Semantic Analysis of Chinese Garden-Path Sentences

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Abstract

This paper presents a semantic model for Chinese garden-path sentences. Based on the Sentence Degeneration model of HNC theory, a garden-path can arise from two types of ambiguities: SD type ambiguity and NP allocated ambiguity. This paper provides an approach to process garden-paths, in which ambiguity detection and analysis take the place of revision. The performance of the approach is evaluated on a small manually annotated test set. The results show that our algorithm can analyze Chinese garden-path sentences effectively.

1 Introduction

A characteristic of garden-path sentences is that they contain a temporarily ambiguous verb structure, in which a participle is confused with the main verb of the sentence. For example, consider the sentence *While Anna dressed the baby spit up on the bed*. Initially *the baby* is assumed to be the object of *dressed*, but when *spit up* is encountered, some sort of error arises. This initial process, then, must be somehow revised. This paper models the phenomenon of garden-path sentences in Chinese and addresses the mechanisms of semantic analysis. Let v1 be the first verb in the sentence and v2 the second verb. Modeling the garden-path that arising from two verbs like v1 and v2 will the focus of this paper.

Models of reanalysis, which concern the syntactic relationships between the error signal and the head of the phrase that has been misanalyzed (Frazier, 1998), attempt to explain how the revisions take place. However, for Chinese garden-path sentence analysis, the syntactic relationship is not enough because the same syntactic relationship can have different semantic interpretations. For example, *咬死猎人的狗* which is temporarily ambiguous in Chinese has different interpretations in the following two sentences. In the first sentence *狗(dog)* is the subject of *咬死(killed)*, and in the second it is the object of *咬死(killed)*.

(1) 咬死猎人的狗逃跑了 (The dog, which killed the hunter, had run away).

(2) 咬死猎人的狗是熊逃跑的唯一出路 (It is the only way for the bear to run away that killed the hunter's dog).

So, semantic analysis is important for Chinese garden-path sentences. In this paper, garden-path sentences will be modeled using the Sentence Degeneration model (SD) of the Hierarchical Network of Concepts theory (HNC) (Huang, 1998; 2004). Furthermore, our analysis algorithm, in which ambiguity analysis takes the place of a revision process, is introduced. We evaluated the model and the algorithm using a small sentence set with grammatical structures like *NP1+V1+NP2+v2+NP3*. The experiment results show that our algorithm can efficiently process Chinese garden-path sentences.

In the rest of this paper: Section 2 discusses previous work. Section 3 gives a detailed definition of the Sentence Degeneration model. Section 4 describes in detail the Semantic Model of Chinese garden-path sentences. Section 5 describes the algorithm and section 6 gives evaluation results. Section 7 presents our conclusions and future work.

2 Previous Work

The phenomenon of garden-path sentences has attracted a lot of attention in the research com-

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munities of psycholinguistics and computational linguistics. The goal of this research is to discover how people understand garden-path sentences and how to analyze them automatically.

In English, garden-path sentences always involve a subordinate clause and a main clause together with an NP that attaches initially to the former but ultimately to the latter (Karl and Fernanda, 2003). This NP is the point of misunderstanding and the verb after the NP is always the error signal. Models of reanalysis are aimed at describing and motivating the mechanisms used by the sentence comprehension system to detect errors, deduce useful information about the nature of the necessary repair of those errors, and ultimately create a successful analysis (Ferreira and Christianson, 2001). Fodor and Inoue(1998) proposed the principles of Attach Anyway and Adjust to explain how reanalysis processes operate. Ferreira and Christianson(2001) stated that Reflexive Absolute Transitive (RAT) verbs, such as *wash, bathe, shave, scratch, groom,* and so on, are likely to give rise to garden-paths. Michael J. Pazzani(1984) demonstrated how to reanalyze one type of garden-path sentence that arises from a passive participle and a main verb conflicting. However Ferreira and Henderson(2001) demonstrated that reanalysis is more difficult when the head of the misanalyzed phrase (*baby* in *the baby that was small and cute*) is distant from the error signal.

