



# The Polysemy and Hyponymy of Mandarin Spatial Prepositions and Localisers: Building Semantic Maps from the Ground up

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### Specialty section:

This article was submitted to  
Language Sciences,  
a section of the journal  
Frontiers in Communication

**Received:** 12 June 2021

**Accepted:** 10 November 2021

**Published:** 08 December 2021

### Citation:

Ursini F-A, Rao Q and Zhang YS (2021)  
The Polysemy and Hyponymy of  
Mandarin Spatial Prepositions and  
Localisers: Building Semantic Maps  
from the Ground up.  
Front. Commun. 6:724143.  
doi: 10.3389/fcomm.2021.724143

The goal of this paper is to offer an overview of polysemy patterns in Mandarin's chief spatial categories: prepositions (e.g., *zai*) and simple and compound localisers (respectively, *qian* and *qian-mian*). The paper presents data from an elicitation study that shows how speakers can access multiple senses and hyponymy relations for the vocabulary items belonging to these categories. The paper shows that while prepositions can potentially cover different spatial relations in the opportune context (e.g., *zai* "at"), localisers select increasingly specific senses (e.g., *qian* "front" and *qian-mian* "front side"). The paper also shows how speakers can access hyponym-like sense relations emerging from these patterns (e.g., *qian-bian* covering a more specific sense than *qian*). Semantic dimensions such as "distance" and "location type" determine the strength of these hyponymy relations. The paper offers an account of these data based on the "semantics maps" model, which captures polysemy and hyponymy patterns via the clusters of locations they refer to. It is shown that this novel model is consistent with previous works on the polysemy of spatial categories and sheds light on how Mandarin offers a unique organisation of this domain.

**Keywords:** polysemy, hyponymy, mandarin, prepositions, localisers, semantic maps

## INTRODUCTION

*Polysemy* is usually defined as the ability of a vocabulary item to cover distinct but related senses (Apresjan 1974). The nature of polysemy is still the topic of intense debate. Some proposals suggest that polysemy is a pragmatic phenomenon based on speakers' use of language in context (e.g., Falkum 2011, 2015, 2017). Other proposals suggest that polysemy is a reflection of the rich semantic content of lexical categories (e.g., Pustejovsky 1995; Asher 2011; Evans 2015). Yet other proposals offer intermediate positions attempting to integrate semantic and pragmatic views into coherent

**Abbreviations:** c, cluster of senses associated with *cong*; cl, classifier; d, cluster of senses associated with *dao*; de, cluster of senses associated with *de*; h, cluster of senses associated with *hou*; li, cluster of senses associated with *li*; n, cluster of senses associated with *nei*; pf, perfective aspect marker; pl, plural marker; q, cluster of senses associated with *qian*; s, cluster of senses associated with *shang*; w, cluster of senses associated with *wai*; x, cluster of senses associated with *xia*; z, cluster of senses associated with *zai*; zh, cluster of senses associated with *zhi*; zu, cluster of senses associated with *zuo*.

models with conceptual underpinnings (e.g., Tyler and Evans 2003). Polysemy therefore presents at least two challenges for linguistic theories. The first is establishing whether this phenomenon is semantic or pragmatic (or both) in nature. The second is establishing whether and how it can emerge across grammatical/functional categories.

The language we analyse in this paper is Mandarin, which we choose for two key reasons. First, Mandarin includes two related categories conveying multiple spatial senses: prepositions and *fangweici*, or “localisers” (e.g., respectively, *zai* and *qian* in *zai zhuozi qian* “in front of the desk”). Second, most works document the polysemy of these categories as involving different sense types. They show that spatial prepositions and localisers can also have temporal senses (e.g., *zai siyue* “in April” and *wuye qian* “before midnight”), and other non-spatial senses (Huang et al., 2017: Appendix VII). However, little is known about the possibility that these categories can cover distinct spatial senses. For instance, the English preposition *on* can cover at least two distinct senses: “support” (e.g., *a book on the table*) and “attachment” (e.g., *a painting on the wall*: Tyler and Evans 2003: Ch. 4). However, this type of polysemy appears understudied in Mandarin, as we can illustrate *via* 1)–4):<sup>1</sup>

- 1) *Zhangsan zuo zai zhuozi qian*  
Zhangsan sit z desk Q  
“Zhangsan sits in front of the desk.”
- 2) *Zhangsan zai Beijing*  
Zhangsan z Beijing  
a. “Zhangsan is in Beijing.”  
b. “Zhangsan is near Beijing.”  
c. “Zhangsan is North of Beijing.”
- 3) *Zhangsan zai Beijing bei/\*de bei*  
Zhangsan z Beijing north/DE north  
“Zhangsan is North of Beijing.”
- 4) *Zhangsan zai Beijing de bei-bian*  
Zhangsan z Beijing DE north-side  
“Zhangsan is in the Northern side of Beijing.”

We first introduce some basic descriptive notions. In 1)–4), *Zhangsan* is a subject noun phrase (NP) denoting a *figure* referent, i.e., a referent located with respect to a landmark object, or *ground* referent (Talmy 2000: Ch. 1; Kibrik 2013: Ch. 1). *Zai* is a preposition in 1), i.e., a functional head possibly introducing the argument of a lexical verb (e.g., *zuo* “sit”: Zhang 2017). In 2)–4), *zai* acts as a co-verb, a copula-like light verb taking figure and ground NPs as its arguments (e.g., Chao 1968). In 1), the localiser *qian* “in front” follows the ground NP as a necessary constituent specifying a location under discussion. In 2), the place name *Beijing* can however license the omission of a localiser (cf. Huang 2009; Zhang 2017). Localisers come in two morphological types. *Simple* localisers are single morphemes that can refer to one or more

related locations (e.g., *qian* “front”). *Compound* localisers involve the suffixation of simple localisers with nouns referring to specific location types (e.g., *bei-bian* “North-side” in 4): Huang et al., 2017: 194). Compound localisers usually follow the relational head *de* (cf. 4)); simple localisers cannot follow this head (cf. the ungrammatical *\*de bei* in 3)).

These sentences encapsulate the following polysemy patterns. In 2), *Zhangsan* is understood to be in some location related to Beijing, and this location may be “in,” or “near,” or even “North” of Beijing. In 3), *Zhangsan* is in a location north of Beijing: the localiser *bei* refers to this “cardinal” location. In 4), the compound localiser *bei-bian* establishes a reference to a Northern side of Beijing as a location that *Zhangsan* occupies. Thus, *zai* seems to potentially cover a range of spatial senses, each referring to distinct locations related to Beijing: it seems a polysemous preposition. Instead, *bei* and *bei-bian* select more specific sense ranges and seem to enter hyponym-like (“type-of”) relations with *zai*. These polysemy patterns and the related hyponymy relations, however, appear understudied in Mandarin spatial categories.

