# On the Derivation of the Non-Canonical Object Construction in Mandarin Chinese

Haojie Li

School of Foreign Languages, Southwest University of Political Science and Law, Chongqing, China

Tongde Zhang

East China University of Technology, Fuzhou, Jiangxi, China

*Abstract*—This paper makes a study of the derivation of the non-canonical object construction in Mandarin Chinese. In light of the transitivity of verbs, two cases in the NOC are discussed: a) the non-canonical object construction with transitive verbs and b) the non-canonical object construction with unergative verbs. Based on the theory of phase and phase extension, a mixture of direct object properties and PP object properties in the non-canonical object construction can be explained in that the non-canonical object is licensed by both the preposition and the verb.

Index Terms-non-canonical object construction; phase; phase extension; derivation mechanism

# I. INTRODUCTION

The object that can appear in the postverbal position in Mandarin Chinese has been a subject of great interest for decades. There are two kinds of objects following the verb: the subcategorized object and the unsubcategorized object, as illustrated in (1)-(5):

(1) chi niu-rou mian

eat beef noodle

'to eat beef noodle'

- (2) chi shitang eat canteen'to eat in the canteen'
- (3) xie maobi

write writing brush

'to write with the writing brush'

(4) fei Shanghai fly Shanghai

'to fly to Shanghai'

(5) xiu libaitian rest Sunday

'to have a rest on Sundays'

*Niu-rou mian* 'beef noodle' in (1) is a subcategorized object, which has the thematic role of Theme/patient. *Shitang* 'canteen', *maobi* 'writing brush', *Shanghai* 'Shanghai', *libaitian* 'Sunday' in (2)-(5) are unsubcategorized objects, which have thematic roles of Location, Instrument, Goal, and Time, respectively.

Barrie and Li (2015, p. 180) define the subcategorized objects as canonical objects and the unsubcategorized objects as non-canonical objects. Non-canonical objects roughly correspond to adjunct PPs, which generally occur preverbally in Chinese, as illustrated in (6):

- (6) a. wo jintian chi shitang le.
  - I today eat canteen PRF
  - 'I ate at the canteen today.'
  - b. Wo jintian zai shitang chifan.
    - I today at canteen eat-meal
    - 'I eat/ate at the canteen today.'

The non-canonical object *shitang* 'canteen' in (6a) directly follows the verb, while in (2b), it is an oblique argument in the adjunct PP introduced by the preposition *zai* 'in'. The two sentences in (6) roughly have the same meaning. This kind of construction is abundant and productive in Mandarin Chinese, and the realization and license of the non-canonical object have always been a frontier topic in the theoretical syntactic research.

In the literature, aside from the term "non-canonical objects", there are different terms for unsubcategorized objects mainly based on their semantic functions: "quasi-object" (Zhu, 1982), "object substitution" (Xing, 1991), "adverbial

object" (Lin, 2001) and so on. Carnie (2013) maintains that the noun phrase other than the subject, the object and the indirect object should be called the "oblique". Following this line, Sun (2009, 2010, 2011, 2019) and Sun and Li (2010, 2020) call the post-verbal component "oblique object". Other names include "post-verbal non-core element" (Deng, 2014), "free oblique object" (Chen & Li, 2016) and "pseudo object" (Yang, 2021). We take the term "non-canonical objects" in this paper to denote unsubcategorized objects and the construction contains the non-canonical object is called the non-canonical object construction (NOC).

The following sections of this paper are organized as follows: Section II presents some related researches of the NOC, Section III provides the theoretical framework for analyzing the NOC, Section IV gives the analysis of the NOC and Section V displays the concluding remarks.

# II. RELATED RESEARCHES

In this section, some approaches to the NOC and some related problems will be reviewed.

#### A. Guo's (1999) Covert Predicate View

The covert predicate view claims that a covert element in the VP construction licenses the non-canonical object. The covert component has something to do with an implicit predicate or an implicit preposition.

