Article

Cognitive linguistic analysis of spatial verbs in "Zuo Zhuan" and exploration of the spatiotemporal relationship bioinformatically

Jia Xu

School of General Education, Hunan University of Information Technology, Changsha 410151, China; 18570613766@139.com

Abstract: In recent years, the digitalization of ancient books has revitalized traditional works and highlighted the "humanistic" dimension of digitalization. This article employs the SikuBERT pre-training model, which is tailored for natural language processing in classical Chinese texts, and forges an innovative connection with the realm of biomechanics, to conduct a comprehensive analysis of spatial verbs in the pre-Qin dynasty text *Zuo Zhuan*. The analysis encompasses detailed annotation, quantitative analysis, automatic recognition, and evaluation of spatial verbs, culminating in the creation of a digital knowledge base for spatial verbs in *Zuo Zhuan*. The study identifies four main types of high-frequency spatial verbs in *Zuo Zhuan*: Motion, state, existence, and direction. To enhance theoretical depth, this classification is grounded in cognitive linguistic theory, which explains the semantic connotations and cognitive basis of each verb type. Motion verbs, are closely linked to the representation of dynamic spatiotemporal contexts, particularly in describing human movement patterns and behaviors, invoking principles from biomechanics such as kinematics and dynamics. These verbs can be integrated with biomechanical concepts like trajectory analysis and mechanical models to understand how ancient humans engaged in dynamic activities within specific spaces. State and existence verbs emphasize static relationships, while directional verbs highlight the guiding nature of movement trajectories, which can be further explored through concepts of displacement and velocity in biomechanics. These verb types interact to construct the spatiotemporal framework of the text, demonstrating how language encodes complex spatial and temporal relationships. Moreover, the study investigates the interactive mechanisms of the four verb types in language use, analyzing how they collectively construct the spatiotemporal context of ancient texts, thereby enhancing our understanding of narrative techniques in pre-Qin literature. For instance, motion verbs often act as the primary drivers of narrative progression, while state verbs provide contextual stability, existence verbs denote presence, and directional verbs guide interpretative focus. Quantitatively, the study examines the characteristics of these verbs from three dimensions: temporal-quantitative relations, behavioral-quantitative relations, and scene-component relations. The findings reveal distinct quantitative features among the four types, with motion verbs exhibiting the highest diversity and quantity. This nuanced exploration not only contributes to the re-interpretation of pre-Qin dynasty texts but also strengthens the ability to deconstruct and analyze digitalized texts from this period, thereby advancing the field of classical Chinese digital humanities. By integrating a biomechanical perspective, this study further explores the application of spatial verbs in describing human movement behaviors, utilizing biomechanical models to analyze the efficiency and postural changes of ancient humans in specific environments, revealing the deep connections between language expression and human activity. This interdisciplinary perspective enriches our understanding of ancient culture and provides a new methodological framework for research in modern humanities.

Keywords: digital humanities; *Zuo Zhuan*; spatial verbs; quantitative features

1. Introduction

Digital humanities integrates computer technology into humanities research, primarily leveraging a series of intelligent processing techniques such as automatic recognition, entity annotation, and visualization to rejuvenate the humanities disciplines and break the monotony of traditional humanities research. Since the 20th National Congress of the Communist Party of China, the academic community's enthusiasm for innovatively inheriting China's excellent traditional culture has continued to rise. Ancient books, as crucial carriers of China's excellent traditional culture, possess immense social value and occupy a significant position in world culture [1,2]. The research boom in the application of digital humanities in the study of ancient Chinese classics has been escalating. Domestic scholars have utilized humanities information technology to construct relevant ancient book knowledge bases. Gao and Wu [3] focused on the "Biographies of Records of the Historian", conducting automatic annotation, manual proofreading, and manual annotation of entity information to create a multi-layered, high-quality digital humanities knowledge base. Gou [4] employed the SikuBERT pre-trained model to construct an animal named entity recognition model for ancient books, aiming to provide an effective method for animal knowledge in ancient books. Guan [5] explored the annotation, organization, and thematic mining of quoted books in *Zuo Zhuan* from a computational humanities perspective on quoted books in ancient books. Huang [6] mainly focused on automatic construction methods for ancient poetry knowledge bases, building an imagery database of *Complete Tang Poems* and analyzing the distribution patterns of imagery. From this perspective, since 2020, many scholars have begun to prioritize research on the digitization of ancient books. Researchers have obtained digitally structured texts through automatic annotation, automatic word segmentation, and automatic extraction of the original texts of ancient books. However, there is a general lack of close integration with humanities disciplines such as history, literature, and linguistics. The digitally structured texts of ancient books have not been integrated into the humanistic spiritual world, presenting a one-dimensional characteristic of digital research on ancient books [7,8]. As the birthplace of China's traditional excellent culture, pre-Qin ancient books laid a solid foundation for the socio-cultural development of China for over two thousand years. *Zuo Zhuan* is an important document for studying pre-Qin history, covering various aspects of the internal affairs, diplomacy, military, economy, and culture of various vassal states. It is the first large-scale narrative work in China and represents the highest achievements of pre-Qin historiography and literature, possessing high research value. The academic community has achieved relevant results in studying verbs in *Zuo Zhuan.* Most studies start with verb structures, such as Lin et al.'s [9] research on directional serial verb constructions in *Zuo Zhuan,* Elakkiya's [10] summarization of verbs that can function as adverbials in *Zuo Zhuan*, and Liu's [11] investigation of serial verb construction types and their assembly functions in *Zuo Zhuan.* An overview of existing research reveals that the academic community has paid less attention to the types and quantitative characteristics of spatial verbs in *Zuo Zhuan.* This paper employs the Siku-BERT pre-trained model to explore the main types and characteristics of spatial verbs in *Zuo Zhuan,*with the aim to provide a

reference for further promoting the humanistic turn in the digitization of pre-Qin classics.

2. Model selection and research framework

For intelligent study on ancient writings, this paper uses the SikuBERT model, which was created by a team at Nanjing Agricultural University's College of Information Management under the direction of Professor Wang Dongbo. The Wenyuange Edition of the Siku Quanshu (Four Treasuries of the Imperial Library) in its whole is chosen as the pre-training corpus for this model. The team proceeds with training, naming the trained models SikuBERT and SikuRoBERTa, respectively, building on the pre-trained models BERT and RoBERTa. These make up the Siku Quanshu's pre-training models. The *Zuo Zhuan* (Commentary of Zuo) serves as the basis for the creation of downstream activities, and the GuwenBERT pre-training model is presented for performance comparison of downstream tasks. Through performance validation of several pre-training models across four different ancient Chinese text tasks, the results demonstrate that the SikuBERT and SikuRoBERTa pre-training models proposed by Professor Wang's team can effectively enhance the processing of ancient Chinese corpora, benefiting the study of ancient Chinese NLP and facilitating the work of researchers in library and information science, philology, history, and related disciplines. Based on this, the paper utilizes the SikuBERT model to train the original corpus of the *Zuo Zhuan* through part-of-speech tagging, constructing a spatial verb digital knowledge base for the pre-Qin classic *Zuo Zhuan*.