The goal of this paper is therefore threefold. First, we offer an overview of polysemy and hyponymy patterns holding among Mandarin prepositions and localisers and how they are related to their grammatical properties. Second, we show that these properties display nuanced intra-speaker patterns, mediated *via* the semantic dimensions defining spatial senses. Third, we offer a theoretical account based on our novel interpretation of the “semantic maps” model. When items from different categories enter hyponym relations, we contend that the context must confirm their semantic “relatedness”. We suggest that such a multi-domain view of polysemy can be captured via our novel semantic maps model, in which localisers and prepositions refer to possibly overlapping regions of space. The paper is organised as follows. *Previous Literature* presents previous literature and motivates our study. *Methodology* and *Results* present an elicitation study and the results. *A Semantic Account of the Data* and *General Discussion* offer a semantic maps model and a discussion; *Conclusion* concludes.

## PREVIOUS LITERATURE

Our goal in this section is to first offer a concise overview of polysemy and the theoretical views on polysemy types (*Theories of Polysemy*). We then offer an overview of the grammatical properties of Mandarin prepositions and localisers and extant analyses of their polysemy, thus outlining the explananda we aim to address (*The Grammar of Mandarin Spatial Categories* and *The Polysemy of Mandarin Spatial Categories: Previous Studies*).

## Theories of Polysemy

Several works have developed distinct but conceptually overlapping views of polysemy (Apresjan 1974; Geeraerts 1993, 2010: Ch. 2; Pustejovsky 1991, 1995, 1998; Cruse 2004: Ch. 6; Murphy 2010, Ch. 3; Riemer 2005; Glynn 2012, 2014, 2016; Falkum and Vicente 2015; Dölling 2020). A relatively general consensus exists on the classification of polysemy into three sub-types: *regular* or *inherent* polysemy, *irregular* polysemy, and

<sup>1</sup>All glosses follow Leipzig Glossing Rules (Croft 2003: xiv–xxv), with one minor variation. Polysemous prepositions and localisers are glossed *via* item-specific glosses (e.g., “z” for *zai*), which stand proxy for the clusters of senses they cover.

*logical* polysemy. Regular polysemy holds when a vocabulary item *a* has several senses (e.g., *s* and *s'*) that can also be expressed *via* vocabulary items *b*, *c*. For instance, *parent* can be considered polysemous because *mother* and *father* capture two of its possible senses (i.e., “female parent” and “male parent”, respectively). Irregular polysemy involves the emergence of “novel” senses *via* processes of metaphor and metonymy, e.g., temporal senses in prepositions (e.g., *at five o'clock*: Haspelmath 1997; Vicente 2018). Logical polysemy holds when an item’s senses form mutually exclusive sense types. For instance, *lunch* can describe a process (e.g., *lunch took forever*) and a physical entity, i.e., what one eats (e.g., *lunch was delicious*: Pustejovsky 1995; Asher 2011: Ch. 4).

Polysemy is usually defined in opposition to other semantic properties: homonymy, monosemy, vagueness, and underspecification (e.g., Ruhl 1989; Kearns 2006; Kennedy 2007; Egg 2011). Aside from monosemy, these other properties will not play a relevant role in our discussion. Hence, we can leave them aside. Most works propose that polysemy can be evaluated *via* the definition, co-predication, ellipsis, and coordination tests (e.g., Kearns 2006; Asher 2011, Ch. 4; Falkum and Vicente 2015; Vicente 2018; Ortega 2020; Murphy 2021). For our purposes, the definition and the coordination tests play a key role and can be defined as follows. According to the definition test, if the senses *s*, *s'* of a vocabulary item *α* involve overlapping but distinct definitions to capture their use in the extra-linguistic context, then the item is polysemous (cf. Tyler and Evans 2003: Ch. 2; and our discussion of 1)–4)). In the coordination test, a vocabulary item heads two conjoined arguments (e.g., *Zhangsan plays ping-pong and the piano*). Consequently, the two distinct senses can coexist in a coordinated phrase. We will fully illustrate their use in our study in *Methodology* and *Results*.

Polysemy is also connected to hierarchical sense relations, possibly defined *via* hyponymy relations (cf. Apresjan 1974; Cruse 2004: Ch. 6; Murphy 2010: Ch. 3; Bjelobaba 2018). A lexical typology study offering evidence on this matter is Levinson and Meira (2003). This study offers a hierarchical model of increasingly specific spatial concepts to account lexicalisation patterns involving spatial senses. Languages can lexicalise at least the general concept of location AT and may lexicalise more specific concepts such as IN, INSIDE, and UP. This increasing element of specificity establishes that, e.g., IN acts as a superordinate concept to INSIDE. Thus, languages that have two distinct vocabulary items for the INSIDE and the IN concepts will also include a hyponymy relation between the items. Case in point, the English *inside* can be understood as describing a more specific type of “inclusion” relation than *in*. Thus, *inside* is a hyponym of *in*, according to this analysis.

These notions apply to our discussion of Mandarin, as follows. Our initial examples in 1)–4) show that the regular polysemy in prepositions and localisers is still understudied. Crucially, the use of the definition test can offer evidence regarding this type of polysemy and its emergence in an extra-linguistic context. Furthermore, if *zai* can refer to any location, a simple localiser such as *bei* can be a hyponym of *zai* referring to any northern location. The compound

hyponym *bei-bian* can then be defined as a hyponym of *bei* and *zai*: it refers to a northern side or region and thus a more specific type of location. Crucially, it is generally assumed that hyponym relations hold only among members of the same category (cf. Cruse 2004: Ch. 5; Murphy 2010: Ch. 4). Whether and how hyponym relations can involve distinct categories seem an open matter. Therefore, the nature of polysemy and hyponymy in prepositions and localisers can be fully analysed only once we address their grammatical properties.

## The Grammar of Mandarin Spatial Categories

Mandarin spatial prepositions and their dual role as co-verbs have been amply discussed (Chao 1968; Li and Thompson 1974, 1981: 381–387; Peyraube 1980; Yin 2003; Lü 2006; Huang 2009; Basciano 2010; Djamouri et al., 2013: 41; Huang et al., 2017: 216–219; Zhang 2017). This category includes a rich inventory of items (66, in Huang et al., 2017); a non-exhaustive list of prepositions is in 5) (cf. Djamouri et al., 2013):

- 5) Prepositions := {*zai* “at,” *dao* “to,” *cong* “from,” *dang* “at,” *dui* “in the opposite direction of,” *li* “away,” *wang* “in the direction of,” *xiang* “in the direction of”}

Some previous works have also suggested that *zai* and other spatial prepositions can combine with bare ground NPs only when these NPs act as place names, i.e., proper names for distinctive locations (e.g., *Beijing*; Huang 2009; Huang et al., 2017: 171). In the opportune context, however, any NP can refer to a unique, salient location in context (e.g., *Pitt Street, the main square*: Anderson 2007: Ch. 4; Köhnlein 2015). This is also possible in Mandarin: for instance, speakers can use the preposition and ground NP *zai shufang* “at/in the study room” to refer to a salient location (cf. Lü 1980, 2006; for a similar point). Thus, spatial prepositions may occur without localisers when they take a salient, specific ground NP as their argument.