Guo (1999) maintains that a covert semantic component *wei* 'predicate' is the key factor leading to the NOC. He attributes the interpretation of the 'Vi+NP' construction (the NOC in this paper) to a covert element *wei* 'predicate'. He observes the phenomenon of intransitive verbs with objects like *fei Shanghai* 'to fly to Shanghai' (literally: fly Shanghai) from the perspectives of the rule of meaning, structural properties, style characteristics, and reasons of formation. He expounds that the non-canonical object is permitted by the corresponding covert components. He argues that 'Vi.+NP' constructions contain semantic relations, which is a covert semantic component *wei* 'predicate' at the syntactic level and may take the form of a verb, a preposition, or a conjunction between the intransitive verb and the object. The function of *wei* 'predicate' is to explain the semantic relations between the verb and the object, which is determined by the "verb", the "object", and contextual clues. The event meaning can be summarized into the following formula: verb+(*wei* 'predicate'+noun), as shown in (7):

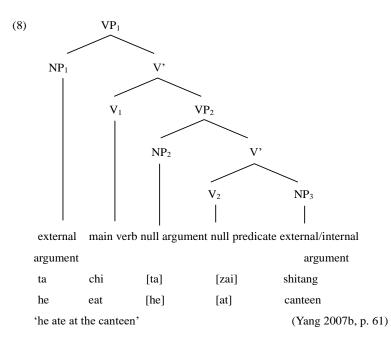
- (7) a. fei Shanghai
  - fly Shanghai
    - 'to fly to Shanghai'
  - b. verb+(*wei* 'predicate'+noun)
    - fei (wang Shanghai)
    - fly to Shanghai

In (7), the non-canonical object *Shanghai* is licensed by the corresponding covert predicate *wang* 'to'. This covert predicate is the preposition *wang* 'to' in (7), i.e., *fei Shanghai* 'fly Shanghai' refers to "fly+(to+Shanghai)".

Guo (1999) does not mention the motivation of assuming the covert predicate. There is no strong evidence to show that *zou baguazhang* 'to walk to practice baguazhang' (literally: walk baguazhang) is derived from *zouzhelian baguazhang* 'to walk to practice baguazhang' (literally: walk-ZHE (PROG) practice baguazhang).

# B. Yang's (2007a, b; 2009) Empty Predicate View

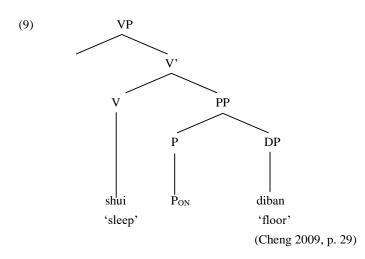
Yang (2007a) maintains that Vi.+NP can be regarded as the product of the syntactic displacement of words due to the omission of prepositions. He points out that "Vi.+NP" is derived by the transformation of "Vi.+Prep+NP" or "Prep+NP+Vi.". The "Prep+NP" originally serves as the complement of the Vi. and then the preposition is omitted, and NP is promoted to the object of the Vi. to form the NOC. Yang (2007b) maintains that an empty argument and an empty predicate are contained in Vi.+NP. The non-canonical object is permitted by the empty predicate. The sentence *Ta chi shitang.* 'He ate at the canteen.' (literally: he eat canteen) is derived from "he ate 0 (he) 0 (in) canteen", as illustrated in (8):



Yang (2009) uses the movement of the verb to explain the generation of the NOC. Take *Ta chiguo shitang*. 'He has eaten at the canteen.' (literally: he eat-ASP canteen) as an example. He holds that the sentence first generates *ta zai shitang guo chifan* 'he at canteen ASP eat the meal' (literally: he at canteen ASP eat-meal). The aspect marker *guo* 'ASP' attracts the verb to move to generate *ta zai shitang chiguo fan* 'he at canteen eat-ASP meal'. The prepositional phrase is preceded by the verb together with the aspect marker, generating *ta chiguo fan zai shitang* 'he eat-ASP meal at the canteen' and then, generating *ta chiguo shitang* 'He has eaten at the canteen.' (literally: he eat-ASP canteen) with the deletion of the preposition. However, *fan* 'meal' appears at the outset of the derivation, it suddenly disappears at the end of the derivation, and Yang does not explain the reason of the disappearance of *fan* 'meal'.