Figure 1 shows an illustration of the study framework. Data integration, part-of-speech tagging, annotation list, and outcome evaluation are sequentially applied to the corpus. In order to create the spatial verb digital knowledge base for the *Zuo Zhuan*, it then successively moves into the SikuBERT model training and assessment process through character, word, and segment embedding.
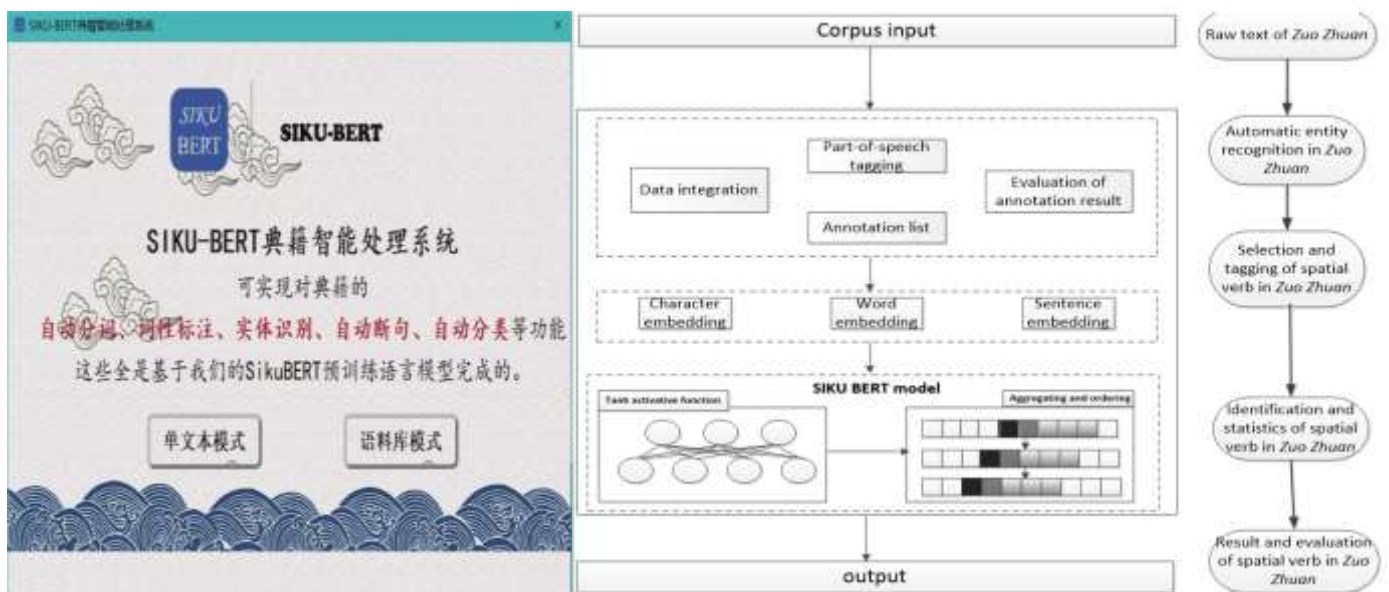

Figure 1. Research framework for the construction of a digital knowledge base of spatial verbs in *Zuo Zhuan*.

3. Construction of the spatial verb digital knowledge base for the *Zuo Zhuan*

3.1. Selection of the *Zuo Zhuan* corpus

This paper selects the original text of the *Zuo Zhuan* from the *Commentaries on the Thirteen* as the corpus source and research object. The entire book, totaling 220,000 characters, is the first chronological history of China. Its historical records begin in the first year of Duke Yin of Lu (722 BC) and end in the twenty-seventh year of Duke Ai of Lu (468 BC). It not only documents the historical facts of the Spring and Autumn period but also contains a wealth of ancient ceremonial and historical materials, making it a classic encyclopedia of Spring and Autumn culture. The Jingxue Tonglun Chunqiu (Comprehensive Treatise on Confucian Classics—Spring and Autumn) comments: "Zuo's narrative skill is exquisite and rich in literary talent. Even if evaluated solely as history, it surpasses Sima Qian and Ban Gu. It does not need to rely on the classics and stands alone through the ages. Its comprehensive and holistic historical perspective has always been highly praised by outstanding historians and is a masterpiece of pre-Qin historiography. In addition, its narratives are complete and tightly written, creating vivid characters through lively and detailed descriptions. It portrays complex wars with intricate and distinctive writing styles, making them full of twists and turns. It is a literary masterpiece with immense linguistic charm. The elegant, rustic, meticulous, and vivid writing style of the *Zuo Zhuan* has become an inexhaustible source for later writers and is an outstanding narrative prose work of the pre-Qin period".

3.2. Extraction and identification of spatial verbs in *Zuo Zhuan*

Zuo Zhuan is not only a historical work but also an outstanding literary masterpiece, adept at depicting dynamic events such as wars, diplomacy, and character stories. It abounds with verbs and verb phrases, which are diverse in type. According to statistics by Shi [12], verb predicates account for 92% of the main predicates, far exceeding adjectival predicates, nominal predicates, and subject-predicate structural predicates. Based on Su [13], there are 33,727 verb phrases in *Zuo Zhuan*, accounting for 85.29% of all natural phrases in the book. From a cognitive spatial perspective, emphasis is placed on the spatial concepts formed when the cognitive subject's perceptual system enters physical space. Cognitive space mainly includes two parts: Spatial relations and spatial regions, with verbs serving as crucial expressions that facilitate spatial relations. Spatial verbs, a special category of verbs, refer to those that exhibit certain actions or states and occupy space [14]. However, the academic classification of Chinese spatial verbs is solely based on their spatiality, dividing them into spatial and non-spatial verbs, without elaborating on the specific types of spatial verbs [15]. This paper attempts to automatically identify and extract spatial verbs in *Zuo Zhuan* using the SikuBERT pre-trained model through five main steps.