Simple localisers form a slightly broader set: more than 80 items are listed in Huang et al. (2017: Appendix VII). Nevertheless, most works consider the monosyllabic items in 6) the most representative list for this category (Djamouri et al., 2013: 72; Huang et al., 2017: 217; Zhang 2017: 2). For this reason, they form the bulk of our analysis:

- 6) (Simple) Localisers := {*li* “in,” *wai* “out,” *shang* “on, above,” *xia* “down, below,” *qian* “front,” *hou* “behind,” *zuo* “left,” *you* “right,” *bei* “North,” *xi* “West,” *dong* “East,” *nan* “South”}

Compound localisers (e.g., *li-mian* and *wai-bian*) are generally formed *via* suffixation and prefixation of simple localisers (e.g., Peyraube 1994, 2003; Chappell and Peyraube 2008; Huang et al., 2017: 189–194). Five well-established suffixes are *-mian* “side, face”, *-bian* “side”, *-bu* “part”, *-tou* “head”, and *-fang* “direction, axis”. These are originally independent spatial nouns (“place

nouns” in Huang et al., 2017). In localisers, they occur as suffixes to simple localisers, thus forming compound localisers that refer to highly specific locations.<sup>2</sup>

Compound localisers can also involve prefixation. Two documented prefixes are *zhi-* and *yi-*. These prefixes usually attach to localisers to restrict their sense to a “distal” location. *Yi-* is mostly used to measure distances. One example is *zhe zuo shan de gaodu zai 2000 mi yi-shang* (“the mountain’s height is 2000 m”: Huang et al., 2017: Appendix VII). *Zhi-* has a broader distribution, although the senses it selects display subtle properties and tend to emerge in specific contexts. If *shang* covers senses approximated *via* the glosses “on, on top, above”, then *zhi-shang* seems to only cover the “above” sense. Thus, compound localisers can involve either form of affixation, even though certain restrictions emerge.

The syntactic status of localisers has been amply debated. Several works suggest that localisers are postpositions, i.e., adpositions following a ground NP (Tai 1973; Hagège 1975; Djamouri et al., 2013; Wu 2015). Some works further propose that localisers form a discontinuous circumposition with prepositions (e.g., Chao 1968; Li and Thompson 1974, 1981). Recent works however show that localisers display properties typical of nominal clitics (Liu 1994, 1998; Huang et al., 2009; Lin 2013; Huang et al., 2017; Zhang 2012, 2017; Ursini and Long, 2018; Ursini et al., 2020; Ursini and Huang, 2020). Several syntactic tests also show that localisers form a single unit with ground NPs. One is based on locative inversion, a form of fronting for prepositional phrases (PPs: den Dikken 2006: Ch. 3). Another is based on *you-* constructions, roughly equivalent to the English *there-* constructions. We show a case of inversion in 7) and a case of *you-* construction in 8):

7) *Zai che qian Zhangsan chouzhe yi zhi yan*  
 z car Q Zhangsan smoke CL cigarette  
 “In front of the car, Zhangsan smokes a cigarette.”

8) *Zai zhuozi de xia-mian you yi ge qiu*  
 z table DE x-façade there CL ball  
 “There is one ball under the table.”

From 7)–8) and 1)–4), we can conclude that prepositions and localisers display a degree of categorial flexibility. Prepositions introduce a ground NP and possibly a localiser as arguments of a verb or may act as co-verbs. Simple localisers act as modifiers to the ground NP and specify which location is involved in the relation between ground and figure. Compound localisers act as arguments of *de*, thus becoming modifiers to the ground NP. Therefore, prepositions and localisers can combine with ground NPs to form full PPs.

These initial examples also show that prepositions seem to contribute two types of senses to a sentence’s interpretation. First, they can capture either a *locative* (e.g., *zai*) or *directional* relation

(e.g., *dao*) between figure and ground. We define directional relations as relations in which the figure changes location over time. Locative relations describe a figure’s static position over time instead (Jackendoff 1983, 1990; Wunderlich 1991, 1993; Lestrade 2010). Second, localisers seem to refer to a cluster of possible locations that the figure can occupy. Prepositions can also refer to these locations, if localisers are absent from sentences. However, this seems possible insofar as the context offers a cue on which location is under discussion.

Three questions thus arise, which are related to the goals outlined in the *Introduction*. The first question is how these forms of regular polysemy interact: how the presence of localisers determines which senses of a preposition are selected in a context. The second question is whether this interaction can confirm the existence of hyponym-like relations connecting the two categories. The third question is whether and how these patterns are context-sensitive and therefore can co-vary with speakers’ intuitions about prepositions and localisers’ senses. The next step is to verify whether answers to these questions exist in the literature.

## The Polysemy of Mandarin Spatial Categories: Previous Studies

Most studies addressing spatial categories in Mandarin seem to offer a fragmented view regarding their putative polysemy. Reference grammars and lexicographic sources generally agree that prepositions and localisers can cover several related senses (Chao 1968; Li and Thompson 1981; Sun 2006; Huang et al., 2009; Huang et al., 2017: Appendix VII). However, these works mostly report forms of logical polysemy, e.g., the fact that *zai* can also cover temporal senses. Recent analyses of *zai* and *cong* (Peng 2012) and *zai*-related constructions (Zhang et al., 2016) show that these prepositions can also cover metaphoric and causal sense types. They therefore offer evidence that the logical polysemy of this preposition has emerged over time (i.e., it starts as a form of irregular polysemy). However, they gloss over the possibility that *zai* and other prepositions can display forms of regular polysemy as the one discussed *via* 1)–4). Thus, this polysemy type is understudied, in Mandarin prepositions.