## C. Cheng's (2009) Null Preposition View

Cheng (2009) proposes the Null Preposition Hypothesis to analyze the NOC. He holds that the non-canonical object in Chinese IVO construction is mediated with the verb by a null preposition P, which establishes the relation between the non-canonical object and the verb in IVO constructions. P selects the non-canonical object as its complement and then projects the PP, and then the PP merges with the verb and forms a VP: [VP [VV P] P P] [P P DP]]]]. Thus, the non-canonical object is included in a PP projected by the null preposition P, as *shui diban* 'to sleep on the floor' (literally: sleep floor) shows in (9):



#### **III. THEORETICAL FRAMEWORK**

In this section, Chomsky's phase theory and Bošković's (2014) theory of phase extension will be presented as the theoretical framework to analyze the NOC.

## A. Chomsky's Phase Theory

Chomsky's (2000, 2001, 2004, 2007, 2008, 2013) phrase theory is static, namely, the once-a-phase-always-a-phase approach. He proposes the derivation of syntactic structures is conducted on the basis of phase because the FL (the faculty of language) must be in line with the law of organism operation. The memories of human beings have a limited capacity and cannot fit too many syntactic structures at one time. As a result, only a limited number of structures can be processed by the FL at a time. The active memory can accommodate simply a limited amount of structural information. Reducing computational burdens and enhancing computational efficiency is the goal of derivation by phase.

Chomsky maintains that proposition is the defining property of the phase. Thus, CPs and v\*Ps are are complete propositional structures, thus, they are phases. Complete argument structures are possessed by v\*P and tense, event structure and force are included by CP. Sentence types are represented by the element of Force. The heads of phase CP and phase v\*P determine all syntactic operations and phases conduct derivations. In terms of principles of derivation by phase, two syntactic elements are merged to form sentences, from below to above as the order of derivation, linear structures are from right to left.

## B. Bošković's Phase Extension Theory

Bošković (2014) argues for what counts as a phase is determined contextually, which is called the dynamic approach to phases. Under this approach, in one context, a phase is taken by a particular phrase, but not in another context. In light of Bošković (2014), phasehood in Chomsky's (2000, 2001, 2004, 2007, 2008, 2013) approach is in a sense rigid: the syntactic context is not depended on by the phasal status of a category; thus, phases are always CPs and v\*Ps (the once-a-phase-always-a-phase approach). This runs counter to barriers (to be more exact, blocking categories; predecessors of phases are barriers in the sense that both barriers and phases are crucially used to define opaque/non-opaque domains for extraction), which is the spirit of the Minimalist predecessor of phases. In terms of barriers (Chomsky 1986), the syntactic context is depended on by whether or not a particular category is a barrier.

Bošković (2014) argues for a contextual approach to phasehood. He maintains that N, P, A, and V (passive and active), which are the highest phrase in the extended projection of all lexical categories, function as a phase. Under this approach, in one context, a phase is acted by a particular phrase, but not in another context; under the rigid phasehood approach, such a situation cannot occur in that a phase is always a phase (in all contexts) or never a phase (in any context).

Bošković's phase extention theory avoids the problem that the complement of the head cannot be moved. He maintains that a phase refers to the highest phrase in the extended projection of all lexical categories, and the phase is determined by the context. Thus, supposing phrase X functions as a phase, it stops to function as a phase when another phrase Y is merged on top of it in the extended projection of the same lexical category. As a result, all the complements inside the phase can implement the movement operation, complying with language facts.