(1) Getting spatial verbs' semantic representations. To create a Chinese sequence, *Zuo Zhuan*'s text is fed into the SikuBERT pre-trained model in character units. In order to further construct word vectors and get document vectors, the model

automatically combines the numerical sequence of each character in the vocabulary by utilizing its bidirectional encoding feature. It creates composite vectors to make the subsequent extraction of spatial verbs easier by skillfully merging the position and part of speech of words in the text.

(2) Data preprocessing. The source text of *Zuo Zhuan* is cleaned, including the removal of numbers, symbols, punctuation, and stop words, to better train the model and extract keywords.

(3) Calculating similarity. The BERT-based Tokenizer method first segments and encodes the source text of *Zuo Zhuan* to generate numerical embeddings. These embeddings are input into a sequence labeling model for training. By employing the cosine similarity algorithm, the similarity between word vectors and document vectors is calculated sequentially, arranged in descending order, to obtain the similarity of different types of spatial verbs and extract high-frequency keywords (as shown in **Figure 2**).

(4) Constructing an encoding function. Based on the calculated similarity, verbs are grouped according to their similarity, and an encoding function is constructed such that similar spatial verbs have similar encodings.

(5) Applying the encoding. When training the BERT model, similar verbs can be encoded into similar vectors or matrices, allowing the model to better capture the semantic relationships between spatial verbs.

Figure 2. Screenshot of the automatic identification interface for spatial verbs "enter" (入) and "love" (爱).

3.3. Result analysis and testing

In this experiment, there are 128 kinds of spatial verbs were identified in *Zuo Zhuan*. These spatial verbs frequently appear in different spatial events. After further statistical classification, it was found that the spatial verbs in *Zuo Zhuan* mainly exist in the following four types of spatial events:

Table 1. Types and examples of spatial events in *Zuo Zhuan*.

Type of Event	Example of Event	Type Code	Example of Semantic Attribute	Main Spatial Verb
Spatial Event of Motion	"Upon entering, he recited: 'In the great tunnel, we are joyful and harmonious'"! (The first year of Duke Yin's time) 公入而赋: "大隧之中, 齐乐也融融"! (隐公•元年)	MOTION = 1	if verb_type == MOTION: Encoded [0] = 1 encoded [1] = 1 encoded [2] = 1 encoded [3] = 0.5	enter (入), arrive (及), return (归), passt through (通), approach (临), go (往), move (行), come (来), return (还), send (送), chase (逐), etc.
Spatial Event of State	"He loved Gongshu Duan and wanted to establish him as the heir or in a position of authority". (The first year of Duke Yin's time) 爱公叔段, 欲立之. (隐公•元年)	STATE = 2	elif verb_type == STATE: Encoded [0] = 1 encoded [1] = 0.5 encoded [2] = 0 encoded [3] = 0.5	surprise (惊), hate (恶), love (爱), cry (哭), resent (怨), like (好), regret (悔), etc.
Spatial Event of Existence	Gongzi Hu of Zheng was at Zhou's court as a hostage. Marquis Chen wished to marry out his daughter to him. (The seventh year of Duke Yin's time) 郑公子忽在王所, 故陈侯请妻之. (隐公•七年)	EXISTENCE = 3	elif verb_type == EXISTENCE: Encoded [0] = 0 encoded [1] = 0 encoded [2] = 0 encoded [3] = 0.5	be (在), have (有), live (居), stand (立), get (得), place (置), 存 (exist), etc.
Spatial Event of Direction	At gatherings of the vassal lords, our sovereign has never lagged behind the ruler of Wei in attendance. (The seventh year of Duke Xiang's time) 诸侯之会, 寡君未尝后卫君. (襄公•七年)	ORIENTATION = 4	elif verb_type == ORIENTATION: Encoded [0] = 1 encoded [1] = 0.5 encoded [2] = 1 encoded [3] = 0.5	move forward (前), retreat (后), move to the left (左), move to the right (右), go up (上), go down (下)

According to **Table 1**, there are mainly four types of spatial events in *Zuo Zhuan,* and each type of spatial event is primarily composed of different spatial verbs. The first type is the spatial event of motion, which uses the moving entity as the image and the spatial verbs of motion as the trajectory to determine the spatial displacement of objects. The second type is the spatial event of state, which uses spatial verbs of state as cues to describe the actual or psychological state of the cognitive subject, as the result to construct the state space of the cognitive subject. The third type is the spatial event of existence, which mainly regards the cognitive subject as the figure and the spatial verbs of existence as the background to determine the spatial existence of objects. The fourth type is the spatial event of

direction, which adopts spatial verbs of direction as spatial cues to trace the spatial location of the cognitive subject.

This paper further explores the distribution of spatial verbs behind different types of spatial events. Based on the descending order of similarity, keywords with higher similarity for each type of spatial verb are selected as the final filtered keywords. This study was conducted in a Python 3.7 environment using Pytorch 1.4.0 as the main experimental tool. Experiments began by running the SikuBERT model and setting the relevant hyperparameter data, as shown in **Table 2** below.

Table 2. Experimental hyperparameter settings.

Hyperparameter	Explanation	Value
max_ _seq_ _length	Maximum input sequence length	256
train_ _batch_ size	Size of each batch for training	32
learning_ _rate	Learning rate	2.0E-5
warmup_ _proportion	Warm-up proportion for learning rate	0.4
num_ train_ _epochs	Number of training epochs	3 or 10

It has found that the most numerous and diverse type of spatial verbs in *Zuo Zhuan* are those belonging to the spatial event of motion. Following closely are the spatial verbs of state, which coexist in both physical and psychological spaces. Subsequently, there are the spatial verbs of existence and the spatial verbs of direction. The keywords extracted for each type are ranked in descending order of frequency.

The types of spatial verb keywords in *Zuo Zhuan* are most abundant in the category of spatial verbs of motion, which typically refer to verbs with certain mobility functions. These verbs are mainly used to depict changes in characters' situations across different spaces, such as "go out" (出), "come" (来), and "enter" (入) (as shown in **Figure 3A**). The article primarily selects spatial verbs of motion with a frequency higher than 100 as the main research objects. This category of verbs generally consists of a starting point and an endpoint of motion, expressing the displacement or spatial range of the moving entity. According to **Figure 3B**, the spatial verbs of state in *Zuo Zhuan* mainly include those of reality and those of psychology. Spatial verbs of reality mainly encompass "promise" (许), "unite" (合), "divide" (分) and so on, which often describe scenarios such as conversations and alliances between countries, kings and ministers, or ministers among themselves. Another type of spatial verb of state mainly highlights the psychological state of characters, such as "hate" (恶), "dislike" (疾), "angry" (怒), "like" (好) etc., vividly expressing changes and fluctuations in the psychological space of characters. Although the number of spatial verbs of existence and spatial verbs of direction among the keywords in *Zuo Zhuan* is less than the previous two categories, they are important components of character stories. As shown in **Figure 3C,D**, spatial verbs of existence like "have" (有) and "not have" (无) can accurately depict the process of emergence and disappearance in motion events, while spatial verbs of direction like "lag behind" (后) and "be below" (下) can specify the exact location of motion