In Chinese, there has been little research that directly addresses the problem of garden-paths. Zhiwei Feng(2003) interpreted the temporarily ambiguous verb structure in a garden-path in two ways; one is as a subordinate clause (MV), the other is a Reduced Relative (RR). He defined Garden Path Degree (GPD) as MV/RR. He studied some types of temporarily ambiguous verb structures such as *NP1+VP+NP2+de+NP3, VP+NP1+de+NP2, V+Adj+de+N and V+V+de+N,* and stated that when GPD is larger than 3, the temporarily ambiguous verb structure may give rise to a garden-path. Moreover he used the Earley algorithm to process garden-path sentences.

3 Sentence Degeneration model (SD)

The Sentence Degeneration model, which is one model of the Hierarchical Network of Concepts theory (HNC), focuses on representing the subordinate clause in a sentence. The theory of the Hierarchical Network of Concepts (HNC theory), founded by Prof. Zengyang Huang of the Institute of Acoustics, Chinese Academy of Sciences, is a theoretical approach to Natural Language Processing (NLP). The objective of HNC is to establish natural language representation patterns based on the association veins of concepts, which can simulate the language perception process of the human brain and can be applied to computational Natural Language Understanding.

Sentence Degeneration (SD) represents the semantic patterns of the subordinate clause in a sentence. There are three types of SD: prototype SD, key-element SD, and packed SD.

In Prototype SD a subordinate clause wholly acts as one role of the other sentence without any alteration. For example, *中国加入世界贸易组织(China joined the WTO)* is a complete sentence. However in sentence (3) this sentence acts as the subject of *促进(accelerate)*. Unlike English, in Chinese there is no relative pronoun, such as *that* or *which*, to indicate that this is a subordinate clause. This phenomenon is named Prototype SD.

(3) 中国加入世界贸易组织会促进全球经济的发展 (That China joined the WTO will accelerate the development of global economics.).

Key-element SD involves an NP which semantically is an attributive clause. For example, although in sentence (4) *加入世界贸易组织的中国* is an NP, it can be transformed from the sentence *中国加入世界贸易组织* by moving the subject *中国* to the tail and adding the Chinese word *的(of or 's)* in front of it. We look at this NP as a specific attributive clause[1] in Chinese, and look at *中国* as the core concept of this clause. Because the core concept of this clause is the subject, which is the key element, this phenomenon is called key-element SD. Besides the subject, the object and the verb of the sentence can be the core of key-element SD. For example, in sentence (5) *中国对世界经济的影响* is one key-element SD transformed from the sentence *中国影响世界经济*, and the verb *影响* is its core.

(4) 加入世界贸易组织的中国将严格遵守贸易规则 (China, which joined WTO, will strictly confirm the world trade rule.)

(5) 这一切体现了中国对世界经济的影响 (Everything of all reflected the influence that China economics impacts on the world).

Packed SD is also an NP in which the attrib-

[1] This NP has to be translated as an attributive clause using *which* in English.

uter is a prototype SD or key-element SD. For example, in sentence (6) and (7) both noun phrases *中国加入世界贸易组织的消息* and *中国对世界经济的影响程度* are Packed SD's. Moreover, the attributer of *消息* is *中国加入世界贸易组织* which is a prototype SD, and the attributer of *程度* is *中国对世界经济的影响* which is a key-element SD. The words *消息* and *程度* are called packed words.

(6) 中国加入世界贸易组织的消息令人激动 (The news that China joined WTO is exciting.)

(7) 中国对世界经济的影响程度将越来越大 (The degree of influence that Chinese economics impacts on the world is deeper and deeper.)