# IV. OUR ANALYSIS

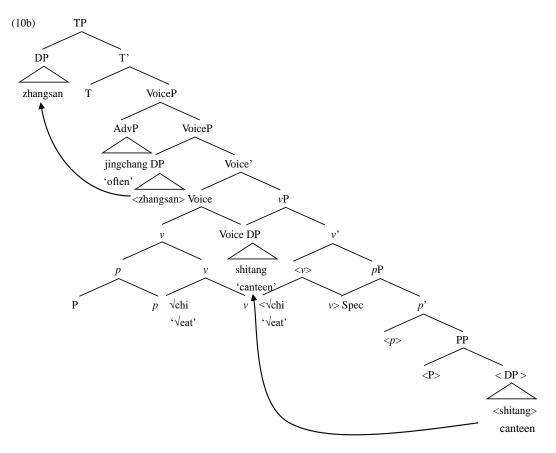
In this section, an account will be provided for the NOC based on the transitivity of verbs: a) transitive verbs such as *chi* 'eat' in *chi shitang* 'to eat at the canteen' (literally: eat canteen) and b) unergative verbs such as *fei* 'fly' in *fei Shanghai* 'to fly to Shanghai' (literally: fly Shanghai) can enter the NOC, while unaccusative verbs such as *lai* 'come', *qu* 'go', *si* 'die', etc. can never be followed by a non-canonical object. The reason why a mixture of direct object properties and PP object properties existing in the NOC will be explicated.

First, transitive verbs such as *chi* 'eat' in *chi shitang* 'to eat at the canteen' (literally: eat canteen) will be examined as a case study in (10).

(10) a. Zhangsan jingchang chi shitang.

Zhangsan often eat canteen

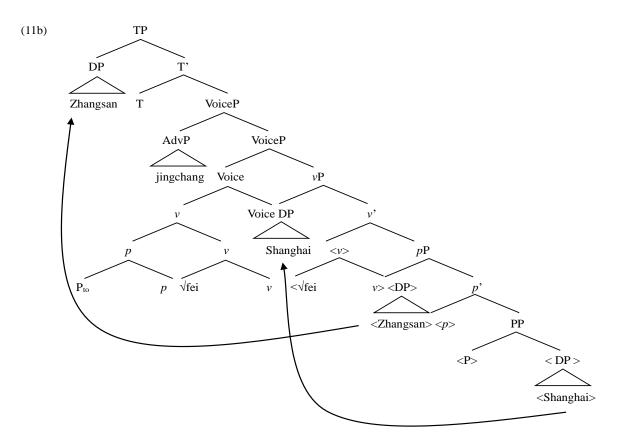
'Zhangsan often eats at the canteen.'



In (10), VoiceP is a phase in that it constitutes a complete propositional structure. The key difference between the transitive construction and the intransitive one lies in the presence of external-argument-introducing Voice, which introduces an external argument. This gives rise to the consequence that phi-features from both transitive Voice and the incorporated p can be inherited by v, which attracts and licenses the internal argument *shitang* into Spec-vP. Assuming a null preposition P in (10) in line with Cheng (2009) and the nominal phrase shitang 'canteen' is merged with it, forming a PP. The resulting PP is merged with a light p to form p'. Then p' is projected into a pP. The verbalizing head is the head v, which categorizes the root (Marantz 1998). The root is syntactically an adjunct, modifying the event denoted by v (Marantz, 2007, 2008; Wood, 2012). The verbalizing head v is distinct from the head that introduces external arguments (Harley, 2006), which is here labeled Voice after Kratzer (1996). Phi-features are inherited by v from the phase head Voice (Chomsky, 2008) in transitive structures, licensing the direct object and attracting it to its specifier. P-to-*p*-to-*v* movement is given rise to by the need for P to incorporate into the verb. The Head Movement Constraint (Travis, 1984) says that the P head cannot raise directly to v skipping p. In this way, v inherits phi-licensing capacities of p in that p ends up in the same complex head as v. This is an updating edition of Baker's (1988, p. 64) Government Transparency Corollary, which says a lexical category has an item incorporated into it governs everything which the incorporated item governed in its original structural position. Thus, the non-canonical object following the transitive verbs is the complement of the verb. Hence, it is v that licenses the non-canonical argument shitang 'canteen', which is attracted to the position of Spec-vP following the proposal that a specifier position in the verbal domain is occupied by direct objects (Pesetsky, 1989; Johnson, 1991). Finally, the complex head  $P+p+\sqrt{fei}$  ( $\sqrt{fly}$ )+ $\nu$  moves to Voice with the standard short verb movement. The AdvP jingchang 'ofen' adjoins to VoiceP as an adjunct of it. The external argument Zhangsan is introduced by Voice. The VoiceP in (10b) is subsequently merged with T, which agrees (invisibly) with and assigns nominative Case to the subject Zhangsan. T has an EPP feature which triggers to raise of the subject Zhangsan to Spec-T. Merging TP with a null declarative C forms the CP to finish the whole derivation.