events, providing important spatial information for the composition of motion events.
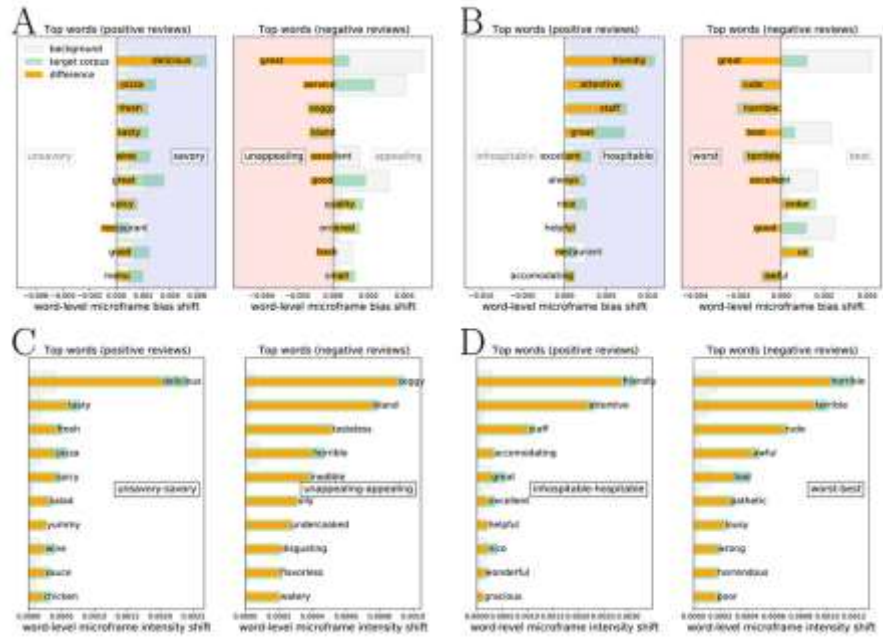

Figure 3. Bar chart of high-frequency keywords for spatial verbs. **(A)** Spatial verb of motion; **(B)** spatial verb of state; **(C)** spatial verb of existence; **(D)** spatial verb of direction.

To evaluate the tokenization and extraction capabilities of the SikuBERT model, the experimental results are typically measured using three evaluation metrics: Precision (P), Recall (R), and the harmonic mean F1-score (F1). These are crucial indicators for assessing a model's performance, and they are usually calculated in the context of binary classification. Precision refers to the proportion of samples predicted as positive (true) by the classifier that are actually positive, i.e., the proportion of samples that are predicted to be positive and are indeed positive. The calculation method is as follows:

$$\text{Precision} = \text{TP/TP} + \text{FP} \times 100\%.$$

In this context, TP stands for True Positive, while FP stands for False Positive. Recall (R) refers to the proportion of all actually positive (true) samples that the classifier correctly predicts as positive, i.e., the proportion of samples that are actually positive and are predicted to be positive. The calculation method is as follows:

$$\text{Recall} = \text{TP/TP} + \text{FN} \times 100\%.$$

In this context, TP represents True Positive, while FN represents False Negative. The F1-score is the harmonic mean of Precision and Recall. The harmonic mean balances Precision and Recall, and therefore, the F1-score is often used as a comprehensive indicator to evaluate the performance of a model. The calculation method is:

$$\text{F1} = 2 \times \text{Precision} \times \text{Recall/(Precision} + \text{Recall)} \times 100\%.$$

Table 3. Evaluation metrics of the Siku-BERT model for four types of spatial verbs.

Type	Precision (%)	Recall (%)	F1 (%)
spatial verb of motion	86.34	88.10	87.21
spatial verb of state	85.46	89.75	87.55
spatial verb of existence	88.76	90.13	89.44
spatial verb of direction	84.59	87.39	85.97

It can be seen in **Table 3** that the SikuBERT pre-trained model is an improvement on the BERT model, with its basic framework adopting a bidirectional transformer encoder structure. The test results demonstrate that the SikuBERT pre-trained model performs well, with F1 scores for the four types of spatial verbs all exceeding 80%. This model maximizes the preservation of the original characteristics of ancient Chinese texts and effectively avoids the impact of tokenization quality on task results.

4. Quantitative characteristics of spatial verbs in *Zuo Zhuan*

For humans to see, understand, and communicate the world, quantity is a crucial category. Both objects and occurrences in the human cognitive environment invariably fall within the "quantity" category. In *Zuo Zhuan*, many spatial verbs are employed to describe various cognitive occurrences that not only occupy a specific space quantity but frequently also occupy a temporal quantity, as well as to represent diverse acts and behaviors. Wei [16] believes that "temporal quantity is a quantity category related to things, events, and properties. Things and properties exist and change within events, and events occur, develop, and end over time. Therefore, to understand and grasp the world, humans cannot do without measuring time from a quantitative perspective". In addition to temporal quantity, behavioral quantity and the relationship between scene components also affect spatial quantity. This section will explore the quantitative characteristics of four types of spatial verbs (motion, state, existence, and direction) in *Zuo Zhuan* from the following three aspects.

4.1. Temporal-quantitative relations

There is a universal and close correspondence between spatial movement and the flow of time [17]. Actions always occupy a certain amount of time, and different types of spatial verbs occupy varying amounts of time.

4.1.1. Example 1 (spatial verb of motion)

a. On the twenty-second day of the sixth month, Duke Zhao of Zheng **entered** to the capital and was on the throne. The duke of Xu **returned** to his own state[1]. (六月乙亥, 昭公入, 许叔入于许.)

b. In winter, Marquis Ji **came to** the state of Lu, begged for an order from King Zhou to make peace with the state of Qi[2]. (冬, 纪侯来朝, 请王命以求成与齐.)

c. On the twenty-third day of the fifth month, Shuduan **fled** again to the state of Gong[3]. (五月辛丑, 大叔出奔公.)

