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 mothertongue effortlessly, although human languages are extremely variant and of great complexity. People usually can not be explicit about the rules of their own mothertongue 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 can not 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

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durative of the Stevent is something like: *shave in five minutes*, but, on the other hand, the non-durative of the Stevent is something like: *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:

Durative:

Floating use:	*to indicate the duration of a matrix event,*
Relative to ToR:	*to place the time of the matrix event within an interval adjoining the ToR (Time of Reference),*

Non-Durative:

Absolute use:	*to place the time of the matrix event in the period specified directly by the prepositional noun phrase.*

The *floating use* is that a temporal phrase is not fixed on a time axis and hence indicates an indefinite duration such as *I run this circle in a minute*. In the case of English, Brée has already sorted out the *for* and *in* in the floating duration of the matrix event. Besides that, *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 (*I will be back in a hour*), or once within the duration (*This country will be destroyed within a week*), or continuously for the duration (*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, 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 *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.
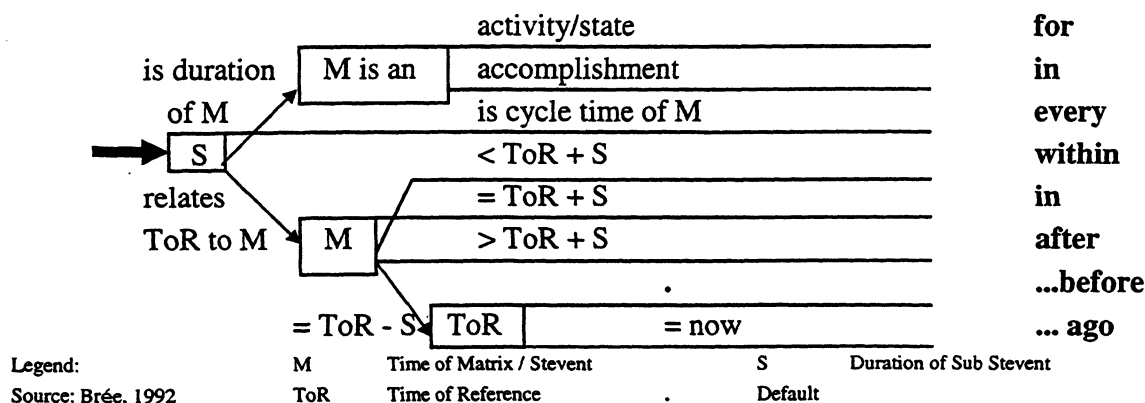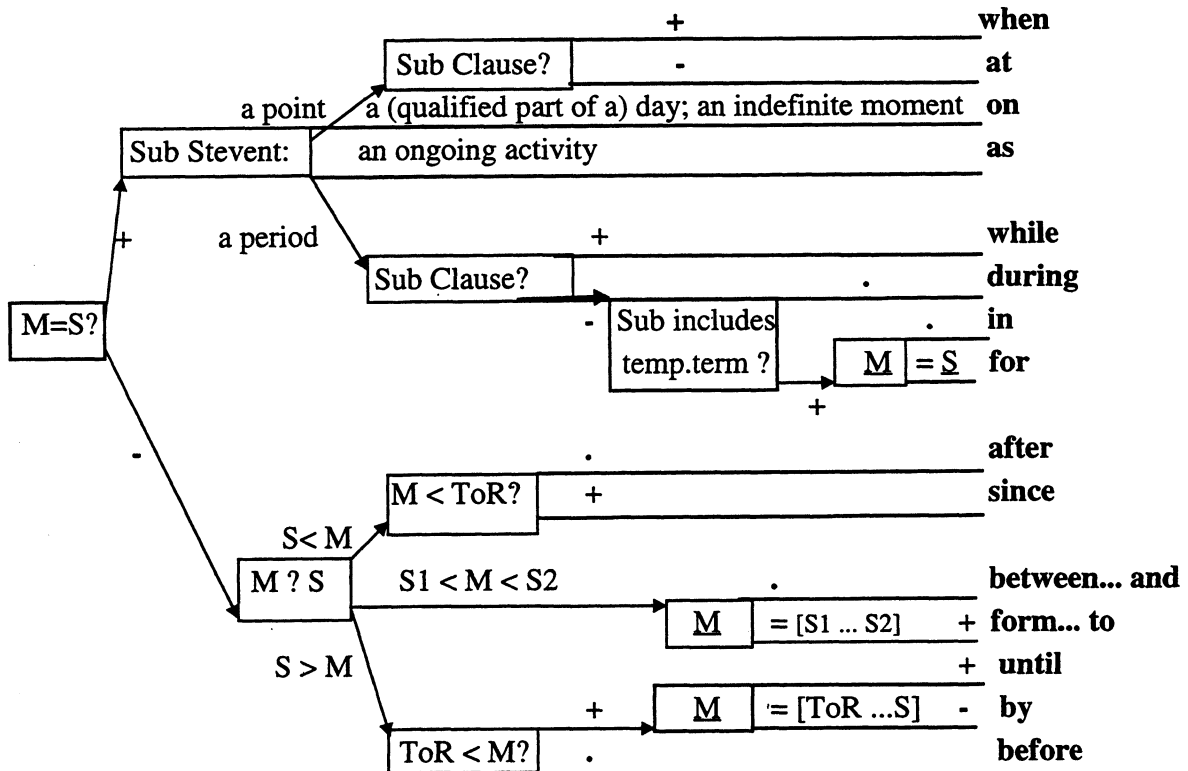