Let *ElJ* be the semantic structure of the subordinate clause, *GBKi* be the subject/object, and *El* be the verb of the clause. The semantic pattern of the clause can be given as *ElJ=GBK1+El+GBK2+GBK3*, where *GBK2* and *GBK3* can be absent and the position of *GBKi* can be changed. Suppose *ElJ-GBKi* stands for the action of subtracting the *GBKi* from *ElJ*, *ElJ-El* stands for subtracting the *El*. The semantic patterns of SD can be given as follows:

1. *ElJ*. It means that *ElJ* is a prototype SD.
2. *(ElJ-GBKi)+的+GBKi*. It means that this key-element SD can be transformed from the clause *ElJ* by moving *GBKi* to the tail and adding the Chinese word *的* in front of GBKi.
3. *(ElJ-El)+ 的 +El*. It means that this key-element SD can be transformed from the clause *ElJ* by moving *El* to the tail and adding the Chinese word *的* in front of *El*. Although this *El* looks like a noun because there is Chinese word *的* in front of it, it is regarded as a verb when restored back to the *ElJ*.
4. *a prototype SD or key-element SD+{的}+noun*. It means the three patterns above can serve as the attributer of the packed SD.

Although the key-element SD and packed SD look like NP's in Chinese, they need to be transformed back into clauses during semantic analysis. It means that in patterns 2 and 3 the *GBKi* and *El* have to be restored into *ElJ*. This is why we named these phenomena Sentence Degeneration. Moreover, in patterns 2 and 3, the Chinese word *的* is necessary to indicate the transformation, and we call it a sign of SD.

Therefore, if an NP or other structure includes a verb and the Chinese word *的*, it has to be analyzed as one type of SD. These semantic patterns of SD are useful for describing the interpretation of temporarily ambiguous verb structures, such as those in garden-path sentences.

4 Semantic Model of Chinese Garden-Path Sentence

Based on the Sentence Degeneration model, there are two types of Chinese Garden-Path Sentences: SD type ambiguity garden-paths and NP allocated ambiguity garden-paths.

A temporarily ambiguous verb structure in a sentence always has more than one semantic interpretation that can be represented as a type of SD. This phenomenon we call SD type ambiguity. If an SD type ambiguity includes a prototype SD, a garden-path arises. For example, an ambiguous structure like *咬死猎人的狗* has two different interpretations as A and B in sentence (1) and (2):

A. It is a key-element SD in sentence (1), where *狗(dog)* is the subject of *咬死(kill)*, and *猎人(hunter)* is the object of *咬死(kill)*.

B. It is a prototype SD in sentence (2), where *狗(dog)* is the object of *咬死(kill)*, and *猎人(hunter)* is the attributer of *狗(dog)*.

Obviously, *咬死猎人的狗* has SD type ambiguity, and one type of SD is prototype SD. Therefore, sentence (1) and sentence (2) are garden-path sentences.

An NP allocated ambiguity garden-path is a sentence in which one *NP* can be both the object of *v1* and the subject of *v2*. Given the structure *NP1+v1+NP2+v2+NP3*, if *NP1+v1+NP2* is a clause, *NP2+v2+NP3* is a clause, too; there is an ambiguity about whether *NP2* serves as either the object of the first clause or the subject of the second clause. Unlike the garden-path that arises from an SD type ambiguity, NP allocated ambiguity garden-paths confuse the main verb of the sentence. For example, Sentence (8) has two different interpretations as A and B. The difference in the two interpretations is the role of *the solution*. So, sentence (8) is a garden-path sentence with an NP allocated ambiguity.

(8)这个学生忘记答案在书的背后 (The student forgot the solution was in the back of the book.)

A. *the solution* is the subject of *was*, the main verb is *forgot*; *the solution was in the back of the book*, which is a prototype SD, is the object of

forgot.

B. *the solution* is the object of *forgot*, the main verb is *was*, *the student forgot the solution*, which is a prototype SD, is the subject of *was*.

We can see that it is necessary for both types of garden-path that *NP1+v1+NP2* be a clause. If there is an NP allocated ambiguity garden-path, *NP1+v1+NP2* is a clause together with *NP2+v2+NP3* as a clause. If there is an SD type ambiguity garden-path, *NP1+v1+NP2* has to be a prototype SD together with one of other two types of SD (Key-element SD or packed SD). Thus, this clause, *NP1+v1+NP2*, is called a garden-path detecting signal.

Therefore, in our model the garden-path is represented as one of two types of ambiguity: the SD type ambiguity and NP allocated ambiguity. Garden-path processing involves detecting and analyzing these two types of ambiguities.

