a Chinese suffix *le can be needed when the matrix Stevent occurs throughout a durative. The Figure-3 below illustrate the floating use in Chinese.

(ex. 6) 我 看了 五小 時的 電視

I have watched five hours television.

In English, there are prepositions such as ago, in, within and after to indicate a time of occurrence of the matrix Stevent at certain duration from the ToR. In Chinese, there are three temporals for this purpose. These temporals are *...* zai...hou, *...* zai...*ruan and *...* zai...*nei (* is optional 以/之/yi/chi). The first one means after, the second one means before and the last one within. The examples are given below.

**Relative Use:**

In the case of the relative use, a duration is an attachment to the ToR. If the Stevent occupies the whole of the interval related to the Time of Reference-ToR, i.e. [ToR-S, ToR] or [ToR, ToR+S], S is the "Duration of Sub Stevent," no preposition will be required in the sentence. The examples (ex. 7) and (ex. 8) listed below show both these cases.

(ex. 7) 我 已經 在 這等你 一個小時了

I will go after an hour.

(ex. 9) 我 在 兩個小時後

I will go after an hour.

(ex. 10) 他 在 五分鐘後

He went 5 minutes ago.

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**Legend:**

* - 以/之/yi/chi (optional)
$ - 之/chi (optional)$
& - 以/yi (optional)

- Duration of Sub Stevent

- No Preposition or Postposition

- Duration of Sub Stevent

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**Figure-3 Chinese Floating Use**
We have to at one week within return. We have to return within one week.

From the examples above, we know that the phrase pattern duration + 以前:yiqian locates an event which happened at ToR-S. Similarly, the structure duration + 以后:yihou marks the time of occurrence of a Stevent after ToR+S. Lastly, the structure 在 + duration + 内:nei indicates the time or event which will be accomplished within the ToR. In addition, one preposition 过:guo, two postpositions 以后:yiqian and 以后:yihou and one adverb 還有:haiyou locate the time occurrence of the main Stevent relative to the ToR instead of reporting the main duration of Stevent. Chinese sometimes use a verb 过:guo which means after or pass to locate the starting time of the matrix Stevent. The verb 过:guo is a preposition, that is, it precedes its phrase. The matrix Stevent starts after ToR+S. For instance, (ex. 12) shows the usage:

(ex. 12) 我 过 一会儿 再来
wo 过 yi- hueir zai lai
I after a while again come.

An adverb 還有:hai-you which means remain can also locate the starting time of the matrix Stevent. (ex. 13) shows a example.

(ex. 13) 还 有 十五 分钟 巴士 就 开 了
hai-you shiwu fenzhong ba shi jiou kai le
Yet 15 minutes coach start
The coach will leave in 15 minutes.

In the cyclic use of Chinese temporals, the Chinese adjective 每:mei has the same meaning as English every, thus if S is the cycle time of matrix Stevent M then 每:mei is used in the sentence. The example is shown as below.

(ex. 14) 约 翼 天 文 学 中 文
uehan 每:mei-tian xue chungwuen
John every day study Chinese
John studies Chinese every day.

We conclude that there are three cases of elementary rules of the relative to ToR:

Figure-4 below illustrates the usage of Chinese relative to ToR.

ToR + S.

\[ \begin{align*}
& \text{ToR} \quad \neg S \\
& \text{ToR} \quad \neg S \\
& \text{ToR} \quad \neg S \\
& \text{ToR} \quad \neg S \\
& \text{ToR} \quad \neg S \\
& \text{ToR} \quad \neg S \\
& \text{ToR} \quad \neg S \\
& \text{ToR} \quad \neg S \\
\end{align*} \]

\[ \text{Legend:} \quad \neg \text{: Every (optional)} \quad S \quad \text{Duration of sub Stevent} \quad \text{ToR} \quad \text{Time of Reference} \quad \neg \quad \text{No Preposition or Postposition} \]

**Figure-4 Chinese Relative Use to ToR**

Absolute Use: S is an Interval

In the absolute or non-duratives use of temporal phrases denote a point or a period on the time axis. They include phrases like at three o'clock, in the afternoon, on Sunday, in February and so on. In Chinese, we have 在:zai which means at, in and on, and we have 的時刻:de-shihou which is a postposition and means of the time. Both preposition and postposition are often used to mark the time phrases. It is quite interesting to know that when sentences use both preposition and postposition to indicate a time phrase, we can omit one or both of them. Consider the phrase 在下午:zai xiawu shi which means at noon. We may omit either 在:zai or 時刻:de-shihou, that is, 在午:zai xiawu shi can be written as 午:zhou shi, in 午:zai shi in 午:zai shi or 午:zhou. Another special characteristic of Chinese temporals is that some temporals are used in several areas. The postposition 時刻:de-shihou is merely used in a meaning of time. We can see the examples from (ex. 15) to (ex. 16).