Figure-1 Selection Tree for English Durative use of Temporals

Legend: M — Time of Matrix / Stevent — S — Duration of Sub Stevent

Source: Brée, 1992 — ToR — Time of Reference — . — Default

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                                              +                    when
                    Sub Clause?  |            -                    at
        a point /  a (qualified part of a) day; an indefinite moment  on
 Sub Stevent: |     an ongoing activity                            as

          a period                    +                            while
                    Sub Clause?  |            .                    during
                              - | Sub includes       .             in
                                | temp.term ?  | M |= S            for
                                                      +

                                              .                    after
                    M < ToR?  |   +                                since
              S< M /
          M ? S        S1 < M < S2            .                    between... and
                                     | M |= [S1 ... S2]    +        form... to
           S > M                                           +        until
                              +      | M |= [ToR ...S]     -        by
                    ToR < M?  |  .                                  before
 M=S?
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Legend: M, S   Time of Matrix/Sub Stevent   +   condition fulfilled
         M, S   Duration of Matrix/Sub Stevent   -   condition not fulfilled
Source: Brée, 1992   ToR: Time of Reference   .   Default

Figure-2 Selection Tree for English Non-Durative use of Temporals

3   Logic Representation in English Temporals

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) $\exists J(J \subset [7:00, 8:00] \ \& \ (York\_eat\_his\_sandwich)(J))$

(TL. 2) $\forall J(J \subset [7:00, 8:00] \rightarrow (York\_eat\_his\_sandwich)(J))$

If we indicate the tenseless sentence to be the symbol ϕ and the two point of time of subStevent to be s1 and s2, we can have

(TL. 3) $\exists J(J \subset [s1, s2]$ & $\phi(J))$
(TL. 4) $\forall J(J \subset [s1, s2] \rightarrow \phi(J))$

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) $\exists J(J \subset I$ & $\phi(J))$
(TL. 6) $\forall J(J \subset I \rightarrow \phi(J))$

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 ϕ 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) $\exists K(K \subset [\text{ToR, END}]$ & $\text{dur}(K)=20\_minutes$
    & $\exists J(J \subset K$ & (*York_eat_his_sandwich*) $(J)))$

(TL. 8) $\exists K(K \subset [\text{START, ToR}]$ & $\text{dur}(K)=20\_minutes$
    & $\forall J(J \subset K \rightarrow$ (*York_be_eating_his_sandwich*) $(J)))$

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) $\exists K(K \subset Ie$ & $\text{dur}(K)= \underline{s}$ & $\exists J(J \subset K$ & $\phi(J)))$
(TL. 10) $\exists K(K \subset Iu$ & $\text{dur}(K)= \underline{s}$ & $\forall J(J \subset K \rightarrow \phi(J)))$

where Ie is the interval [ToR, END], Iu is [START, ToR] and $\underline{s}$ 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:*zai* to specify a definite point of time, for example, 在5點 (**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 的時候:*deshiho* can be interpreted as *while, as* and *when*. This Chinese phrase 的時候:*deshiho* can also be represented by only one character 時:*shi*. That is, the word 時:*shi* is the short form for the phrase 的時候:*deshiho*. Moreover, many of the Chinese postpositions the first syllable is optional, such as 起:*qi*, 之:*zhi* and 以:*yi*. For example, in Chinese 之時:*zhishi* and 的時候:*deshiho* and 時:*shi* express a same temporal concept, *while* (or *when, as*). We construct the Chinese temporals with their corresponding meaning in English in the Table-1 as below.

Table-1 Chinese Temporal Coverbs and Postpositions

PostPosition / English/ Coverb	Ø	(的)時(候): (de) shi (hou)	* 後: *hou	起: qi	* 前: *qian	$ 間: $jian	* 內: *nei	& 來: &lai	間/中: jian/ zhong
Ø	for, at, as, in, while, when	as, at, while, when	After		Ago, before			for	
在,於: zai, yu	at, in, on	As, at, while	After		Ago, before, by	between ...and	within		During
當: dang	When	when	After						
還有: haiyou	(in)								

過:guo	In		After						
過了: guole	After		After						
自從: zicong	From	since	Since	since					
從:cong	From	since	Since	since					
到 :dao	to, until			By					
整:zheng	Throug-hout								
臨:lin	Just			Before					

Legend: * - 以/之:yi/zhi (optional) $ - 之:zhi (optional)   & - 以:yi (optional)

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 在..內: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, 在..以內:zai..yinei or 在..之內:zai..zhinei. The phrase 在 .. 內:zai..nei here means *in* or *within*. (ex. 5) shows the example.