Examples of the first three high-frequency spatial verbs motion (enter, come, and leave) are chosen at random from *Zuo Zhuan* using the Siku-BERT pre-trained

model. Because temporal terms like "on the twenty-second day of the sixth month", "in winter", and "on the twenty-third day of the fifth month" appear in all three sentences, Example 1 demonstrates the strong relationship between spatial verbs of motion and temporal quantity. This suggests that these three categories of spatial verbs of the displacement type are very mobile and occupy a sizable amount of space. Example 1a describes the cognitive subjects (Duke Zhao and Duke Xu) respectively entering the state of Zheng and Xu, with the physical displacement of the cognitive subjects occurring through the application of the spatial verb "enter" (入). Similarly, in Example 1b, the cognitive subject (Duke Ji) comes to Lu from Ji in winter, completing the spatial displacement event of Duke Ji entering Lu to request orders through the displacement-type spatial verb "ru" (to enter).

It is worth mentioning that in Example 1c, the displacement-type spatial verb "出" (to leave/exit) is used in conjunction with "奔" (to flee), a combination of verbs that rarely appears in *Zuo Zhuan*. This is because ancient Chinese is a verb-framed language [18]. That means an individual verb serving as the primary means of encoding entire motion events. The conjunction of "出奔" emphasizes the speed and large spatial displacement of Uncle Tai (son of Duke Wu of Zheng) fleeing out of the city. Therefore, actions with strong mobility expand in spatial quantity as the range of displacement increases. The larger the spatial range of movement, the longer the time required and the greater the temporal quantity occupied.

4.1.2. Example 2 (spatial verb of state)

a. Duke Li sent one messenger to Yuan Fan, his official, said to him: "Any one who helped me to return home without betrayal was endowed with high rank from me. I am willing to **promise** administer government with you, my uncle[4]". (使谓原繁曰: "纳我而无二心者, 吾皆**许**之上大夫之事".)

b. Duke Chu of Zhou **was annoyed** by the pressure from the descendants of Kings Hui and Xiang of Zhou, and at the same time he contended for government power with Bo Yu of loyal house, but he was defeated, **greatly angered** he left his capital[5]. (周公楚**恶**惠, 襄之偪也, 且与伯与争政, 不胜, **怒**而出.)

c. The Zheng's army **united** to attack them, and the royal troops suffered a decisive defeat[6]. (郑师**合**以攻之, 王卒大败.)

The spatial verbs of state mainly refer to changes in the behavioral state of the cognitive subject in *Zuo Zhuan*. They are mainly divided into two categories: Spatial verbs of psychological state (e.g., Example 2a,b) and spatial verbs realistic state (Example 2c). Example 2a mainly depicts the state behavior of the cognitive subject (Duke Li) conveying his firm promise to the cognitive object (Yuan Fan). Specifically, the cognitive subject (Duke Li) sends a messenger to orally inform (the general of Zheng) that as long as the cognitive object (Yuan Fan) agrees to Duke Li's sole dominance, Duke Li solemnly promises to appoint Yuan Fan as the senior minister. The spatial verb of state "promise" (许) is used to express the cognitive subject's firm psychological state of fulfilling the promise, constructing a psychological space from non-existence (no promise) to existence (promising to appoint Yuan Fan as the senior minister). The application of double quotation marks in Example 2a (directly quoting the cognitive subject's original words) shows that

this construction process occurs rapidly and is closely linked to the contextual time of the moment, occupying a small amount of time and being dominated by the immediate context. Similarly, in Example 2b, spatial verb of state "be annoyed" (恶) and "greatly angered" (怒) construct changes in the psychological space of the cognitive subject (Duke Chu of Zhou). The first layer of psychological space is the cognitive subject's (Duke Chu of Zhou) hatred of the coercion by King Hui of Zhou and the Zhou Xiang clan. The word "and" (且) indicates simultaneity, showing how quickly the first layer of psychological space transitions to the second layer, where the cognitive subject (Duke Chu of Zhou) becomes angry due to his failure to secure political power. The amount of time occupied is not extensible and is immediate. Example 2c describes a real-state space of the cognitive subject (the Zheng's army), transitioning from a dispersed state to a consolidated state and defeating the army of the Zhou emperor (the emperor's army was defeated). With the help of the spatial verb of state "unite" (合), the state space of the cognitive subject changes and directly leads to the outcome of the event (victory in the battle). Cause and effect are inseparable, occupying a small and non-extensible amount of time.

4.1.3. Example 3 (spatial verb of existence)

a. Trees on the mountain **show the existence of** the carpenter. The guests **have politeness** and what they should do will be arranged by the host[7]. (山有木, 工则度之; 宾有礼, 主则择之.)

b. Duke Zhuang of Lu made a covenant with the ministers of Qi at the place of ji because **there was no sovereign** in the state of Oi[8]. (公及齐大夫盟于蒇, 齐无君也.)

c. When Duke Hui **was in** the state of Liang, the Duke Liang married his daughter to him[9]. (惠公之在梁也, 梁伯妻之.)

The spatial verbs of existence express the presence, emergence, or disappearance of cognitive entities in specific spaces. In *Zuo Zhuan*, high-frequency spatial verbs of existence primarily describe realistic spaces, and the events occurring in these specific spaces generally last for extended periods, involving substantial amounts of time. As shown in Example 3a, the existential verbal expression "show existence of" and "have" (有) appears twice, depicting two causal clauses respectively. Causal Clause 1: Because there is a lot of timber on the mountain, the craftsman can measure and make utensils. Causal Clause 2: Because the guest is polite, the host will entertain him warmly. The two instances respectively portray two different linguistic spaces: Timber on the mountain (Existential Space 1) and polite guests (Existential Space 2). Neither existential space has specificity or referentiality, and they can generally refer to any mountain with timber and any polite guest. Therefore, they possess temporal extensibility, indicating a substantial amount of time. In contrast to Example 3a, the linguistic spaces in Examples 3b and 3c have specificity and referentiality. However, the occurrence of the two state events (the absence of a ruler in the State of Qi and Duke Hui being in the State of Liang) can also persist for a period of time. A longer duration implies a substantial amount of time.

4.1.4. Example 4 (spatial verb of direction)

a. Marquis Teng argued: "My ancestor was the first diviner of Zhou, and your [Xue's] family is not even of the royal clan. I cannot **go after** you[10]". (滕侯曰: "薛, 庶姓也, 我不可以**后**之".)

b. Marquis Ji (纪) was unable to **submit** to the state of Qi. He would rather hand over his state to his younger brother Ji Ji[11].

c. The people of Chu **give prominence to** the left, so the king of Chu should **be in the left** army[12]. (季梁曰: "楚人**上**左, 君必**左**, 无与王遇".)