(ex. 15) 在下午三点多来找我
zai xiawu san di lai zhaowo
Please come to see me at three o'clock this afternoon.

(ex. 16) 他 吃 晚飯 的 時候 一直 看 電視
he eat dinner of-time yizhi kang dianshi
He is watching the television as he is having his dinner.
In addition, there are two subclause structures that are used in time clauses. One of them is in the time phrase: *de-shihou* which often involves ongoing activities. And the time phrase: *de-shihou* is used when the subclause gives the point in time at which the matrix Stevent occurs. We can refer to the examples as below.

When you have a cold, you should rest at home. You should rest at home when you have a cold.

When I returned home, he has already died. When I returned home, he already died.

It is shown that in Chinese three similar structures are used to indicate that the time of occurrence of the matrix Stevent is somehow in parallel to that of the sub Stevent. They are *de-shihou* which corresponds to English conjunctions such as *when, while* and *as*. In particular, the subclause pattern *de-shihou* denotes a point in time where the main Stevent occurs, and the subclause structure *de-shihou* introduces a period of time where the matrix Stevent occurs.

Furthermore, a time phrase structure in the time phrase *de-shihou* will be used for representing an occurrence of matrix during the period of the sub Stevent. Normally, Chinese *zhong* means *middle* but it can be translated as *during* a Stevent. In other words, in Chinese *zhong* indicates a time that the matrix Stevent occurs at some points during the period of the time of the sub Stevent. Besides, one Chinese Coverb *zhong* marks the matrix Stevent which occurs continuous throughout the time of the sub Stevent. This Coverb is special. It marks a long time measure of a day, a year, one hundred years, etc. Here are two examples of their use, respectively.

I fell asleep during the lecture. I fell asleep during the lecture.

I stay in England all through the Christmas holiday. I stay in England all through the Christmas holiday.

From our discussion and those examples, we have already known that Chinese temporal *de-shihou* is widely used for temporal clauses. In addition, a Coverb *zhong* is used for denoting a Stevent occurs throughout a given period of time. Figure-5 illustrates the Chinese absolute temporals in which S is an interval of sub Stevent.

**Figure-5 Chinese Absolute Temporals (S is an Interval)**

**Legend:**

- S: Interval of Sub Stevent

**Absolute Use:** S is a Point

As the point use, there are three temporal words which denote that the time of the matrix Stevent occurs before or after the time of the sub Stevent. These words are *quole, yihou* and *yiqian*. The preposition *quole* has the same meaning as the postposition *yihou* and *yiqian*. Both temporals mean *after*, but the former cannot take phrases other than temporal phrases while the later can take verb phrases as well as temporal phrases. The third word *yiqian* is a postposition which means *before*. The examples are shown below.

After the new year, we will have a vacation for 7 days. After the new year, we will have a vacation for 7 days.

After I knocking off, I walked home. After I knocking off, I walked home.
The absolute uses of Chinese temporals we have discussed and is that the main event happens within an interval time which the subclause indicates. And this section is that the main Stevent occurs at a point which is also the time of the sub Stevent. Now we represent the situation of \( S \) is a point in Figure-6 as below.

![Figure-6 Chinese Absolute Temporals (S is a point)](image)

**Absolute Use: Two Boundary Points**

There are three cases that indicate a temporal interval by two points of time. The first one is to show the two ends of the period within which the main Stevent occurs. Here we use \( \text{zai...he...zhijian} \) to indicate the meaning of between...and...

(ex. 25) 他在今年和明年之間，有一次旅行

他 at this year and next year between, will have once travel

He will travel between this year and next year.

In the second case, when the matrix Stevent is to last for the whole of period between the two points of time, Chinese use the structure \( \text{zai...he...zhijian} \) to indicate this.

(ex. 26) 我从星期一 work 到星期五

I work from Monday to Friday.

In the second case, when the matrix Stevent is to last for the whole of period between the two points of time, Chinese use the structure \( \text{zai...he...zhijian} \) to indicate this.

In the second case, when the matrix Stevent is to last for the whole of period between the two points of time, Chinese use the structure \( \text{zai...he...zhijian} \) to indicate this.

(ex. 27) 他从:qian (by)

The former marks the time where the matrix Stevent stops and the later specifies the time where the Stevent will be stopped.