(ex. 5)　　他　.　在　　一　個　月　　內　花　了　五佰　　　磅
　　　　　　ta　　　**zai**　yi ge wue　　**nei** hia le wu bai　　bang
　　　　　　He　　**within** one month　　spent　500　　　pounds.
　　　　　　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 (∅) or a Chinese suffix 了: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 視了
　　　　　　wou kan　le　∅　　wu xiaosh de　　dianshle
　　　　　　I have watched　　　five hours　television.
　　　　　　I have watched television **for** five hours.
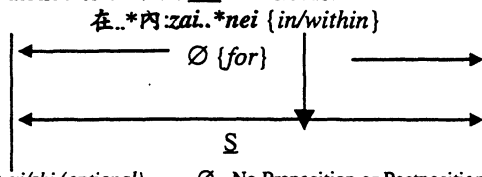
Legend:　　　　　* – 以/之:yi/zhi (optional)　　∅ - No Preposition or Postposition
　　　　　　　　　S - Duration of Sub Stevent
Figure-3 Chinese Floating Use

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　∅ 兩 個　　小時　了
　　　　　　wo　yijing　　zai　　zher deng ni　∅ liang ge　xiaoshi le
　　　　　　I　already　at　　　here wait you　∅　2 hours .
　　　　　　I have already been waiting for you **for** 2 hours.

(ex. 8)　　他　想　　在　英 國 住　∅ 三　年
　　　　　　ta　xiang　zai　yingguo zhu　∅　san　nian
　　　　　　He　think　in　England stay　　three　years.
　　　　　　He plans to live in England **for** three years.

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 在..*後:zai..*hou, 在..*前:zai..*qian and 在..*內:zai..*nei (* is optional 以/之:yi/zhi). The first one means *after*, the second one means *before* and the last one *within*. The examples are given below.

(ex. 9)　　我　在　　一 個 小 時　以 後 去
　　　　　　wo　zai　yi-ge　xiaoshi　**yi hou** hui
　　　　　　I　at　　one　hour　**after**　go
　　　　　　I will go **after** an hour.

(ex. 10)　　他　在　　五分鐘　　以 前　　走 了
　　　　　　ta　zai　fenzhong　**yi qian**　　zou le
　　　　　　He　at　5 minutes　**ago**　　went
　　　　　　He went 5 minutes **ago**.

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(ex. 11)

我 們	一定	要	在	一 個	星期	內	回来
women	yiding	yiao	**zai**	yi ge	xinqi	**nei**	huilai
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* + 以後*:yihou* marks the time of occurrence of a Stevent after ToR+S. Lastly, the structure 在*:zai* + *duration* + 內*:nei* indicates the time or event which will be accomplished within the ToR. In addition, one preposition 過*:guo*, two postpositions 以前*:yiqian* and 以後*: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 過*:guo* which means *after* or *pass* to locate the starting time of the matrix Stevent. The verb 過*: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	過	一 會兒	再 来
wo	**guo**	yi- hueir	zai lai
I	**after**	a while	again come

I will come again **after** a while.

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)

還 有	十五 分鐘 巴士	就	開 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)

約 翰 每 天	學 中 文
uehan **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**:
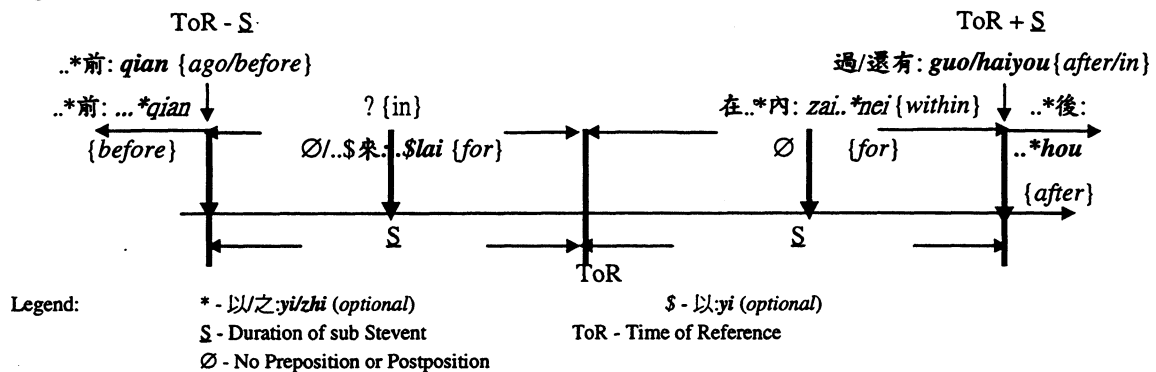Figure-4 below illustrates the usage of Chinese relative to ToR.