Spatial verbs of direction mainly express the relative spatial positional relationships of cognitive subjects. As shown in the three sentences of Example 4, the linguistic constructions containing spatial verbs of direction in *Zuo Zhuan* all have specific cognitive subjects, and they often convey the positional relationship between the cognitive subject and the object through temporal markers (double quotation marks), exhibiting immediacy. For instance, in Example 4a, the cognitive subject (Duke Teng) uses temporal markers (double quotation marks) and the directional spatial verb "go after" (后) to outline the cognitive subject's immediate psychological state: The Xue family belongs to a different surname, while my surname (Duke Teng) is the same as the emperor's, so my feudal reward cannot be placed behind theirs. The cognitive subject subjectively judges their own and the cognitive object's status based on the closeness of their surnames, demonstrating specificity and immediacy. Similarly, Examples 4b and 4c respectively depict the cognitive subject's specific psychological states by using the directional spatial verbs "submit to" (下) and "give prominence to" (上). Example 4b mainly describes the cognitive subject's psychological expectation for the cognitive object (Duke Ji), namely that Duke Ji should not submit to the State of Qi. Example 4c portrays the cognitive subject's (Ji Liang's) psychological state since the people of Chu respect the left, the national army must be among the left army. Spatial verbs of direction mostly describe the cognitive subject's immediate spatial events, lacking extensibility and occupying a small amount of time. It is noteworthy that the linguistic constructions containing directional spatial verbs often shift from literal spatial relationship constructions to metaphorical spatial relationship constructions. In Example 4a, the directional spatial verb "go after" (后) outlines the hierarchical relationship between the trajector (Duke Teng's status) and the landmark (the Xue family's status). Metaphorical spatial constructions mostly express symbolic structures of non-concrete spatial relationships between two abstract things, with directional spatial verbs serving as crucial components of these constructions [18].

4.2. Behavioral-quantitative relations

Motion is measurable, and the prerequisite for measuring an action is that it is divisible and discrete [19]. Behavioral quantitative relation refers to the quantity associated with actions and behaviors. Zheng [20] regards behavioral quantity as momentum, primarily referring to the repetition of actions. Behavioral quantity is often used to measure the number of actions, force, scope of involvement, range of motion, and other quantitative categories associated with actions and behaviors [21].

However, the semantic features and structures of force, scope, and range of motion involved in actions are complex and difficult to define [22]. Due to space limitations, this section primarily considers the frequency quantity (number of repetitions) of spatial verbs and does not discuss the scope and range of actions and behaviors.

4.2.1. Example 5 (spatial verb of motion)

a. After his escape, Duke Qing of Qi **entered the army of Jin three times** in order to seek Feng Choufu[13]. (齐侯免, 求丑父, 三入三出.)

b. The people of Zheng were ready to resist, but Zichan did not agree. He said,"The states of Jin and Chu are about to make peace, and all the states wish to be in accord, This time King Kang makes bold to attack us. The best way is to let him content his desire and **return** in ease[14]". (郑人将御之, 子产曰: "晋, 楚将平, 诸侯将和, 楚王是故昧于**一来**".)

As shown in Example 5, the behavioral quantity of motion verbs is closely related to numerals, and is often described using the paradigm of "numeral-quantifier + spatial verb". In Example 5a, the numeral-quantifier "three" (三) vividly records the three times of Duke Qing of Qi entering and exiting the army of the State of Jin after narrowly escaping capture. The adverb of degree "mei" (every) further emphasizes the high status of Duke Qi, who was highly supported by his own army each time he exited the Jin army, ensuring his safe passage. "One" is the smallest whole number, and "one + V" easily lends an additional connotation of "a small amount" to the verb [23]. Therefore, in Example 5b, "return" (一来) presents an abstracted semantic feature, no longer expressing the number of times but referring to the event of the Duke of Chu invading the State of Jin, with the focus on the verb "return" and the numeral-quantifier "one" being virtualization. Such abstracted expressions of "numeral-quantifier + spatial verb" in *Zuo Zhuan* include "san xun" (三巡), "jiu xian" (九献), etc.

4.2.2. Example 6 (spatial verb of state)

a. When Xie Yang passed through the territory of Zheng he was caughtby Zheng and handed over to the state of Chu. The king of Chu bribed him lavishly towish him to tell the state of Song that Jin would not assist it, but Xie Yang refused.After **urging him three times**, he agreed to do what Chu told him to do[15]. (郑人因而献诸楚, 楚子厚赂之, 使反其言, 不许, 三而许之.)

b. Later Dou Jiao **heavily hated** Wei Jia and aroused the Ruo'ao clan to take Wei Jia into prison at Liaoyang, then killed him there. Dou Jiao was in Zhengye and about to attack the king of Chu. The king let the sons of his three predecessors be hostages, but Dou Jiao refused[16]. (子越又恶之, 乃以若敖氏之族圉伯的赢于轑阳而杀之, 遂处烝野, 将攻王.)

Apart from numerals can express the frequency of spatial verbs, there are also some adverbs preceding spatial verbs that can depict frequency. In *Zuo Zhuan*, the quantity of occurrence of spatial verb of state is mainly outlined by numerals and adverbs. Example 6a describes a situation where the cognitive subject (King of Chu) uses coercion and inducement to force the cognitive object (the messenger of the State of Jin, Xie Yang) to change his original intention and convey false information. In this clause, the adverb "not" (不) and the numeral "three" (三) are used to

construct the behavioral quantity of the spatial verb "accept" (许), vividly depicting the change in attitude of the messenger of the State of Jin, Xie Yang. That is, facing the generous treatment offered by the King of Chu for the first time, Xie Yang did not accept but after the King of Chu proposed it three times, Xie Yang finally agreed. The spatial verb "accept" undergoes a spatial state transition from non-existence to existence, with the numeral "three" playing a role in escalating the situation. Example 6b mainly describes the character of Dou Yuejiao (the son of Dou Ziliang, the Simon of Chu) is a fierce, arrogant, and bloodthirsty person. The adverb "heavily" (又) modifies the spatial verb "hate" (恶), further illustrating the cognitive subject's (Dou Yuejiao's) repeated aversion and abandonment of those around him, conveying the repetitiveness and cyclical nature of the state-space event where the cognitive subject hates the cognitive object.

4.2.3. Example 7 (spatial verb of existence)

a. It says in Shangshu [the Great Declaration]: 'King Zhou **has** millions of people, but they all torn by dissension and discord[17]'. ("大誓" 曰: "纣**有**亿兆夷人, 亦**有**离德".)

b. Evil is produced for government **without** morality and punish **without** sternness. Now evil **has appeared**[18]. (即无德政, 又无威刑, 是以及邪.)