5 Algorithm for processing Chinese Garden-Path Sentences

A Chinese Garden-Path Sentence is processed in four steps:

(1) Initially, *v1* is analyzed as the main verb.
(2) When *v2* is encountered, if there is a clause before *v2*, this is a garden-path detecting signal. It is necessary to detect and analyze the garden-path in this sentence.
(3) Detect if v1 and v2 can give rise to a garden-path (see section 5.1).
(4) Determine the main verb of the sentence and the semantic interpretation of the garden-path sentence (see section 5.2).

5.1 Garden-path detection

Given an input string *S*, suppose its grammatical structure is *NP1+v1+NP2+v2+NP3*, where *NP1* and *NP3* can be absent. Therefore, a garden-path detecting signal means that *NP1+v1+NP2* is a clause.

The garden-path can be detected in two steps as follows:

Step 1: test if there is SD type ambiguity in *NP1+v1+NP2*.

We can look at the clause *NP1+v1+NP2* as a prototype SD without any change. If this prototype SD can be analyzed as another type of SD, such as key-element or packed SD, an SD type ambiguity is found, and the input *S* is a garden-path sentence. Otherwise, if there is no SD type ambiguity, the input *S* is a non garden-path sentence.

As mentioned above, sentence (1) has an ambiguity between a prototype and a key-element SD, and it is a garden-path sentence. Consider another sentence (9), with grammatical structure *NP1+v1+NP2+v2*. Because the Chinese word *的*(of) in *NP2* is a sign of SD, the structure can be rewritten as *NP1+v1+NP21+的+NP22+v2*.

(9) 小王研究鲁迅的文章发表了 (The paper which Mr. wang research on Luxun is published.)

The structure *NP1+v1+NP21+的+NP22* can be analyzed in two different ways as follows. Obviously there is an ambiguity between prototype SD and packed SD, and sentence (9) is a garden-path sentence.

A. It is a prototype SD, where *文章(paper)* is the object of *研究(research)*, and *文章(paper)* was written by *鲁迅(Luxun)*.

B. It is a packed SD, where *鲁迅(Luxun)* is the object of *研究(research)*, and *文章(paper)* was written by *小王(Mr. wang)*.

Although the structure *v1+NP2+v2* in sentence (1) and the structure *NP1+v1+NP2+v2* in sentence (9) can give rise to garden-paths, not all the instances of these two structures are like this. For example, in sentence group (10) *年轻人(younger)* and *刀(knife)* disfavor being objects of *热爱(love)* and *削(peel)*, so *热爱祖国的年轻人* is only analyzed as a key-element SD, and *小王削苹果的刀* is only analyzed as a packed SD. There is no garden-path detecting signal, so these sentences are non garden-path sentences.

(10) 热爱祖国的年轻人回国了 (The younger who love his country go back.)

小王削苹果的刀不见了 (The knife with which Mr. wang peeled the apple is lost.)

Furthermore, in sentence group (11), *v1+NP2* is a clause, so there is a garden-path detecting signal. However, *皮(fruit skin)* disfavors being the subject of *削(peel)*, and *门(door)* is not a packed word, so *削苹果的皮* and *小王推开房间的门* are only analyzed as prototype SD. There is no SD type ambiguity, so these sentences are non garden-path sentences.

(11) 削苹果的皮要小心 (Peeling the apple need to be careful.)

小王推开房间的门走了 (Mr. wang opened the door and went away.)

Step 2: test if *NP2+v2+NP3* is a clause.

If *NP2+v2+NP3* is not a clause, definitely there is no NP allocated ambiguity, and the sentence is not a garden-path sentence. For example,

in sentence (12) *伊拉克起因于能源危机(Iraq is due to the crisis of energy)* is not a clause, so sentence (12) is a non garden-path sentence.

(12) 美国打击伊拉克起因于能源危机 (That USA attacked Iraq is due to the crisis of energy)

If *NP2+v2+NP3* is a clause, there are two interpretations for *v1* and *v2*.

First, *v1* and *v2* are serial verbs, and the sentence can be divided into two separate sentences; one is *NP1+v1+NP2*, the other is *NP2+v2+NP3* and the subject of v2 is *NP2*. For example, sentence (13) can be divided into sentences (14) and (15). This phenomenon can be interpreted as sentence (15) sharing *大会(conference)* with sentence (14), which is not NP allocated ambiguity, so the sentence (13) is a non garden-path sentence.