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 的時候*: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 在中午時*:zai zhong wu shi* which means *at noon*. We may omit either 在*:zai* or 時*:shi* or both, that is, 在中午時*:zai zhong wu shi* can be written as 中午時*:zhong wu shi,* 在中午*:zai zhong wu* or 中午*:zhong wu*. Another special characteristic of Chinese temporals is that some temporals are used in several areas. The postposition 時*:shi* or 的時候*:de-shihou* is used in sub-clause when the meaning is *when, as,* and *while*. However, the temporal phrase 時候*:shihou* is merely used in a meaning of time. We can see the examples from (ex. 15) to (ex. 16).

(ex. 15)

請	在 下 午	三 點来	找 我
qing	**zai** xiawu	sandian	lai zhaowo
please	**in** this afternoon	three o'clock come	find me

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
ta chi uanfan **de-shihou**	yizhi	kang	dianshi
he eat dinner **of-time**	continuously	watch	television

He is watching the television **as** he is having his dinner.

(ex. 17)   現 在 是 什麼 時候 兒？
           xian zai shi shenme **shihou** r?
           now is what **time**
           What **time** is it now?

In addition, there are two subclause structures that are used in time clauses. One of them is 在..的時候:*zai..de-shihou* which often involves ongoing activities. And 當..的時候:*dang..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.

(ex. 18)   在 你 感冒 的時候 應該 在 家裏 休息
           zai ni ganmao **de-shihou** yinggai zai jiali xiuxi
           when you have a cold of-time should at home rest
           You should rest at home **when** you have a cold.

(ex. 19)   當 我 回 到 家 的 時候 ，他 已經 去世 了
           dang wo hui dao jia **de-shihou**, ta yijin qushi le
           at I return reach home of-time, he already died.
           When I returned home, he has 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 的時候:*de-shihou* which corresponds to English conjunctions such as *when, while* and *as*. In particular, the subclause pattern 當..的時候:*dang..de-shihou* denotes a point in time where the main Stevent occurs, and the subclause structure 在..的時候:*zai..de-shihou* introduces a period of time where the matrix Stevent occurs.

Furthermore, a time phrase structure 在..中:*zai..zhong* will be used for representing an occurrence of matrix during the period of the sub Stevent. Normally, Chinese 中:*zhong* means *middle* but it can be translated as *during* a Stevent. In other words, 在..中:*zai..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 整:*zheng* 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.

(ex. 20)   我 在 課堂 中 睡著 了
           wo **zai** ketang **zhong** shueizhao le
           I **within** lecture **middle** fall:asleep
           I fell asleep **during** the lecture.

(ex. 21)   整 個 耶誕節 我 都 在 英國
           zheng gu iedianjie wo du zai ing-guo
           through Chrismas:holiday I all in England
           I stay in England all **through** the Chrismas holiday.

From our discussion and those examples, we have already known that Chinese temporal 在:*zai* is widely used for temporal clauses. In addition, a Coverb 整:*zheng* 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.
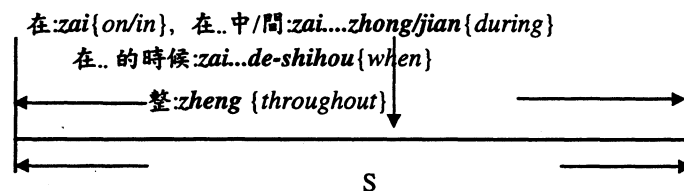
Legend: S- Interval of Sub Stevent
Figure-5 Chinese Absolute Temporals (S is an Interval)
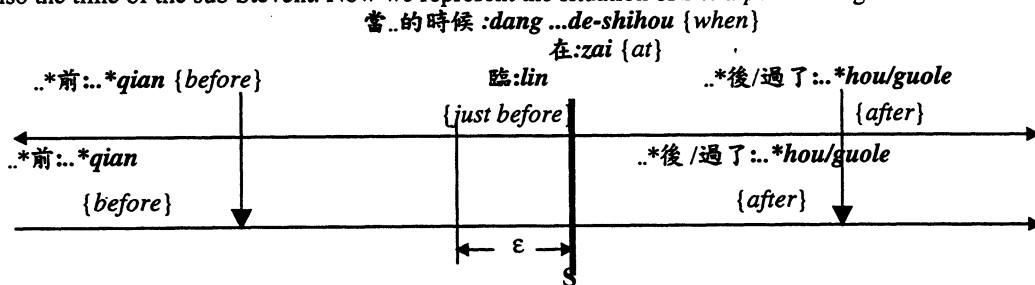
Absolute Use: S is a Point

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 過了:*quole*, 以後: *yihou* and 以前:*yiqian*. The preposition 過了:*quole* has the same meaning as the postposition 以後:*yihou*. 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 以前:*yiqian* is a postposition which means *before*. The examples are shown below.