Second, unergative verbs such as *fei* 'fly' in *fei Shanghai* 'to fly to Shanghai' (literally: fly Shanghai) will be discussed in (11).

(11) a. Zhangsan jingchang fei Shanghai.
Zhangsan often fly Shanghai
'Zhangsan often flies to Shanghai'



In (11), the Goal argument *Shanghai* has a mixture of direct object properties and PP object properties. The pP is a phase in that it constitutes a complete propositional structure. First, the nominal phrase Shanghai is merged with a null preposition P, forming a PP. Then the resulting PP is merged with a light p to form p'. The p' is merged with the DP Zhangsan forming a pP. In light of Svenonius (2003, 2007), the functional head p introduces the theme argument Zhangsan and the Goal argument Shanghai is also phi-licensed by p. The head v categorizes the root functioning as the verbalizing head (Marantz, 1998). The root modifies the event denoted by v functioning as an adjunct syntactically (Marantz, 2007, 2008; Wood, 2012). The head v is distinct from Voice (Kratzer, 1996), which is the head that introduces external arguments (Harley, 2006). In transitive structures, phi-features from the phase head Voice are inherited by the head v (Chomsky, 2008), the direct object is licensed and attracted to its specifier by Voice. In unaccusative structures, this is usually impossible in that the Voice head in such structures has no phi-features. T P-to-p-to-v movement is caused by the need for P to incorporate into the verb. In light of the Head Movement Constraint (Travis, 1984), the head P cannot raise directly to v skipping p. In this way, the original phase p is extended into v. This gives rise to two consequences. Firstly, v inherits phi-licensing capacities of p in that p ends up in the same complex head as v, which is an updating edition of Baker's (1988) Government Transparency Corollary. Hence, the goal argument Shanghai is licensed by the head v, and so Shanghai is attracted to Spec-vP following the proposal that a specifier position in the verbal domain is taken up by direct objects (Pesetsky, 1989; Johnson, 1991). The second consequence of P-to-p-to-v movement Shanghai can raise to Spec-vP over Zhangsan without inducing a minimality violation in that the pP phase is extended. Finally, the complex head  $P+p+\sqrt{fei}$  ( $\sqrt{fly}$ )+v moves to Voice with standard short verb movement and T has an EPP feature which triggers the raising of the subject Zhangsan to Spec-T. Merging TP with a null declarative C forms the CP to finish the whole derivation.

#### V. CONCLUSION

In this paper, the derivation of the NOC in Mandarin Chinese is explored by applying the phase theory and the phase extension theory. In light of the transitivity of verbs, the NOC can be divided into two categories: a) the NOC with transitive verbs such as *chi* 'eat' in *chi shitang* 'to eat at the canteen' (literally: eat canteen) and b) the NOC with unergative verbs such as *fei* 'fly' in *fei Shanghai* 'to fly to Shanghai' (literally: fly Shanghai). Unaccusative verbs such as *lai* 'come', *qu* 'go', *si* 'die', etc. can never enter the NOC. In a), VoiceP functions as a phase and P-to-*p*-to-*v* movement is caused by the need for P to incorporate into the verb. Thus, *shitang* 'canteen' is attracted to Spec-*v*P and *v* licenses the non-canonical argument *shitang* 'canteen'. In b), *p*P is a phase and then it is extended by way of P-to-*p*-to-*v* movement and *Shanghai* raises to Spec-*v*P. In this way, a mixture of direct object properties and PP object properties can be explained in that the non-canonical object is licensed by both the preposition and the verb.