![Figure-8 Chinese Absolute Temporals (Related to the ToR)](image)
registration until today do terminate
Registration will be terminated today.

To sum up, temporals may include several grammatical classes in Chinese. These temporals consist of coverbs, postpositions, adjectives, adverbs and preposition-postposition pairs. The following, we will present the temporal logic that applies to Chinese temporal sentences.

5 Logic Representation in Chinese Temporals

To do this we will sketch a fairly simple theory of time and use this to provide an account of the Chinese temporals may correspond to English equivalences.

After a brief account of meaning categories in terms of logic function in English temporals, we would like to survey the same representations in Chinese. To demonstrate Chinese temporal logic forms we also divide Chinese temporals into durative use and non-durative use. That is, floating use, relative use to ToR and absolute use will be individually given an account of logic representation forms.

Floating Use

In the previous section, we have the functions for floating use:

(TL. 9) \[ \exists K (K \subseteq le \& \text{dur}(K) = s \& \exists J (J \subseteq K \& \phi(J))) \]
(TL. 10) \[ \exists K (K \subseteq lu \& \text{dur}(K) = s \& \forall J (J \subseteq K \rightarrow \phi(J))) \]

Chinese temporal system have one preposition-postposition pair in Chinese, which means in/within, for existential temporal form. Here we propose the Chinese example as following.

(ex. 5) 他 在一個月內 花了 五百 塊
He spent 500 pounds within one month.

Now we see the translation using the definition of (TL. 9):

(T_F-5C) \[ \exists K (K \subseteq [\text{ToR, END}] \& \text{dur}(K) = \text{one month} \& \exists J (J \subseteq K \& (\text{he_spends_500_pounds}(J)))) \]
(T_F-5E) \[ \exists K (K \subseteq [\text{ToR, END}] \& \text{dur}(K) = \text{one month} \& \exists J (J \subseteq K \& (\text{he_spends_500_pounds}(J)))) \]

where T_F means temporal function and capital letters C and E mark Chinese form and English form respectively. Accordingly, Chinese in/within preposition-postposition pair has an existential temporal function logic form: \[ \exists K (K \subseteq le \& \text{dur}(K) = s \& \exists J (J \subseteq K \& \phi(J))) \] and the inside of preposition-postposition pair is a duration: one month.

Chinese temporal in universal floating use, on the other hand, employ no coverb before a temporal subclause. Consider the example (ex. 6) as below:

(ex. 6) 我看了 五小時的電視了
I have watched television for five hours.

Thus its the temporal logic form will be:

(T_F-6C) \[ \exists K (K \subseteq [\text{START, ToR}] \& \text{dur}(K) = \text{five hours} \& \forall J (J \subseteq K \rightarrow (\text{I was watching television}(J))) \]
(T_F-6E) \[ \exists K (K \subseteq [\text{START, ToR}] \& \text{dur}(K) = \text{five hours} \& \exists J (J \subseteq K \& (\text{I was watching television}(J)))) \]

In Chinese floating use, we therefore assert if there is no any Chinese coverb in front of temporal expression, its temporal function would be: \[ \exists K (K \subseteq lu \& \text{dur}(K) = s \& \forall J (J \subseteq K \rightarrow \phi(J))) \]. Although Chinese employ nothing for universal floating use, Chinese verb suffix \(-le\) usually indicates a past tense. For example, 我看了電視 and 我看了 are different meaning in Chinese. First one indicates a past event of complete accomplishment but, on the other hand, the second one marks a present or future event. Table-2 illustrates the Chinese floating temporal functions as below.

| \(\exists\) | Coverb, Coverb-Postposition pair | past/future | reference interval I |
|---|---|---|---|
| \(\forall\) | \(\emptyset\) (for) | past | [START, ToR] |
| \(\exists\) | \(\text{在/於/在/於}\) | past | [START, ToR] |
| \(\in\) | \(\text{在/於/在/於}\) | future | [ToR, END] |

Legend: \* - \(\text{在/於/在/於}\) (optional)  
ToR - Time of Reference

Relative Use to ToR

We attempt to construct the explicit of Chinese relative use to ToR temporals, which include \(\emptyset\), \(\text{在/於/在/於}\) and \(\text{在/於/在/於}\) and \(\text{在/於/在/於}\) and \(\text{在/於/在/於}\). In this category, we should distinguish the backward-looking (B_L) and forward-looking (F_L) in the relative use to ToR part in temporal sentences. We generalise if a temporal sentence is indicated by past tense or perfect aspect, the function is a backward-looking; if not, on the other hand, the function is a forward-looking. Besides, one operator \(\varepsilon\) represents a small duration of time. As we introduced in previous section, the temporal functions can divide into universals and existential, and their illustration can be shown below.
Consider the following examples and their temporal functions:

(1) I have been waiting for you for 2 hours.
(2) He plans to live in England for three years.
(3) I will go after an hour.
(4) He went 5 minutes ago.

where B_L, F_L and T_F stand for backward-looking, forward-looking and temporal function, respectively.