(ex. 22)   過 了 新年 ，我們 有 七 天 假
           quole xinnian, women you qi tan jia
           after new year, we have 7 days vacation
           After the new year, we will have a vacation for 7 days.

(ex. 23)   下 班 以 後, 我 走路 回家
           xia ban **yihou**, wo zoulu huijia
           knock off **after**, I walk go home
           After I knocking off, I walked home.

(ex. 24)   下 班 以 前, 我 先 喝 一 杯 咖啡

> xia ban   **yiqian**, wo xian he yi be kafei
> knock off   **before**, I   first drink one cup coffee
> **Before** I knocking off, I first drank a cup of coffee.

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.

Legends: S - Time of Sub Stevent (a point) * - 以/之:*yi/zhi* (optional)
      ToR - Time of Reference   ε - A Short Duration

Figure-6 Chinese Absolute Temporals (S is a point)

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 在..和..之間:*zai...he...zhijian* to indicate the meaning of *between..and...*

(ex. 25)   他 在 今年 和 明年 之間,   會 有 一 次 旅 行
         ta **zai** jin nen **he** ming nen **zhijian**, huei you yi chi lu xing
         he **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 從..到:*cong..dao* to indicate this.

(ex. 26)   我 從 星期一 工作 到 星 期 五
         wo **cong** xingqiyi gongzuo **dao** xingqiwu
         I **from** Monday work **to** Friday
         I work **from** Monday **to** Friday.
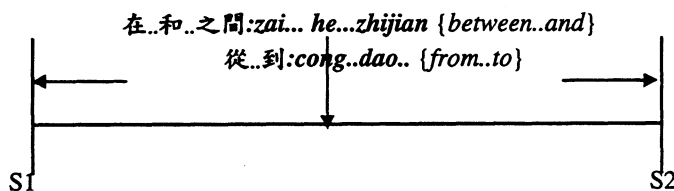

Legend: S1, S2 - Time of Sub Stevent (two points)

Figure-7 Chinese Absolute Temporals (Between two points in Time)

Absolute Use: Between ToR and one Boundary Point

The last case to be considered is the use of temporals to indicate one boundary point of an interval, the other boundary point being given by the ToR. When the matrix Stevent is before the time of reference, we use 自從..以後:*zicong..yihou* or 從..起:*cong..qi* to mark the time phrase. The last two Chinese temporals to be discussed are 到:*dao*, which means *until*, and 在..以前:*zai..yiqian*, which means *by*. The former marks the time where the matrix Stevent stops and the later specifies the time where the Stevent will be stopped.
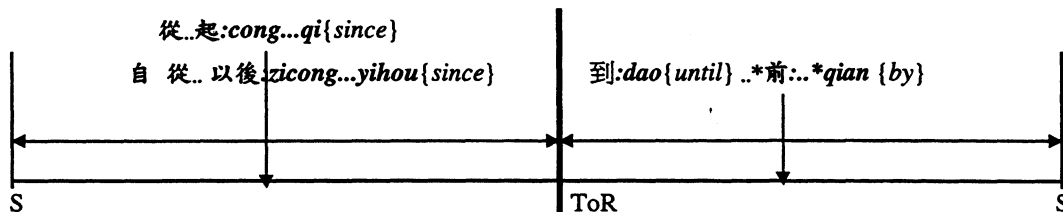
Legends: S - Time of Sub Stevent (a point) * - 以/之:*yi/zhi* (optional)
      ToR - Time of Reference

Figure-8 Chinese Absolute Temporals (Related to the ToR)

(ex. 27)   報名 到 今天 爲 止
         baoming **dao** jintan wuei zhi

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 correspondent 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) $\exists K(K \subset Ie$ & dur$(K)= \underline{s}$ & $\exists J(J \subset K$ & $\phi(J)))$

(TL. 10) $\exists K(K \subset Iu$ & dur$(K)= \underline{s}$ & $\forall J(J \subset K \rightarrow \phi(J)))$

Chinese temporal system have one preposition-postposition pair 在..（之／以）内:zai..(zhi/yi)nei , which means *in/within*, for existential temporal form. Here we propose the Chinese example as following.

(ex. 5)   他　在　一　個　月　内　花　了　五佰　磅
He spent 500 pounds **within** one month.

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

(T_F-5C) $\exists K(K \subset$ [ToR, END] & dur$(K)=$一個月 &
$\exists J(J \subset K$ & (他花五佰磅) $(J)))$

(T_F-5E) $\exists K(K \subset$ [ToR, END] & dur$(K)=$one_month &
$\exists J(J \subset K$ & (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 在..（之／以）内:zai..(zhi/yi)nei preposition-postposition pair has an existential temporal function logic form: $\exists K(K \subset Ie$ & dur$(K)= \underline{s}$ & $\exists J(J \subset K$ & $\phi(J)))$ and the inside of perposition-postposition pair is a duration $\underline{s}$: 一個月- *one month*.