# ACKNOWLEDGEMENTS

This paper is funded by Chongqing Social Sciences Planning (Ph.D.) Project "A Study on the Generation of Chinese Non-canonical Object Constructions under the Framework of Generative Constructivism" under Grant No. 2021BS030 and by 2020 Western Project of National Social Sciences Fund of China "Reuven Tsur's Theory of Cognitive Poetics" under Grant No. 20XWW001.

#### REFERENCES

- [1] Baker, M. (1988). Incorporation: A Theory of Grammatical Function Changing. Chicago: University of Chicago Press.
- [2] Barrie, M. & Y.-H. A. Li. (2015). Analysis versus synthesis: objects. In Y.-H. A. Li., A. Simpson & Wei-Tien Dylan Tsai (Eds.). Chinese Syntax in a Cross-linguistic Perspective, 179-206. Oxford: Oxford University Press.
- [3] Bošković, Ž. (2014). Now I'm a phase, now I'm not a phase: On the variability of phases with extraction and ellipsis. *Linguistic inquiry*, 45 (1), 27-89.
- [4] Carnie, A. (2013). Syntax: A Generative Introduction (3rd ed.). Chichester: John Wiley & Sons.
- [5] Chen, Zhe & Yafei Li. (2016). Looking at vP from the Chinese perspective. *Foreign Language Teaching and Research 4*, 483-497.
- [6] Cheng, Jie. (2009). The Null Preposition Hypothesis and the applicative construction: A syntactic study of the post-intransitive-verb non-core arguments. *Modern Foreign Languages* (1): 23-32.
- [7] Chomsky, N. (1986). Barriers. Cambridge: MIT Press.
- [8] Chomsky, N. (2000). Minimalist inquiries: The framework//Martin, R., Michaels, D. & J. Uriagereka. Step by Step: Minimalist Essays in Honor of Howard Lasnik. Cambridge, Mass: MIT Press, 89-155.
- [9] Chomsky, N. (2001). Derivation by phase. In Kenstowicz, M (ed.) *Ken Hale: A life in language*. Cambridge, Mass: MIT Press, 1-52.
- [10] Chomsky, N. (2004). Beyond explanatory adequacy//Belletti, A. Structures and Beyond-The Cartography of Syntactic Structure vol 3. Oxford: OUP, 104-131.
- [11] Chomsky, N. (2007). Approaching UG from below//Sauerland, U.&H-M. Gärtner. *Interfaces+Recursion=Languages*? New York: Mouton de Gruter, 1-29.
- [12] Chomsky, N. (2008) On phases. In Freidin. R., Otero, C. & M. L. Zubizaretta (Eds.). *Foundational Issues in Linguistic Theory*, 133-166. Cambridge, MA: MIT Press.
- [13] Chomsky, N. (2013) Problems of projection. Lingua 130: 33-49.
- [14] Deng, Haoxi. (2014). Differences between constructions with post-verbal non-core element and the Applicative constructions in Bantu languages. *Language Teaching and Research* 6: 54-64.
- [15] Feng Shengli. (2005). Light Verb Movement in Modern and Classical Chinese. Language Science (1): 3-16.
- [16] Guo, Jimao. (1999). A Tentative Study on "fei Shanghai" (Flying Shanghai) and other intransitive verbs with object phenomenon. *Studies of the Chinese Language* (5): 337-346.
- [17] Han, Jingquan & Mengmeng Xu. (2014). A phase-based approach to the derivation of the oblique object construction in Mandarin Chinese. *Journal of Central South University (Social Science)* (2): 243-247.
- [18] Harley, H. (2006). The morphology of nominalizations and the syntax of vP. LingBuzz/000434.
- [19] Johnson, K. (1991). Object positions. Natural Language and Linguistic Theory 9 (4), 577-636.
- [20] Kratzer, A. (1996) Severing the external argument from its verb. In J. Rooryck & L. Zaring (Eds.). *Phrase structure and the lexicon*, *33*, 109-137. Dordrecht: Kluwer.
- [21] Lin, T.-H. Jonah. (2001). Light Verb Syntax and the Theory of Phrase Structure. Ph. D. Dissertation, Irvine: University of California.
- [22] Marantz, A. (1998). "No escape from syntax: don't try morphological analysis in the privacy of your own lexicon". *Proceedings of the 1998 Penn Linguistics Colloquium*.
- [23] Marantz, A. (2007). Phases and words. In *Phases in the theory of grammar*, ed. Sook-Hee Choe, Dong-Wee Yang, Yang-Soon Kim, Sung-Hun Kim, and Alec Marantz, 191–222. Seoul: Dong-In Publishing Company.
- [24] Marantz, A. (2008). *Phases and words revisited*. NYU: Seminar Handout.
- [25] Pesetsky, D. (1989) Language-particular processes and the Earliness Principle. Handout, GLOW 1989.
- [26] Sun, Tianqi. (2009). On Oblique Objects in Chinese. Chinese Language Learning 3: 70-77.
- [27] Sun, Tianqi. (2010). A Study on the License Pattern and Mechanism of Non-canonical arguments. Ph.D. Dissertation, Peking University.
- [28] Sun, Tianqi. (2011). A Review of Research on Object Selection in Mandarin Chinese. Chinese Language Learning 3, 71-81.
- [29] Sun, Tianqi. (2019). A Study on the Realization Pattern and License Mechanism of Non-canonical arguments in Modern Chinese. Shanghai: Chinese and Western Book Company.
- [30] Sun, Tianqi & Yafei Li. (2010). Licensing non-canonical arguments in Chinese. Studies of the Chinese Language 1, 21-33.
- [31] Sun, Tianqi & Yafei Li. (2020). An Analysis on the Mechanism of Oblique Object Constructions in Chinese: The Monosyllabic Constraint and the "Bare Root" Theory. *Contemporary Linguistics* 2, 199-216.
- [32] Svenonius, P. (2003). Limits on P: filling in holes vs. falling in holes. Nordlyd 31: 431–445.
- [33] Svenonius, P. (2007). Adpositions, particles and the arguments they introduce. In E. Reuland, T. Bhattacharya & Giorgos Spathas (Eds.). *Argument structure*, 63–103. Philadelphia: John Benhamins.
- [34] Travis, L. (1984). Parameters and effects of word order variation. Ph.D. Thesis, MIT.
- [35] Wood, J. (2012). Icelandic morphosyntax and argument structure. Ph.D. Thesis, New York: NYU.
- [36] Xing, Fuyi. (1991). Observation on the phenomenon of object substitution of Mandarin Chinese. *The World Chinese Teaching* (2): 76-84.
- [37] Yang, Daran. (2021). The Variability of the Realization of Chinese Arguments. Beijing: Science Press.