A similar fragmented view exists for localisers. For instance, Lin (2013) observes that pairs such as *qian* and *qian-mian* involve forms of sense restriction obtained *via* suffixation. Wu (2008) discusses *hou* and how this localiser also captures temporal and causal senses. Similar works offer evidence regarding *xia* “down”, *qian* “front”, and *hou* “back” (Lü 1980; Scott 1989; Xing 1996; Lan 1999; Wu and Muchine, 2018). These works analyse in detail the possible sense types associated with these localisers but do not analyse their spatial senses. For instance, Wu (2008) discusses the possible use of *hou* as a temporal localiser capturing a “before” sense. However, it does not address the senses associated with its suffixed forms (e.g., *hou-mian* and *hou-bian*) and whether and how they display forms of polysemy. More in general, these works offer evidence for the logical polysemy of specific localisers but do not address the possibility that localisers can display forms of regular polysemy. Hence, they also leave aside the possibility that prepositions and localisers may enter hyponymy relations, across and within categories (e.g., respectively, *zai* with *bei* and *bei* with *bei-bian*).

<sup>2</sup>This work also observes that *-bu* is usually reserved for written texts, so that compound localisers based on this suffix can be considered as belonging to a “formal” register. Since the study we present in *Methodology* and *Results* was based on a written task, this dimension does not play a key difference in the overall analysis

Another proposal is outlined in Tai (1989, 1993, 2005), which extends the “Conceptual Semantics” framework to Mandarin (Jackendoff 1983, 1990). These works propose that Mandarin prepositions and localisers respectively denote the conceptual functions PATH and PLACE-FUNCTION. Tai (1993, 2005) proposes that spatial nouns occurring in *de*-phrases realise a type of genitive phrase and thus select a sub-type of PLACE-FUNCTION. For instance, while *li* is treated as denoting the IN function, *li-tou* is treated as denoting the INSIDE sub-type of function (Tai 1993: (20); cf. also Tai 1975, 1976). Thus, these works hint at the existence of hyponymy relations holding among Mandarin prepositions and localisers, as a logical consequence of their regular polysemy. However, they leave a full analysis for future research. More in general, what is still missing in the literature is an analysis of the regular polysemy of prepositions and localisers and the hyponymy relations potentially emerging from these patterns. Our three questions must therefore still meet their respective answers. The next two sections present the methodology and results that permit us to offer these answers.

## METHODOLOGY

### Task Selection

Our study was based on an elicitation task. We chose this task over the collection of corpus data, the favoured method in studies on polysemy (e.g., Tyler and Evans 2003; Deignan 2005, 2014; Glynn 2016). Our choice was motivated by practical reasons. To test whether two items belonging to the same category stand in a hyponymy relation (e.g., *apple* and *fruit*), one must query corpora and find sentences explicitly stating such relations (e.g., *an apple is a kind of fruit*: Glynn 2012). However, the feasibility of this approach appears low if one wishes to investigate categories other than nouns and verbs (i.e., lexical categories). Mandarin prepositions and localisers are equivalent to functional categories (e.g., Huang et al., 2017). Furthermore, testing hyponymy relations holding among their items entails testing relations among subtly different categories. Therefore, a different task seems necessary for our goals.

Elicitation tasks can avoid this problem for two reasons. First, experimenters can create novel sentences including the target categories and vocabulary items that easily lend themselves to the testing of a given hypothesis. Second, experimenters can carefully control the extra-linguistic contexts in which participants evaluate these sentences. For instance, in the “Topographic Relation Picture Series”, participants are asked to describe pictures from a series representing one of 71 topographic relations (e.g., “support”, “attachment”, and “inclusion”: Bowerman and Pederson, 1992; Bowerman, 1996; Levinson and Wilkins 2006: Ch. 1). The sentences that speakers can produce are then analysed with respect to their grammatical and semantic properties, and their relation to the pictorial context of evaluation. We therefore decided to design a task in which participants would evaluate the use of sentences in different contexts, in a manner similar to the Topographic Relation Picture Task.

### Participants

Participants were undergraduate students (N = 64, age range 21; 0–25; 0 years) who joined the study on a voluntary basis. Participants were asked if the test sentences could be used to describe scenarios (i.e., contexts) describing different spatial configurations. Participants were evenly balanced among genders, had normal or corrected-to-normal eyesight, and had no history of speech impairment. Participants originated from several Chinese provinces, but no participant reported knowledge of dialects or forms of bilingualism. We nevertheless leave open the possibility that geographical, social, or register influences may have affected participants’ answers in the task. Participants were recruited *via* an advertisement in the faculty message board and had to sign a consent form before participating (see the **Supplementary Materials**). The consent form granted anonymity in the treatment of personal data and the disclosure of the study’s goals after its completion if participants wished to access it.

### Materials

The test sentences involved the three prepositions *zai* “at”, *dao* “to”, and *cong* “from”, alone and in combination with localisers. These prepositions respectively cover “location”, “goal”, and “source” directional sense types, i.e., the most common directional sub-types across languages (Stolz et al., 2014: Ch. 1). To test the polysemy of these prepositions, we used sentences lacking localisers but including place names or ground NPs referring to unique, salient locations in context (cf. *Beijing* in 2), from the *Introduction*). For localisers, we tested each simple localiser in 6) in combination with each preposition. We tested a subset of compound localisers derived from the localisers referring to the horizontal axis (*zuo* “left” and *you* “right”), the vertical axis (*xia* “up” and *shang* “down”), and the longitudinal axis (*qian* “front” and *hou* “back”). We examined whether each of the suffixes (i.e., *-mian* “face”, *-bian* “side”, *-tou* “head”, *-bu* “part”, and *-fang* “direction”) would cover unique senses denoting highly specific locations. We also examined whether prefix *zhi-* would cover senses denoting “distal” locations along these axes (e.g., *zhi-shang* denoting a relation that can be glossed as “above” vs. “on”).

We organised sentences according to the “location type” to which localisers can refer. These are in turn defined *via* a combination of semantic dimensions that partition the conceptual domain of space (cf. Cresswell 1978; Levinson 2003: Ch. 1; Levinson and Wilkins 2006: Ch. 1; Zwarts 2017). First, we distinguished between axial and topological localisers. The first group refers includes the aforementioned six localisers plus localisers *bei* “North”, *nan* “South”, *dong* “East”, and *xi* “West”, to be defined in the next paragraph. The second group includes *li* “in,” *wai* “out,” and *nei* “within”: localisers that can refer to internal/external (i.e., topologically defined) locations. Note that the spatial senses of *wai* and *nei* seem rarely used in current Mandarin (Huang et al., 2017: 217). We thus monitored their acceptance in context as being possibly linked to speakers’ infrequent use of these rare senses.