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

(ex. 6)   我　看　了　　$\varnothing$　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) $\exists K(K \subset$ [START, ToR] & dur$(K)=$ 五小時 &
$\forall J(J \subset K \rightarrow$ (我看了電視) $(J)))$

(T_F-6E) $\exists K(K \subset$ [START, ToR] & dur$(K)=$five_hours &
$\exists J(J \subset K$ & (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:$\exists K(K \subset Iu$ & dur$(K)= \underline{s}$ & $\forall J(J \subset K \rightarrow \phi(J)))$. Although Chinese employ nothing for universal floating use, Chinese verb suffix 了:*le* usually indicates a past tense. For example, 我看了電視 and 我看電視 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.

Table-2 Chinese Floating Use

$\exists/\forall$	Coverb, Coverb-Postposition pair	past/future	reference interval I
$\forall$	$\varnothing$ {*for*}	past	[START, ToR]
		future	[ToR, END]
$\exists$	在_*内:*zai..*nei {*in/within*}	past	[START,ToR]
		future	[ToR, END]

Legend:　　　* - 之／以:*zhi/yi* (*optional*)　　　ToR - Time of Reference

Relative Use to ToR

We attempt to construct the explicit of Chinese relative use to ToR temporals, which include $\varnothing$, （以）来:*yilai*, 在..（之／以）内:*zai..(zhi/yi)nei*, ..（之／以）後:..(zhi/yi)hou, ..（之／以）前:..(zhi/yi)qian and 還有:*haihou*. In this category, we should distinct 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 ε represents a small duration of time. As we introducd in previous section, the temporal functions can divide into universals and existential, and their illustration can be shown below.

(TL. 5) $\exists J (J \subset I \ \& \ \phi(J))$

(TL. 6) $\forall J (J \subset I \rightarrow \ \phi(J))$

Consider the following examples and their temporal functions:

(ex. 7)   我 在 這 等 你 Ø 兩 個 小 時 了

(B_L, ∀)   I have been waiting for you **for** 2 hours.

(T_F-7C) $\forall J (J \subset [\text{ToR} - 兩小時, \text{ToR}] \ \rightarrow \ (我在這等你)(J))$ ·

(T_F-7E) $\forall J (J \subset [\text{ToR} - 2\_\text{hours}, \text{ToR}] \ \rightarrow \ (\text{I\_wait\_for\_you})(J))$

(ex. 8)   他 想 在 英 國 住 Ø 三 年

(F_L, ∀)   He plans to live in England **for** three years.

(T_F-8C) $\forall J (J \subset [\text{ToR}, \text{ToR} + 三年] \ \rightarrow \ (他想住在英國)(J))$

(T_F-8E) · $\forall J (J \subset [\text{ToR}, \text{ToR} + 3\_\text{years}] \ \rightarrow \ (\text{he\_plan\_to\_live\_in\_England})(J))$

(ex. 9)   我 在 一 個 小 時 以 後 去

(F_L, ∃)   I will go **after** an hour.

(T_F-9C) $\exists J (J \subset [\text{ToR} + 一小時 - \varepsilon, \text{ToR} + 一小時 + \varepsilon] \ \& \ (我去)(J))$

(T_F-9E) $\exists J (J \subset [\text{ToR} + 1\_\text{hour} - \varepsilon, \text{ToR} + 1\_\text{hour} + \varepsilon] \ \& \ (\text{I\_go})(J))$

(ex. 10)   他 在 五分鐘 以 前 走 了

(B_L, ∃)   He went 5 minutes **ago**.

(T_F-10C) $\exists J (J \subset [\text{ToR}-五分鐘 - \varepsilon, \text{ToR}-五分鐘 + \varepsilon] \ \& \ (他走了)(J))$

(T_F-10E) $\exists J (J \subset [\text{ToR} - 5\_\text{minutes} - \varepsilon, \text{ToR} - 5\_\text{minutes} + \varepsilon] \ \& \ (\text{he\_go})(J))$

where **B_L**, **F_L** and **T_F** stand for **backward-looking**, **foward-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

∃/∀	Backward/forward	Coverb, Preposition-Postposition pair	reference interval I
∀	Forward	Ø {for}	[ToR, ToR+s]
	Backward	Ø/..$来:..$lai{for}	[ToR-s, ToR]
∃	Forward	在..*內:zai..*nei {within}	[ToR, ToR+s]
	Backward ·	? {in}	[ToR-s, ToR]
∀	Forward	..*後:..*hou {after}	[ToR+s-ε, ToR+s+ε]
	Backward	..*前:...*qian {before}	[ToR-s-ε, ToR-s+ε]
∃	Forward	過/還有:guo/haiyou{after/in}	[ToR+s-ε, ToR+s+ε]
	Backward	..*前:...*qian {before/ago}	[ToR-s-ε, ToR-s+ε]

Legend: * – 以/之:yi/zhi (optional) $ – 以:yi (optional)

         s - Duration of sub Stevent   ToR - Time of Reference

         ε - a small duration of time   Ø - No Preposition or Postposition

Absolute Use: S is an Interval

Absolute use in temporal system is a bit more complicate 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 scetion, absolute use and s is a interval, we attempt to present its Chinese temporal functions. The Chinese example sentences are shown as below.