- [38] Yang, Yongzhong. (2007a). On the Pragmatic Motivation of Vi.+NP Construction. Chinese Journal (1): 58-65.
- [39] Yang, Yongzhong. (2007b). The Syntactic Status of NP in Vi+NP. Language Research (2): 59-64.
- [40] Yang, Yongzhong. (2009). A parametric approach to the typology of non-patient objects. *Modern Foreign Languages (1)*: 33-41.
- [41] Zhu, Dexi. (1982). Grammatical Lecture. Beijing: Commercial Press.

**Haojie Li** was born in Shandong, China in 1974. He received his Ph.D. degree at Guangdong University of Foreign Studies, China. He is currently a lecturer at the School of Foreign Languages, Southwest University of Political Science and Law, Chongqing, China. His research interests include syntax and theoretical linguistics. He has published a number of papers in his areas of expertise, which have appeared in scholarly publications in China and Europe.

**Tongde Zhang** is the corresponding author of this paper, who was born in Shandong, China in 1978. He received his Ph.D. degree at Guangdong University of Foreign Studies, China. He is currently a lecturer at the Department of English Education, East China University of Technology, Fuzhou, Jiangxi, China. His research interests include cognitive poetics, comparative cultural studies, foreign literature theory and methodology. He has published a number of papers both at home and abroad. E-mail: 200961015@ecut.edu.cn