We also identified localisers according to the reference system they capture: *intrinsic*, *relative*, and *absolute/cardinal* (Levinson

and Wilkins 2006; Palmer 2015; Palmer et al., 2017a). A relative reference system involves a speaker describing a figure's position from the speaker's reference point, whereas an intrinsic system involves the ground's reference point. For instance, if a speaker is behind a car acting as a ground, a ball is in front of the speaker, and the speaker uses a relative reference system, then the ball can be described as being "in front" of the car. If the speaker uses an intrinsic relative system, then the ball can be described as "behind" the car. *Via* this semantic dimension, we split *bei*, *nan*, *dong*, and *xi* into the cardinal (axial) subset. We then assumed that the other axial localisers are ambiguous between intrinsic and relative senses. Furthermore, it is known that terms referring to "left" and "right" locations display strong context sensitivity for their disambiguation (cf. Levinson 1996; Levinson and Meira 2003). We thus monitored their acceptance rates in relation to contextual disambiguation.

Overall, we tested  $13 \times 6 = 78$  localisers in combination with three prepositions (i.e., 234 items). We deemed this a sufficient number of sentences to test our hypotheses but also to avoid overloading participants. Sentences were presented in a random order, to avoid cueing effects in answers (Schütze and Sprouse 2013; and references therein). For instance, the pair testing whether *qian-mian* and *qian* can be used in the same context was the 20th and 47th test sentences, respectively, in the overall list. We acknowledge that a fully randomised presentation of the sentences would have been the best option, but for practical reasons (i.e., the test being very long), we could only resort to this simpler method. At 64 participants and 234 items, we collected a total of  $64 \times 234 = 14,976$  token sentences, which were then processed for statistical analysis. A file presenting the full list of sentences is found in the **Supplementary Materials** to this article.

## Procedure

Participants received the written task with the full list of sentences, with no time limit for completion. Each sentence was tested against a text describing a fictional scenario that acted as an extra-linguistic context of evaluation. Contexts introduced a short description of a target relation holding between figure and ground. For instance, the acceptability of 1) was tested by describing a context in which a man called Zhangsan was in front of the desk and thus whether 1) (i.e., *Zhangsan zuo zai zhuozi qian*) would aptly describe this context. Conversely, a sentence such as 2) (i.e., *Zhangsan zai Beijing*) can also be used in contexts in which Zhangsan is in some other location (e.g., near or North of Beijing). Instead, 3) and 4) (respectively, *Zhangsan zai Beijing bei* and *Zhangsan zai Beijing de bei-bian*) can only be used to describe Zhangsan as being in the northern "region" of this city, *via* *bei* and *bei-bian*.

We designed sentences in related subsets: without localisers (e.g., 2)) and with localisers (e.g., 3)–4)). Both sentences could accurately describe a context, but speakers' answers would determine if the absence of localisers was acceptable and, consequently, if prepositions could be polysemous in context. Our reason for choosing this binary choice (acceptable/unacceptable) instead of other options, e.g., Likert scales, was as follows. Likert scales can be used to evaluate if participants can accept the grammaticality of sentences, or their accuracy in context (cf. de Clercq and Haegeman, 2018; Murphy 2021).

For grammaticality tests, it is however often useful to establish cut-off points. For instance, de Clercq and Haegeman (2018) present a task involving grammaticality judgements in which sentences were considered grammatical if evaluated as "3" or higher on a 5-point scale. We thus decided to use binary answers but also to invite participants to motivate if sentences were unacceptable due to grammatical or contextual factors (or both). In this manner, participants would explain whether the absence of localisers or the mismatch between sentence content and context would trigger their responses.

## Predictions

Our predictions were as follows. We assume that prepositions and localisers display forms of regular polysemy. For instance, *zai* is polysemous if it covers senses that localisers such as *qian* and *bei* can also cover a given sense (cf. again the definition of Apresjan, 1974). If prepositions are polysemous, then speakers would accept sentences without localisers, e.g., *Zhangsan zai Beijing (=2)*, as referring to a given location under discussion. This can be the case only if the precise status of this location can be retrieved from the context (e.g., Zhangsan is described as being located North of Beijing). If prepositions do not display forms of regular polysemy, then sentences lacking a localiser cannot be used in a context in which a specific location is under discussion. Given the fact that polysemy in prepositions may involve categorial boundaries between prepositions and localisers, we assume that this property may not be absolute. Most but not necessarily all speakers may accept polysemous prepositions in context.

A second, consequent prediction is that if prepositions are polysemous, then localisers can display hyponymy relations with them (e.g., *zai* and *bei*). This may be the case because localisers can refer to some of the distinct but related locations that prepositions can refer to. This prediction can be confirmed by evaluating if participants would accept a first sentence without a localiser and a second sentence with a localiser in the same contexts. A third prediction is that simple and compound localisers can also enter hyponymy relations (e.g., *bei-bian* and *bei*). This prediction can be tested by also analysing the use of paired simple and compound localisers in the same contexts. With these predictions in mind, we turn to the results.

## RESULTS

The goal of this section is to present the results regarding prepositions, simple localisers (*The Polysemy of Prepositions: Variation and Simple Localisers*), and compound localisers (*Compound Localisers*). We conclude by outlining the *desiderata* for an account of their polysemy and hyponymy relations (*Interim Summary*).

### The Polysemy of Prepositions: Variation and Simple Localisers

The results suggest that a certain degree of nuanced intra-speaker variation emerged when testing the polysemy of prepositions. Participants differentiated among "location types" (i.e., axial,

**TABLE 1 |** Descriptive statistics and chi-square test statistics of *zai*, *dao*, and *cong*.

N = 64	Zai			Dao			Cong		
	Mean ± SD	Chi-square <sup>a</sup>	Asymp. Sig.	Mean ± SD	Chi-square <sup>a</sup>	Asymp. Sig.	Mean ± SD	Chi-square <sup>a</sup>	Asymp. Sig.
<i>bei</i> "north"	1.484 ± 0.504	10.360	0.001 (3) <sup>b</sup>	1.500 ± 0.504	12.190	0.000 <sup>c</sup>	1.500 ± 0.504	12.190	0.000 <sup>c</sup>
<i>nan</i> "south"	1.531 ± 0.503	16.298	0.000 <sup>c</sup>	1.547 ± 0.502	18.574	0.000 <sup>c</sup>	1.563 ± 0.500	21.000	0.000 <sup>c</sup>
<i>dong</i> "east"	1.531 ± 0.503	16.298	0.000 <sup>c</sup>	1.547 ± 0.502	18.574	0.000 <sup>c</sup>	1.547 ± 0.502	18.574	0.000 <sup>c</sup>
<i>xi</i> "west"	1.547 ± 0.502	18.574	0.000 <sup>c</sup>	1.563 ± 0.500	21.000	0.000 <sup>c</sup>	1.531 ± 0.503	16.298	0.000 <sup>c</sup>
<i>nei</i> "within"	1.203 ± 0.406	2.860	0.091	1.313 ± 0.467	0.048	0.827	1.391 ± 0.492	2.503	0.114
<i>li</i> "in"	1.219 ± 0.417	2.012	0.156	1.281 ± 0.453	0.107	0.743	1.359 ± 0.484	1.074	0.300
<i>wai</i> "out"	1.172 ± 0.380	5.003	0.025 <sup>b</sup>	1.281 ± 0.453	0.107	0.743	1.219 ± 0.417	2.012	0.156
<i>qian</i> "front"	1.266 ± 0.445	0.360	0.548	1.297 ± 0.460	0.003	0.956	1.391 ± 0.492	2.503	0.114
<i>hou</i> "back"	1.328 ± 0.473	0.241	0.623	1.375 ± 0.488	1.714	0.190	1.406 ± 0.495	3.440	0.064
<i>zuo</i> "left"	1.344 ± 0.479	0.583	0.445	1.469 ± 0.503	8.679	0.003 <sup>b</sup>	1.469 ± 0.503	8.679	0.003 <sup>b</sup>
<i>you</i> "right"	1.266 ± 0.445	0.360	0.548	1.484 ± 0.504	10.360	0.001 (3) <sup>b</sup>	1.453 ± 0.502	7.146	0.008 <sup>b</sup>