As shown in Example 7, spatial verbs of existence are also frequently used with adverbs "all" (亦, 又, 复) to convey frequency. In Example 7a, the spatial verb "have" (有) establishes an existential space, indicating that the cognitive subject (King Zhou) has billions of people, but also has people who are disloyal and divided. Example 7b mainly discusses the mode of national governance, stating that a country lacks both moral politics and authoritative punishment, leading to the occurrence of evil. The existential spatial verb "wu" (non-existent), enhanced by the adverbs "ji" and "you", constructs a space (country) where morality and authority are absent. Finally, the copula "shi" (is) introduces the result: Evil proliferates, and the people suffer.

It is noteworthy that in *Zuo Zhuan*, there are no expressions of frequency for directional spatial verbs. On the one hand, it indicates that spatial verbs of direction account for a relatively small proportion in *Zuo Zhuan* and are mostly used as adjectives to modify nouns, such as "heaven" (上天), "high-ranking officials" (上大夫), "the lower path" (下道), etc. On the other hand, it also suggests that spatial verbs of direction have a weak behavioral quantity, low action frequency, and are used infrequently.

4.3. Scene-component relations

Space is a crucial means for humans to perceive and express the world, and the scene components within space are important constituents of spatial regions. The three main components involved in spatial scenes outlined by spatial verbs are: Figure, Ground, and Reference Object. These three scene components form different relationships (both static and dynamic) among objects in spatial regions over time. These diverse object relationships are frozen in different spatial regions, resulting in various spatio-temporal expressions. Spatial regions are primarily composed of

locational spatial regions and directional spatial regions, which are constructed by four dimensions: Point, line, plane, and volume. This section mainly discusses the similarities and differences in the scene components of four types of spatial verbs in *Zuo Zhuan* within different spatial regions.

4.3.1. Example 9 (spatial verb of motion)

a. Then he divided his army into two parts, One part **entered** Mengmen Pass and **climbed up** on Taihangshan Mountain where they built a landscape at Yingting[19]. (为二队, 入孟门, 登大行.)

b. (Duke Qing of Qi sent his officials Gao Gu, Yan Ruo, Cai Chao and Nan Guoyan to attend the allied meeting.) When they **arrived** at Lianyu, Gao Gu **fled back** to Qi because he learned that Xi Ke hated Oi[20]. (齐侯使高固, 晏弱, 蔡朝, 南郭偃会及敛盂, 高固**逃归**.)

Spatial verb of motion primarily relies on specific spatial regions, with point regions serving as the spatial background and the moving subject as the main figure within a dynamic space. Example 9a describes the cognitive subject (Duke Qi) leading Qi's army to invade the State of Jin. The displacing subjects are the two divisions of Qi's army, one invading Mengmen of Jin and the other climbing up toTaihangshan Mountain. Therefore, Example 9a occurs within the territory of the State of Jin (a locational spatial region), where **Figure 1** (one division of Qi's army) invades Mengmen (Background 1), and **Figure 4** (the other division of Qi's army) ascends the Daxing Pass (Background 2), both with the territory of Jin as the reference (see **Figure 4**).

Unlike Example 9a, the scene components (figure, ground, and reference object) in the construction of Example 9b undergo a secondary transfer. The background of this sentence is that King Qing of Qi sent four ministers, including Gao Gu, to attend an alliance meeting. When the four arrived at the state of Lianyu, Gao Gu took the initiative to flee back to Qi. As shown in **Figure 4b** below, the figure (moving subject) changes from the four Qi ministers to Gao Gu alone. When Gao Gu temporarily fled back to Qi, the other three ministers became Gao Gu's background, and the reference object also shifted from Qi territory to Lianyu territory.
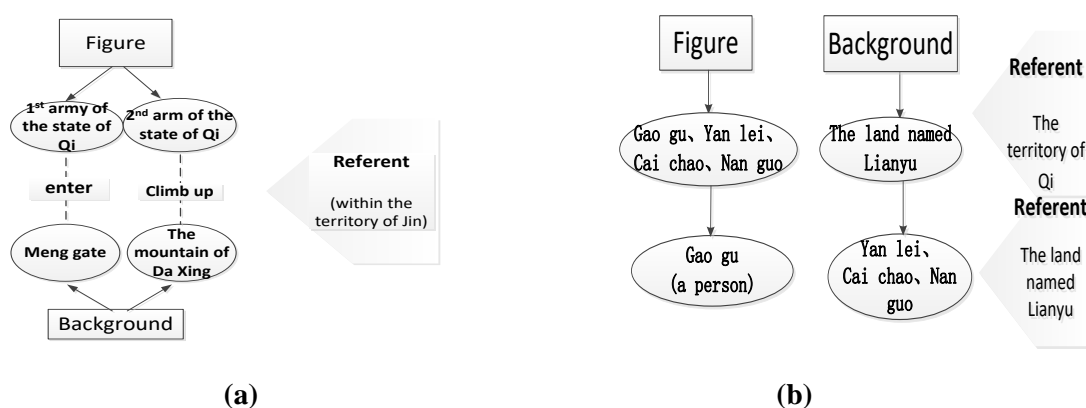

(a)   **(b)**

Figure 4. Transfer path of scene components in displacement-type spatial verbs.

4.3.2. Example 10 (spatial verb of state)

a. So heavy is my crime, how can I escape from punishment so as to **enrage** you? I ask you to send me to the law[21]". (臣之罪重, 敢有不从, 以**怒**君心, 请归死于司寇.)

b. Yili replied: "I serve junzi. He **dislikes** me but I dare not leave him too far; I am **favored** by him but I dare not approach too close. I always obey his order with respect, and how could I dare have two minds[22]"? (小人之事君子也, **恶**之不敢远, **好**之不敢近, 敬以待命, 敢有贰心乎?)

Based on the realis-irrealis distinction in linguistics, spatial verbs can be categorized into realis spatial verbs and irrealis spatial verbs. In *Zuo Zhuan* (a classic Chinese historical text), spatial verbs of state are predominantly irrealis spatial verbs, acting on the psychological space of the cognitive subject. In Example 10a, "enrage" is a psychological emotion verb that connects the figure (Wei Jiang) and the ground (the ruler's heart). The occurrence of this example is based on the cognitive subject's perspective, where Wei Jiang, after killing the driver of the younger brother of the Duke of Jin, voluntarily requested punishment from the Duke. With borders that may touch the ground (the monarch's heart), the emotional state verb "enrage" is spatially embodied, indicating that the driver's death at the hands of Wei Jiang infuriated the ruler. The spatiality of the psychological state verbs "dislike" and "favor" in Example 10b is utilized to gauge the separation between the subject and the ruler. The inferior man cannot be close if the superior man (figure) despises him, and the inferior guy (ground) cannot be far away if the superior man likes him. The geographical embodiment of psychological state verbs constructs both proximity and distance. State spaces are primarily produced by the distance space (linear space) of psychological proximity, as opposed to body-space scenes, which are constructed by displacement spatial verbs.