(13) 文件将提交给大会讨论 (The file will be given to the conference to discuss.)

(14) 文件将提交给大会 (The file will be given to the conference.)

(15) 大会讨论这个文件 (The conference will discuss the file.)

Second, one of *v1* and *v2* is the main verb of the sentence, and *NP2* has to be in *NP1+v1+NP2* or *NP2+v2+NP3*, and cannot be shared. For example, in sentence (8), the *solution* cannot be shared by *forgot* and *was*. Absolutely this is an NP allocated ambiguity, and the sentence is a garden-path sentence.

The difference between a serial verb interpretation and an NP allocated ambiguity interpretation is the semantic information of the two verbs. Suppose *VS(pro)* is the set of all verbs whose subject can be a prototype SD, *VO(pro)* is the set of all verbs whose object can be a prototype SD. Verbs about mental acts, emotions or other human feelings, such as *forget, worry, cry*, belong to the *VS(pro)*. Verbs about propositions, causes and results, such as *be, result in, be due to*, belong to both *VO(pro)* and *VS(pro)*.

If *NP2+v2+NP3* is a clause, and if *v1* is not one of *VO(pro)* and *v2* is not one of *VS(pro)*, the sentence is a non garden-path sentence and these two verbs are serial verbs. Otherwise, the sentence is a garden-path sentence.

5.2 Garden-path analysis

A garden-path is always affected by the selection of the main verb of a sentence. In the garden-path caused by SD ambiguity, *v1* is regarded as the main verb initially, however, in the end, *v2* is the real main verb. In the garden-path caused by NP allocated ambiguity, both *v1* and *v2* can be the main verb. So, the garden-path analysis includes two steps: the first step is determining the main verb of the sentence; the second step is disambiguating the SD type or the NP allocated ambiguity, and determining the semantic structure of the sentence.

Given a garden-path sentence with grammatical structure *NP1+v1+NP2+v2+NP3*, the analysis process is as follows:

First, if an SD type ambiguity is detected, it means *NP1+v1+NP2* can be a prototype SD and key-element or packed SD, and *v2* always is the main verb of the sentence. The ambiguity can be processed as in Figure 1. For example, In sentences (1) and (2), *是(is)* is one of VS(pro) and *逃跑(run away)* is not, so *咬死猎人的狗* is processed as a key-element SD in sentence (1) and a prototype SD in sentence (2).

Second, if an NP allocated ambiguity is detected, it means that both *NP1+v1+NP2* and *NP2+v2+NP3* can be clauses. The main verb can be determined in Figure 2. The NP allocated ambiguity can be processed as in Figure 3.

(16) 张先生看见李小姐正在跳舞 (Mr. Zhang saw Miss. Li dancing.)

The result of garden-path analysis is a semantic structure for the sentence. In Figures 1 and 3, a flag of prototype SD, key-element SD and packed SD, which indicates the semantic interpretation, is added to the grammatical structure of the sentence. Therefore, the main verb, which is always outside the flag, and the semantic structure of the sentence are both represented.

v2 is	*NP1+v1+NP2* is	Sentence semantic structure	Example
one of VS(pro)	a prototype SD	(NP1+v1+NP2)+v2+NP3	Sentence (2)
not one of VS(pro)	a key-element SD	<NP1+v1+NP2>+v2+NP3	Sentence (1)
not one of VS(pro)	a packed SD	{NP1+v1+NP2}+v2+NP3	Sentence (9)

Figure 1: The process of SD type ambiguity in garden-path sentences. Where ( ) is the flag

indicating that the content in it is prototype SD, < > is the flag of key-element SD, and { } is the flag of packed SD.