Note. The table offers the mean and SD values for sentences including bare prepositions (i.e., sentences lacking a localiser). Expectation value was set at 0.7; asymptotic signature values display deviation from the expected outcome (cf. Abu-Bader 2021). We place prepositions on columns and possible locations on rows. We use localisers to capture which location was under discussion in each example. For instance, the cell on the *zai* column and the *qian* row shows that participants accepted a sentence including *zai* but lacking *qian* in a context in which a "front" location was under discussion, as per predictions (cf. 11–12)). Sentence types approaching statistical significance are marked with an asterisk; we discuss them in the main text.

<sup>a</sup>0 cells (0.0%) have expected frequencies less than 5. The minimum expected cell frequency is 19.2.

<sup>b</sup>Asymp. Sig. < 0.05.

<sup>c</sup>Asymp. Sig. < 0.001.

**TABLE 2 |** The acceptance rates of sentences including localisers referring to locations, divided per preposition type (*zai*, *dao*, and *cong*).

N = 64	Zai			Dao			Cong		
	Mean ± SD	Chi-square <sup>a</sup>	Asymp. Sig.	Mean ± SD	Chi-square <sup>a</sup>	Asymp. Sig.	Mean ± SD	Chi-square <sup>a</sup>	Asymp. Sig.
<i>bei</i> "north"	1.688 ± 0.467	0.048	0.827	1.719 ± 0.453	0.107	0.743	1.766 ± 0.427	1.313	0.252
<i>nan</i> "south"	1.656 ± 0.479	0.583	0.445	1.688 ± 0.467	0.048	0.827	1.766 ± 0.427	1.313	0.252
<i>dong</i> "east"	1.625 ± 0.488	1.714	0.190	1.734 ± 0.445	0.360	0.548	1.766 ± 0.427	1.313	0.252
<i>xi</i> "west"	1.688 ± 0.467	0.048	0.827	1.719 ± 0.453	0.107	0.743	1.766 ± 0.427	1.313	0.252
<i>nei</i> "within"	1.406 ± 0.495	26.298	0.000 <sup>b</sup>	1.203 ± 0.406	75.241	0.000 <sup>b</sup>	1.391 ± 0.492	29.170	0.000 <sup>b</sup>
<i>li</i> "in"	1.688 ± 0.467	0.048	0.827	1.547 ± 0.502	7.146	0.008 <sup>c</sup>	1.719 ± 0.453	0.107	0.743
<i>wai</i> "out"	1.313 ± 0.467	45.762	0.000 <sup>b</sup>	1.203 ± 0.406	75.241	0.000 <sup>b</sup>	1.203 ± 0.406	75.241	0.000 <sup>b</sup>
<i>qian</i> "front"	1.719 ± 0.453	0.107	0.743	1.750 ± 0.436	0.762	0.383	1.688 ± 0.467	0.048	0.827
<i>hou</i> "back"	1.719 ± 0.453	0.107	0.743	1.719 ± 0.453	0.107	0.743	1.672 ± 0.473	0.241	0.623
<i>zuo</i> "left"	1.484 ± 0.504	14.170	0.000 <sup>b</sup>	1.469 ± 0.503	16.298	0.000 <sup>b</sup>	1.563 ± 0.500	5.762	0.016 <sup>c</sup>
<i>you</i> "right"	1.484 ± 0.504	14.170	0.000 <sup>b</sup>	1.453 ± 0.502	18.574	0.000 <sup>b</sup>	1.516 ± 0.504	10.360	0.001 (3) <sup>c</sup>
<i>shang</i> "on, above"	1.719 ± 0.453	0.107	0.743	1.625 ± 0.488	1.714	0.190	1.672 ± 0.473	0.241	0.623
<i>xia</i> "down, below"	1.750 ± 0.436	0.762	0.383	1.688 ± 0.467	0.048	0.827	1.609 ± 0.492	2.503	0.114
<i>Qian(zhi-qian)</i>	1.766 ± 0.427	1.313	0.252	1.797 ± 0.406	2.860	0.091	1.750 ± 0.436	0.762	0.383
<i>Hou(zhi-hou)</i>	1.766 ± 0.427	1.313	0.252	1.578 ± 0.498	4.527	0.033 <sup>c</sup>	1.609 ± 0.492	2.503	0.114

Note. Expectation value is as per Table 1. Thus, the first row shows that sentences including *bei* and *zai*, *bei* and *dao*, and *bei* and *cong* in a context introducing a "north" location were unproblematic. We discuss statistically significant cases in the main text.

<sup>a</sup>0 cells (0.0%) have expected frequencies less than 5. The minimum expected cell frequency is 19.2.

<sup>c</sup>Asymp. Sig. < 0.05.

<sup>b</sup>Asymp. Sig. < 0.001.

topological, and cardinal types) when evaluating the acceptability of sentences in context. Furthermore, for some localisers, subtle contextual factors further affected acceptance rates. We illustrate this variation *via* Table 1.

Participants rejecting sentences without localisers usually observed that localisers' absence appeared grammatical but poorly matching the context for them. Participants accepting these sentences acknowledged that prepositions could be used to refer to the locations under discussion in a context. The presence of matching localisers was however preferred because it explicitly introduced reference to the location under discussion (e.g., *qian*

to refer to a "front" location). Location types played a role, with some subtle type-internal differences. Participants preferred the presence of cardinal locations and their matching localisers (e.g., *bei* "north") in a statistically significant manner. Participants accepted the absence of topological *li*, *wai*, and *nei* in context, though their presence led to different results, as we discuss in the next paragraph. A similar pattern held for *zuo* and *you* when used with *dao* and *cong*. Participants motivated their reticence to accept sentences without these localisers, as the context would leave open whether reference to an intrinsic or relative "left/right" location was under discussion.