(ex. 18)   在 你 感 冒 的 時 候   應 該 在 家 裏 休 息

          You should rest at home **when** you have a cold.

(T_F-18C) $\exists J (J \subset [s \ ] \ \& \ ((你感冒 \subset [s]) 應該在家裏休息)(J))$

(T_F-18E) $\exists J (J \subset [s] \ \& \ ((\text{you\_have\_a\_cold\_you} \subset [s])$

          $\text{you\_should\_rest\_at\_home})(J))$

(ex. 20)   我 在 課 堂 中   睡 著 了

          I fell asleep **during** the lecture.

(T_F-20C) $\exists J (J \subset [s] \& \ ((課堂 \subset [s]) 我睡著了)(J))$

(T_F-20E) $\exists J (J \subset [s] \ \& \ ((\text{the\_lecture} \subset [s]) \text{I\_fall\_asleep})(J))$

(ex. 21)   整 個 耶 誕 節 我 都 在 英 國

          I stay in England all **through** the Chrismas holiday.

(T_F-21C) $\forall J (J \subset [s] \ \rightarrow \ ((耶誕節 \subset [s]) 我都在英國)(J))$

(T_F-21E) $\forall J (J \subset [s] \ \rightarrow \ ((\text{Chrismas\_holiday} \subset [s]) \text{I\_stay\_in\_England})(J))$

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)

∃/∀	Coverb, Preposition-Postposition pair	reference interval I
∀	整:zheng {throughout}	[s]
∃	在:zai {on/in}	[s]
	在..中/間:zai....zhong/jian{during}	
	在..的時候:zai...de-shihou {when}	

Legend: s - Time of Sub Stevent

Absolute Use: S is a Point

This category of Chinese temporals, we have （之／以）前:*(zhi/yi)hou*, （之／以）後:*(zhi/yi)hou*, 過了:*guole*, 臨 :*lin*, 當.. 的時候:*dang ...de-shihou*, and the Chinese coverb 在. Following examples show the logic representationsin universal and existential respectively.

(ex. 22)　　　　過 了 新 年, 我們 將 住 在 台 北
　　　　　　　　After the new year, we will be living in Taipei.

(T_F-22C)　　　$\forall J(J \subset [s, END] \rightarrow ((新年 \subset [s, END]) 我們住在台北) (J))$

(T_F-22E)　　　$\forall J(J \subset [s, END] \rightarrow ((the \_new\_year \subset [s, END])$
　　　　　　　　$we\_live\_in\_Taipei) (J))$

(ex. 23)　　　　下 班 以 後 , 我 走 路 回 家
　　　　　　　　After I knocking off, I walked home.

(T_F-23C)　　　$\exists J(J \subset [s, END] \& ((下班 \subset [s, END]) 我走路回家) (J))$

(T_F-23E)　　　$\exists J(J \subset [s, END] \& ((knocking\_off \subset [s, END]) I\_walk\_home) (J))$

We gather this category as Table-5 as below.

Table-5 Chinese Absolute Use (s is a point)

∃/∀	Coverb, Preposition-Postposition pair	reference interval I
∀	..*前:..*qian {before}	[START, s]
	..*後 /過了:..*hou/guole{after}	[s, END]
	在:zai {at}	[s-ε, s+ε]
∃	..*前:..*qian {before}	[START, s]
	..*後 /過了:..*hou/guole{after}	[s, END]
	臨:lin {just before}	[s-ε, s]
	當..的時候 :dang ...de-shihou {when}	[s-ε, s+ε]
	在:zai {at}	[s-ε, s+ε]

Legend:　　　* - 以/之:yi/zhi (optional)　　s - Time of sub Stevent
　　　　　　　ε - 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.. 和.. 之間:*zai...he...zhijian* for existential form.

(ex. 25)　　　　他 在 今年 和明 年 之間, 會 有一次旅行
　　　　　　　　He will travel **between** this year **and** next year.

(T_F-25C)　　　$\exists J(J \subset [s1, s2] \& (他會有一次旅行) (J))$

(T_F-25E)　　　$\exists J(J \subset [s1, s2] \& (he\_travel) (J))$

(ex. 26)　　　　我 從 星期一工作 到 星 期 五
　　　　　　　　I work **from** Monday **to** Friday.