4.3.3. Example 11 (spatial verb of existence)

a. The army of Jin **stationed** between the two mountains of Aoshan and Qiaoshan[23]. (晋师**在**敖, 鄗之间.)

b. The people **had** their houses to live alive and temples after death, and the animals **had** luxuriant fodder to eat and places to rest, The people and the beasts lived in harmony and did not disturb each other[24]. (民**有**寝庙, 兽**有**茂草, 各**有**攸处, 德用不扰.)

Spatial verbs of existence primarily rely on spatial existential references, using the existent as the figure, the existential space as the ground, and the existential spatial verb as the link to connect the figure and the ground, thereby constructing a static existential spatial area. As shown in Example 11a, the existential spatial verb "station" serves as the link to construct the existential space where the army of the State of Jin (figure) is stationed between the mountains of Ao and Hao (ground). Similarly, in Example 11b, the existential spatial verb "have" outlines two existential spaces: The first existential space is where the people (**Figure 1**) have dwellings and ancestral temples (ground 1), and the second existential space is where wild animals (**Figure 2**) have lush grass (ground 2). These two existential spaces are independent of each other and remain relatively static without specific reference frames in the

short term. Spatial verbs of existence primarily construct main space through three-dimensional backgrounds and figures.

4.3.4. Example 12 (spatial verb of direction)

a. The crown prince said:"In chariot I have saved your life and on the ground I defeated the enemy. My merit **is at the top of all the right guards**[25]". (大子曰: "吾救主于车, 退敌于下, 我**右**之上也".)

b. I cannot compare Han Qi but he **recommended** Zhao Wu, I beg you to listen him[26]. (臣不如韩起, 韩起愿上赵武, 君其听之.)

Spatial verbs of direction adopt spatial orientation as a reference and primarily outline the positional relationship between the figure and the ground. In Example 12a, Duke Jingkui (the figure) establishes himself as the most meritorious warrior on the right side of the ruler's chariot based on specific deeds (saving the ruler on the chariot and repelling enemy soldiers off the chariot), using the ruler's chariot as the ground. With the ruler's chariot as the reference and other warriors as the background, the directional spatial verb "be in the right" connects the cognitive subject Jingkui (the figure) and the background (other warriors on the right side of the chariot). Through this spatial orientation, Jingkui confirms that he has achieved the greatest deeds among the warriors on the right side of the ruler's chariot. Directional spatial verbs primarily construct the plane space of the scene through three-dimensional backgrounds and figures.

By analyzing the quantitative category characteristics of four high-frequency types of spatial verbs in *Zuo Zhuan*, it is found that there are varying degrees of relationship between different types of spatial verbs. As shown in **Table 4**, spatial verbs of motion exhibit a high degree of quantitative category and have a close relationship with temporal quantity, with the size of displacement space being directly proportional to temporal quantity. They can also express behavioral quantity with the help of numerals, and the figures and backgrounds mainly constitute a three-dimensional displacement space. Spatial verbs of state have a slightly lower degree of quantitative category and occupy a non-extendable amount of temporal quantity, exhibiting immediacy. They can convey the frequency of behavioral quantity with numerals and degree adverbs, and the degree of behavioral quantity is relatively high. The figures construct distance spaces of varying proximity (one-dimensional linear space). Spatial verbs of existence have a high degree of quantitative category and are generally used in conjunction with time periods, occupying a larger amount of temporal quantity. They can form three-dimensional spaces with figures but mostly use adverbs to express the frequency of these verbs. Spatial verbs of direction have a lower degree of quantitative category and are not frequently used in *Zuo Zhuan*. They mostly describe immediate spatial events of the cognitive subject and lack extensibility, occupying a small amount of temporal quantity. There is currently no expression of behavioral quantity relationships, and they commonly construct a two-dimensional planar space of the scene with figures and backgrounds.

Table 4. Degree of quantity category of the four types of spatial verbs in *Zuo Zhuan*.

	Spatial verb of motion	Spatial verb of state	Spatial verb of existence	Spatial verb of direction
Temporal-quantitative relation	+++	+	+++	+
Behavioral-quantitative relations	++	+++	+	null
Scene-component relations (Point-Line-Plane-Volume)	+++ Three-Dimensional Space	+ One-Dimensional Linear Space	+++ Three-Dimensional Space	++ Two-Dimensional Planar Space

5. Conclusion

Verbs are one of the key parts of speech in ancient Chinese. By examining spatial verbs in "*Zuo Zhuan*" as the research object, this study focuses on verbs with spatial attributes in ancient Chinese. Utilizing the SikuBERT pre-training model—a natural language processing model tailored for ancient Chinese—a digital knowledge base of spatial verbs in "*Zuo Zhuan*" was constructed through a systematic process, including corpus selection, automatic entity recognition, spatial verb extraction and annotation, and spatial verb identification and statistical analysis.

The results reveal that "*Zuo Zhuan*" predominantly includes four types of high-frequency spatial verbs: Motion, state, existence, and direction. Among these, spatial verbs of motion and state are the most widely distributed and diverse in types. A comparative analysis of the four types of spatial verbs highlights their distinct relationships with temporal quantity, behavioral quantity, and scene components. Spatial verbs of motion exhibit the highest degree of quantitative categorization, followed by existence spatial verbs, state spatial verbs, and finally directional spatial verbs. These findings indicate that the four types of spatial verbs play different roles in constructing sentence meaning and demonstrate a basic quantitative system within pre-Qin classics, with varying degrees of prominence across the types.

To improve the practicality of these conclusions, the study explores potential applications of the findings in modern contexts. For instance, the quantitative categorization of spatial verbs could enhance the precision of modern language teaching by deepening learners' understanding of the semantic and syntactic functions of verbs in ancient texts. Additionally, the structured knowledge base and annotated corpus of spatial verbs provide valuable resources for advancing machine translation systems, particularly for improving the translation of classical Chinese texts into modern languages. Moreover, the insights into verb functionality and their spatial-temporal roles could support the development of algorithms for automatic text interpretation, thereby bridging ancient linguistic research and contemporary language processing technologies.

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Notes

1. Zuo Qiuming (author), Luo Zhiye (translator) *Zuo Zhuan* [M]- Nanjing: Southeast University Press, 2017.1:34.
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