The results regarding the acceptance of sentences including localisers reveal that semantic dimensions/location types and their role in context were significant. We show the relevant results in **Table 2**.

These results highlight that four of our localisers were not always accepted in the context provided in the study: *wai*, *nei*, *zuo*, and *you*. For *wai* and *nei*, a factor we mentioned in *Materials* played a role: their spatial senses seem rare in Modern Mandarin. Participants who accepted sentences including these localisers acknowledged that their spatial use was perhaps a bit surprising but adequate in the proposed context. Participants who did not accept these sentences admitted that they found this use extraneous to their understanding of these localisers. They would generally prefer compound localisers *li-mian* “in-side” for *li* and *wai-mian* “out-side” for *wai*. Similarly, participants who accepted *you* and *zuo* observed that they preferred an “intrinsic” use in context mediated via *you-bian* and *zuo-bian*. They interpreted sentences without these localisers, in the same context, with such a use. For these localisers, intra-speaker variation thus involved how participants accessed their item-specific senses, in line with previous analyses (e.g., Huang et al., 2017: 217; on *wai* and *nei*).

To better offer an overview of the general results, we discuss some examples from a qualitative perspective. Participants were asked if 9) and 10) could describe a context in which Zhangsan would be in a given study room. Most but not all participants accepted 9), whereas all participants accepted 10) as accurate in context: it included topological localiser *nei* “in” ( $M \pm SD = 1.203 \pm 0.406$ ). A similar pattern occurred for 11) and 12), including axial localiser *qian* ( $M \pm SD = 1.266 \pm 0.445$ ), but deviation was significant for 13) and 14), with cardinal localiser *bei* ( $M \pm SD = 1.484 \pm 0.504$ ):

- 9) *Zhangsan zai shufang.*  
Zhangsan Z studio  
“Zhangsan is in the study room.”
- 10) *Zhangsan zai shufang nei.*  
Zhangsan Z studio N  
“Zhangsan is in the study room.”
- 11) *Jundui zai chengbao de damen.*  
Army Z castle DE gate  
“The army is at the castle’s gate.”
- 12) *Jundui zai chengbao de damen qian.*  
Army Z castle DE gate Q  
“The army is in front of the castle’s gate.”
- 13) *Dijun zai Xiaogang cun.*  
Enemy Z Xiaogang village  
“The enemy is at the Xiaogang village”
- 14) *Dijun zai Xiaogang cun bei.*  
Enemy Z Xiaogang village north  
“The enemy is north of the Xiaogang village.”

Most participants did not accept the sentences in 9), 11), and 13) but based their answers on the absence of a context-matching localiser. They found these sentences grammatically deviant, even if they could to an extent describe the context under discussion. Conversely, participants accepting pair-wise examples such as

9)–10), 11)–12), and 13)–14) also accepted that localisers ideally referred to the location under discussion in each context. They accepted that a preposition can refer to one location (e.g., *zai*) and a localiser can also refer to that location (e.g., *qian*). Therefore, they accepted that preposition and localiser stand in a hyponym relation (e.g., *zai* and *qian* form a hyponymy relation). We can conclude that polysemy begets hyponymy, for participants who accepted the polysemy of prepositions.

A similar picture emerges for *dao* and *cong*, thereby confirming the roles of semantic dimensions and context sensitivity in the acceptance of their polysemy. For instance, participants were split when *dao* “to” described a context in which *nan* “South” referred to the location under discussion (cf. 15)–16):  $M \pm SD = 1.547 \pm 0.502$ ). Axial locations improved rates (for 17), vs. the acceptable 18) including *hou*:  $M \pm SD = 1.375 \pm 0.488$ ). When *cong* “from” was used to describe Zhangsan as moving out of a room, a majority of participants accepted 19), but almost all accepted 20) ( $M \pm SD = 1.359 \pm 0.484$ ). The use of axial localisers was also preferred over their absence in context. However, for *zuo* and *you*, variation approached statistical significance. Participants observed that reference to an “intrinsic” location made sentences unproblematic, unlike “relative” cases (cf. 21)–22) with *zuo*:  $M \pm SD = 1.469 \pm 0.503$ ):

- 15) *Dijun dao le Xiaogang cun.*  
Enemy D PF Xiaogang village  
“The enemy has gone to the Xiaogang village.”
- 16) *Dijun dao le Xiaogang cun nan.*  
Enemy D PF Xiaogang village south  
“The enemy has gone South of the Xiaogang village.”
- 17) *Jundui dao le chengbao de damen.*  
Army D PF castle DE gate  
“The army has gone to the castle’s gate.”
- 18) *Jundui dao le chengbao de damen hou.*  
Army D PF castle DE gate back  
“The army has gone behind the castle’s gate.”
- 19) *Zhangsan cong shufang zou chulai le.*  
Zhangsan C studio walk out PF  
“Zhangsan has come from the study room.”
- 20) *Zhangsan cong shufang li zou chulai le.*  
Zhangsan C studio LI walk out PF  
“Zhangsan has come from inside the study room.”
- 21) *Jundui cong chengbao de damen chufa le.*  
Army C castle DE gate set-off PF  
“The army has come from the castle’s gate.”
- 22) *Jundui cong chengbao de damen zuo chufa le.*  
Army C gate DE castle ZU set-off PF  
“The army has come from the left of the castle’s gate.”

Overall, we found that most participants interpreted the triplet of prepositions *zai*, *dao*, and *cong* as polysemous, i.e., as potentially covering the senses of localisers in context. Deviation from an ideal case was minor for axial sense types and the localisers that would capture these senses: *qian* “front”, *hou* “behind”, *xia* “down”, and



*shang* “up”, Note that sentences referring to “right” and “left” locations and only including prepositions *dao* “to” and *cong* “from” approached statistical significance (cf. **Table 1** *Asymp. Sig.* < 0.05). Variation depended on items’ semantic properties for topological sense types and their localisers: *li* “in”, *wai* “out”, and *nei* “within”. Instead, cardinal sense types and their localisers (i.e., i.e., *bei* “North”, *xi* “West”, *dong* “East”, and *nan* “South”) involved statistically significant deviations from the expected outcomes (cf. **Table 1** *Asymp. Sig.* < 0.001, with *Asymp. Sig.* < 0.05 for *zai* + *bei*).