Here we illustrate the correspondent temporal functions of Chinese relative to ToR to Table-3 below.

### Table 3: Chinese Relative Use to ToR

| Φ/∀ | Backward/forward | Coverb, Preposition-Postposition pair | reference interval |
|------|------------------|-------------------------------------|--------------------|
| ∀    | Forward          | (for)                               | [ToR, ToR+g]       |
|      | Backward         | 求...求...求(求)                    | [ToR-g, ToR]       |
| ∃    | Forward          | 在...内:zai...nei (within)            | [ToR, ToR+g]       |
|      | Backward         | ? (in)                              | [ToR-g, ToR]       |
| ∀    | Forward          | ...後:...hou (after)                | [ToR+t, ToR+t+e]   |
|      | Backward         | ...前:...qian (before)               | [ToR-t, ToR-t+e]   |
| ∃    | Forward          | 過過有:quai/haiyou (afterin)         | [ToR+t, ToR+t+e]   |
|      | Backward         | ...前:...qian (beforeago)            | [ToR-t, ToR-t+e]   |

Legend: * - 似/似/似( optional)  s - 似/似( optional)  $ - 求( optional)  ε - Duration of sub Stevent  ToR - Time of Reference  ε - a small duration of time  \( \emptyset \) - No Preposition or Postposition

### Absolute Use: S is an Interval

Absolute use in temporal system is a bit more complicated than the previous floating use and relative use. As explicated in last section, we divided absolute use into four sections as s is a interval, s is a point, two boundary points, and between ToR and one boundary point. In this section, absolute use and a is a interval, we attempt to present its Chinese temporal functions. The Chinese example sentences are shown as below.

(18) You should rest at home when you have a cold.
(19) I fell asleep during the lecture.
(20) I stay in England all through the Christmas holiday.

where s is a time of sub Stevent. The tableau form illustrates as Table-4 below.

### Table 4: Chinese Absolute Use(s is a interval)

| Φ/∀ | Coverb, Preposition-Postposition pair | reference interval |
|------|-------------------------------------|--------------------|
| ∀    | 求:zeng (throughout)                | [s]                |
| ∃    | 求:zai (on/in)                      | [s]                |
|      | 求:...yong/jian (during)            | [s]                |
|      | 求...zui...shihou (when)            | [s]                |

Legend: s - Time of Sub Stevent
Absolute Use: S is a Point

This category of Chinese temporals, we have (之/以) 前:zhili/hou, (之/以) 後:zhili/hou, 通了:guole, 臨:lin, 當的時候:de-shihou, and the Chinese coverb 在. Following examples show the logic representations in universal and existential respectively.

(ex. 22) 之后，我們在台北居住。
(T_F-22C) ∀J ∈ [s, END) → ((年賀 [s, END]) 住在台北) (J)
(T_F-22E) ∀J ∈ [s, END) → ((the_new_year [s, END]) we_live_in_Taipei) (J)

(ex. 23) 我走回家。
(T_F-23C) 3J(J ∈ [s, END]) & ((年賀 [s, END]) we_live_in_Taipei) (J)
(T_F-23E) 3J(J ∈ [s, END]) & ((knocking_off [s, END]) I_walk_home) (J)

We gather this category as Table-5 as below.

| 3/4 | Coverb, Preposition-Postposition pair | reference interval |
|-----|--------------------------------------|-------------------|
| ∀   | *之....*qian (before)                 | [START, s]        |
|     | *過了....*hou/guole (after)          | [s, END]          |
|     | 在:zai (at)                          | [s-e, s+e]        |
| ∃   | *之....*qian (before)                | [START, s]        |
|     | *過了....*hou/guole (after)          | [s, END]          |
|     | 前:lin (just before)                 | [s-t, s]          |
|     | 當的時候:de-shihou (when)            | [s-e, s+e]        |
|     | 在:zai (at)                          | [s-e, s+e]        |

Legend: * - yi/zi/yi (optional)  s - Time of sub Stevent
       t - a small duration of time

Absolute Use: Two Boundary Points

Chinese have only two preposition-postposition pairs for this group. One is 從...到:cong..dao.. for universal function and the other is 在...之際:zai...he...zhijian for existential form.