(T_F-26C)　　　$\forall J(J \subset [s1, s2] \rightarrow (我工作) (J))$

(T_F-26E)　　　$\forall J(J \subset [s1, s2] \rightarrow (I\_work) (J))$

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

∃/∀	Coverb, Preposition-Postposition pair	reference interval I
∀	從..到:cong..dao.. {from..to}	[s1, s2]
∃	在..和..之間: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 .. (以/之)前:*..(zhi/yi)qian* (English equivalent *by*). On contrary, the backward looking temporals specify two Chinese preposition-postposition pairs 從.. 起:*cong...qi* and 自從.. 以後:*zicong...yihou* which have the same meaning as English *since*. The examples and their temporal functions are shown as follows.

(ex. 27)　　　　報名 到 今天截 止
(F_L, ∀)　　　　Registration will be terminated today.

(T_F-27C)　　　$\forall J(J \subset [ToR, s] \rightarrow (報名截止(J))$

(T_F-27E)　　　$\forall J(J \subset [ToR, s] \rightarrow (registration\_terminate (J))$

(ex. 28)　　　　我 必需 在明 天 以 前回來
(F_L,∃)　　　　I must be back **by** tomorrow.

(T_F-28C)　　　$\exists J(J \subset [ToR, s] \& (我必需回來(J))$

(T_F-28E) $\exists J(J \subset [ToR, s]$ & (I_must_be_back(J))

Table-7 Chinese Absolute Use (s relative to ToR)

∃/∀	forward/backward	Coverb, Preposition-Postposition pair	reference interval *I*
∀	forward	到:*dao*{*until*}	[ToR, s]
	backward	從..起:*cong...qi*; 自從..以後:*zicong...yihou*{*since*}	[s, ToR]
∃	forward	..*前:..*qian {by}	[ToR, s]
	backward	從..起:*cong...qi*; 自從..以後:*zicong...yihou*{*since*}	[s, ToR]

Legend: * – 以/之:*yi/zhi* (*optional*)   s – Time of sub Stevent   ToR – Time of Reference

We sum up the Chinese temporal functions as the Table-8.

Table-8 Chinese Temporal Functions

Category		∃/∀	F/B	Chinese temporals	reference interval *I*
Floating Use		∀		Ø {*for*}	[START, ToR]
					[ToR, END]
		∃		在..*內:*zai..*nei* {*in/within*}	[START,ToR]
					[ToR, END]
Relative use to ToR		∀	Forward	Ø {*for*}	[ToR, ToR+s]
			Backward	Ø/..$來:..$*lai*{*for*}	[ToR-s, ToR]
			Forward	..*後:..*hou* {*after*}	[ToR+s-ε,ToR+s+ε]
			Backward	..*前:...*qian {*before*}	[ToR-s-ε, ToR-s+ε]
		∃	Forward	在..*內:*zai..*nei* {*within*}	[ToR, ToR+s]
			Backward	? {*in*}	[ToR-s, ToR]
			Forward	過/還有:*guo/haiyou*{*after/in*}	[ToR+s-ε,ToR+s+ε]
			Backward	..*前:...*qian {*before/ago*}	[ToR-s-ε, ToR-s+ε]
Absolute	Interval	∀		整:*zheng* {*throughout*}	[s]
		∃		在:*zai*{*on/in*}	[s]
				在..中/間:*zai....zhong/jian*{*during*}	[s]
				在..的時候:*zai...de-shihou* {*when*}	[s]
	Point	∀		..*前:..*qian {*before*}	[START, s]
				..*後 /過了:..*hou/guole{*after*}	[s, END]
				在:*zai* {*at*}	[s-ε, s+ε]
		∃		..*前:..*qian {*before*}	[START, s]
				..*後 /過了:..*hou/guole{*after*}	[s, END]
				臨:*lin* {*just before*}	[s-ε, s]
				當..的時候:*dang..de-shihou*{*when*}	[s-ε, s+ε]
				在:*zai* {*at*}	[s-ε, s+ε]
	Two Points	∀		從..到:*cong..dao*.. {*from..to*}	[s1, s2]
		∃		在..和..之間:*zai...he...zhijian* {*between..and*}	[s1, s2]
	Relative to ToR and one Point	∀	Forward	到:*dao*{*until*}	[ToR, s]
			Backward	從..起:*cong...qi*; 自從..以後:*zicong...yihou*{*since*}	[s, ToR]
		∃	Forward	..*前:..*qian {*by*}	[ToR, s]
			Backward	從..起:*cong...qi*; 自從..以後:*zicong...yihou*{*since*}	[s, ToR]

Legend: * – 以/之:*yi/zhi* (*optional*) $ – 以:*yi* (*optional*)

s/s – Time/Duration of sub Stevent   ToR – Time of Reference

ε – a small duration of time   Ø – No Preposition or Postposition

6   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 最多五天 (at most 5 days) or 另外两年 (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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