V1 is	v2 is	the main verb is	Example
one of VO(pro)	not one of VS(pro)	v1	Sentence (16)
one of VO(pro)	one of VS(pro)	prior to be v1	Sentence (8)
not one of VO(pro)	one of VS(pro)	v2	Sentence (12)

Figure 2: The main verb determining in garden-path sentences. Here *prior to* means that if v1 is one of VO(pro) and v2 is one of VS(pro), the main verb is v1 in most cases. In some cases it depends on the meaning of v1 and v2, whether v1 is the main verb. These cases are out of the scope of consideration of this paper.

Main verb is	NP2 is	Sentence semantic structure	Example	Comment
v1	The subject of v2	NP1+v1+(NP2+v2 +NP3)	Sentence (8),(16)	NP2+v2+NP3 is a prototype SD, this SD is the object of v1.
v2	The object of v1	(NP1+v1+NP2)+v2 +NP3	Sentence (12)	NP1+v1+NP2 is a prototype SD, this SD is the subject of v2.

Figure 3: The process of NP allocated ambiguity in garden-path sentence. Where ( ) is the flag indicating that the content in it is prototype SD.

6. Evaluation and Discussion

To conduct a reliable evaluation, a test sentence set and a simple knowledge base were developed. The test set includes 100 manually annotated Chinese garden-path sentences and 100 non garden-path sentences with grammatical structure *NP1+v1+NP2+v2+NP3*. The knowledge base includes two aspects: one is if the verb is one of VS(pro) or VO(pro), the other is the concepts which the subject/object of the verb favor. And there are about 800 verbs in our knowledge base.

Next, two experiments have been conducted. The first one is designed to test if our model can detect garden-paths effectively. The second one is designed to evaluate if garden-path sentences can be correctly analyzed. The results of the experiments are shown in Tables 1 and 2.

Total Num	Detected	Correct	P(%)	R(%)	F(%)
100	85	79	92.9	79	85.4

Table 1: Performance of detection algorithm.

Total of Detected	SD type ambiguity Analysis Correct	NP allocated ambiguity Analysis Correct	Total of Correct	P(%)
85	53	24	77	90.6

Table 2: Performance of analysis algorithm.

Where, P is precision ratio, R is recall ratio, and F is F-measure (F β =1, which is defined as 2PR/(P+R)).

We can see that on this small test set, our algorithm achieves good performance in detection and analysis of Chinese garden-path sentences. We also conducted an error analysis, showing that two main factors lead to detection errors.

The first is that attributer processing of NP2's is not considered. For example, in *管理朋友的*

公司(manage the friend's company), 朋友的公司(the friend's company) is an NP which cannot be divided to *NP21(朋友 friend)+的+NP22(公司 company*) and cannot be detected if there is an SD type ambiguity.

The second is coordination ambiguity interacting with NP allocated ambiguity, as in *Sandra bumped into the busboy and the waiter told her to be careful*, which has not been considered.

Furthermore, there are two sentences correctly detected as Chinese garden-path sentences, but there are neither SD type ambiguities nor NP allocated ambiguities in them. This is why there are 79 correct detections in Table 1, but only 77 correct analyses in Table 2. One of these sentences is sentence (17), in which *我是县长(I am the mayor)* looks like a prototype SD, however "是…的" is used to emphasized 县长(the mayor) in Chinese.

(17) 我是县长派来的（It is the mayor that instructed me to come here）

7. Conclusions and Future Work

The contributions of this paper are three-fold.

First, the Sentence Degeneration model is introduced which can represent the differences in interpretation of the same grammatical structure.

Second, we represent garden-paths as SD type ambiguity and NP allocated ambiguity. These two ambiguities come from semantics but not grammar.

Third, we present a unified approach to processing garden-paths, in which ambiguity detection and analysis take the place of revision. The result of our approach is the semantic structure of a garden-path sentence.

The results of two experiments we conducted show that our model and algorithm can analyze Chinese garden-path sentences effectively. In our future work, we will build a complex knowledge base for verbs to support our semantic analysis. We will also develop attributer processing and coordination disambiguation to improve the performance of our algorithm.

Moreover, we will extend our algorithm to detect and analyze garden-paths caused by sentences which have no verbs. This phenomenon is a typical ambiguity in Chinese sentences, such as. Sentence (18):

(18) 她穿裙子很漂亮(She is beautiful dressing skirt).

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