(ex. 25) 他今年和明年之際，會有一次旅行
He will travel between this year and next year.
(T_F-25C) ∃J ∈ [s1, s2] & (他會有一次旅行) (J)
(T_F-25E) ∃J ∈ [s1, s2] & (he_travel) (J)

(ex. 26) 我從星期一工作到星期五
I work from Monday to Friday.
(T_F-26C) ∀J ∈ [s1, s2] → (我工作) (J)
(T_F-26E) ∀J ∈ [s1, s2] → (I_work) (J)

Table-6: Chinese Absolute Use (Between two points in Time)

| 3/4 | Coverb, Preposition-Postposition pair | reference interval |
|-----|--------------------------------------|-------------------|
| ∀   | 從...cong..dao.. (from to)             | [s1, s2]          |
| ∃   | 在...之際:zai...he...zhijian (between and) | [s1, s2] |

Legend: s1, s2 time of sub Stevent

Absolute Use: Between ToR and one Boundary Point

This group of Chinese temporals also includes forward looking and backward looking. The Chinese forward looking universal temporal denotes the coverb 到:dao (English equivalent until) and existential is the postposition (之/以) 前:zhili/qian (English equivalent by). On contrary, the backward looking temporals specify two Chinese preposition-postposition pairs 從...起:cong...qi and 自...起:cong...yihou which have the same meaning as English since. The examples and their temporal functions are shown as follows.

(ex. 27) 今天報名截止
Registration will be terminated today.
(F_L, ∀) 3J(J ∈ [ToR, s] → (報名截止) (J)
(T_F-27C) ∀J ∈ [ToR, s] → (registration_terminate (J)
(ex. 28) 我必須在明天以前回來
I must be back by tomorrow.
(F_L, ∃) 3J(J ∈ [ToR, s] & (我必須回) (J)
(T_F-28C) 3J(J ∈ [ToR, s] & (I_must_back) (J)

30
Conclusion

Chinese temporal system employ Coverbs, Postpositions, Coverb-postposition pairs, and some temporal adverbs to indicate the temporality of sentence. In this paper, we have presented an account of the semantics of Chinese sentences involving multiple temporal phrases. We have introduced a restricted temporal logic (TL) into which a wide range of such sentences can be translated, and we have outlined a translation process from Chinese into this logic. Together with specialised procedures for making inferences in this logic, this account holds out the prospect of exploiting the restricted expressiveness of temporal quantification of Chinese to design more effective natural language understanding system.

The taxonomy of Chinese temporals has been briefly defined in our work. From the temporal logic (TL) representations of Chinese, we learnt the theory of Chinese temporal system and the concept of Chinese logic.
representation forms. These forms are ready to code into a program for translation purposes. We found many interesting characteristics after we use this approach to represent Chinese temporal systems. For example, Chinese has no morphological problem because its characters can not be changed by tense, aspect, time, gender and so on. Thus in the logic representation forms, Chinese get a good property in matrix Stevent because of its non-inflection feature.

Furthermore, we argued that since a decision procedure exists for temporal logic (TL), automating the translation from temporal Chinese into TL gives us a system capable of determining the deductive validity of temporal arguments expressed in Chinese. Such a system has been implemented, and represents a useful development tool for our semantics, and in the purpose of preliminary beta version of multi-lingual (Chinese/English/Japanese) MT system. The ability to determine the precise ramifications of modifying and any one part of the total system, such as the syntax rules, the semantics of TL, the interpretation rules and the decision procedure for TL that is crucial for our strategy of piecemeal refinement and extension. One of the practical applications of our system is temporal deduction using Chinese input that includes the design of natural language interactive interface and the development of systems for MT.

However, in this paper, we ignored to discuss the problems of truth-conditions made by verb-aspect of Chinese, and of the delicate and somewhat irregular interactions between verb-aspect and temporals. Likewise, we have not describe how Chinese temporals interact with the determiners in their complements, or with a variety of temporally significant quantifiers, for example, in the expressions of 五天 (at most 5 days) or 五 (for another two years). We supposed that our approach proposed here, is to try to find out a suitable rule in translation for temporal sentences among different languages. In proposing TL as a promising basis for giving the semantics of temporal expressions in Chinese, we presume that the extensions necessary to capture a much wider range of Chinese temporal expressions than considered here can be made gracefully, allowing the decision procedure to be extended in step with the expanded linguistic capabilities.

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