Therefore, intra-speaker variation emerged when the sense ranges of prepositions included these sense types. Nevertheless, most speakers accepted that these prepositions could cover at least some of the senses associated with localisers. Variation ultimately involved which locations would be included in each preposition’s range. Thus, most speakers also indirectly accepted that hyponym relations would hold among these vocabulary items, as per predictions.

## Compound Localisers

We begin with a brief reminder: simple localisers can combine with the suffixes *-mian*, *-bian*, *-tou*, *-bu*, and *-fang* to form compound localisers. In so doing, they can respectively refer to the sides, facades, edges, parts, and directions defined with respect to a given axis, cardinal point, or topological (internal/external) location. The data involving compound localisers thus involve a further dimension of semantic variation. We isolate three significant patterns from the data *via* examples sets and discuss the acceptance rates specific to these data.

First, participants generally confirmed that compound localisers would have more restricted senses than their simple counterparts. Participants thus indirectly confirmed that simple and compound localisers would enter restricted hyponym relations. For instance, informants generally accepted that while 23) could be used to describe the figure being in any “posterior” location, 24)–25) restricted *hou*’s sense to a “side” type of location. We approximate *hou*’s sense *via* the English preposition “behind,” although there are clear sense differences between *hou* and this preposition (cf. Tyler and Evans, 2003: Ch. 4). Crucially, these sentences were tested in a context in which an individual called *Lisi* occupied a location described as the “back side” of a house, as 23)–25) show:

- 23) *Lisi zai fangzi hou.*  
Lisi Z house H  
“Lisi is behind the house.”
- 24) *Lisi zai fangzi de hou-mian.*  
Lisi Z house DE H-façade  
“Lisi is at the back side of the house.”
- 25) *Lisi zai fangzi de hou-bian.*  
Lisi Z house DE H-side  
“Lisi is at the back side of the house.”

Overall, *hou* acts as a hyperonym term to hyponyms *hou-mian* and *hou-bian*. The same reasoning can be extended to each localiser and set of corresponding compound localisers.

Second, compound localisers were generally interpreted as monosemous, i.e., as referring to only one location type. For instance, participants did not accept *qian-mian* and *qian-bian* in a context in which luggage was in the front of a given car (e.g., its trunk: cf. 26)). In such a context, *qian-bu* was instead considered appropriate (cf. 27)). In contexts in which one talks about the “edge” or “extremity” of an object, then only the suffix *-tou* becomes accessible, mostly in combination with *li* and *wai*. For instance, *li-tou* was deemed acceptable to describe some luggage in the trunk of a car as the car’s extremity, but it was considered unacceptable in any other context (cf. 28a–b)). The suffix *-fang* was generally preferred when a figure was along an axis of a ground and at a non-minimal (or “distal”) distance from the ground (cf. 29)). For most participants, the prefix *zhi-* also captured a “distance” sense when attached to localisers *xia* “down” and *shang* “up” (cf. 30):

- 26) *Xingli zai chezi de qian-mian/qian-bian.*  
Luggage Z car DE Q-facade/Q-side  
a. “The luggage is in front of the car.”  
b. #“The luggage is in the front of the car (=in the car’s trunk).”
- 27) *Yinqing zai chezi de qian-bu.*  
Engine Z car DE Q-part  
a. #“The engine is in front of the car.”  
b. “The engine is in the front of the car (=in the car’s trunk).”
- 28) *Xingli zai chezi de li-tou.*  
Luggage Z car DE LI-edge  
a. #“The luggage is inside the car.”  
b. “The luggage is inside the car’s trunk (=in the car’s edge).”
- 29) *Xingli zai chezi de hou-fang.*  
Luggage Z car DE H-axis  
a. “The luggage is behind the car.”  
b. “The luggage is far behind the car.”
- 30) *Cunzhuang zai shangu zhi-xia.*  
Village Z valley ZH-X  
“The village is below the valley.”

Overall, these data suggest that the semantic dimensions of “distance” and “part type” are also part of localisers’ senses and that the specific combinations of these senses associated with each localiser may render them monosemous. For instance, one can define only one location as being the “front side” of a ground. Thus, the localiser *qian-mian* can have only one sense, which allows reference only to this location.

Third, for most speakers, axial *qian*, *hou*, *shang*, and *xia* would display a minimal form of polysemy with respect to this “reference system” sense dimension, but more regularly than for *you* and *zuo*. The specific patterns can be illustrated by taking *qian* as an example. For this pattern, we used the coordination test to investigate the “co-existence” of these senses (cf. again *The Polysemy of Mandarin Spatial Categories: Previous Studies*). Most participants accepted the use of *qian* in a context in which multiple children (i.e., figures) could occupy the “intrinsic front” of a first car but the “relative front” of a second car (cf. 31);  $M \pm SD = 0.743 \pm 1.686$ ). Compound

localisers *qian-mian* and *qian-bian* would license similar though slightly decreasing responses, and so would *qian-fang* (cf. 32)  $M \pm SD = 1.714 \pm 1.824$ ). Compound localiser *qian-bu* would instead only license an “intrinsic” sense in this context. Participants understood that the children occupied the front “parts” of each car (cf. 33);  $M \pm SD = 0.629 \pm 2.545$ :

- 31) *Haizi men fenbie zai Fute che he Fengtian che qian.*  
 Child PL respectively z Ford car and Toyota car Q  
 “The children are in front of the Ford and the Toyota cars.”
- 32) *Haizi men fenbie zai Fute che he Fengtian che qian-mian/qian-bian/qian-fang.*  
 Child PL respectively z Ford car and Toyota car Q-façade/Q-side/Q-axis  
 “The children are in front of the Ford and the Toyota cars.”
- 33) *Haizi men fenbie zai Fute che he Fengtian che qian-bu.*  
 Child PL respectively z Ford car and Toyota car Q-part  
 “The children are at the front of the Ford and the Toyota cars.”

Overall, these three qualitative results highlight that simple localisers can also be polysemous, though their polysemy involves more restricted semantic ranges. The “location type” (e.g., “side,” “axis,” and “cardinal”), “reference system” (e.g., “intrinsic,” “relative,” and “absolute”), and “distance” semantic dimensions determine how these senses become increasingly specific. From a quantitative point of view, it seems clear that simple and compound localisers stand in hyponym relations. We thus suggest that some compound localisers are monosemous because they involve unique combinations of these dimensions and values. If *qian* can refer to any location type along a “front” axis, then *qian-mian* can only refer to a “front side” location type. Localisers thus seem to spell out the distinct semantic dimensions defining the semantic domain of Mandarin spatial categories.

## Interim Summary

Let us take stock. Our results show that the polysemy of Mandarin prepositions (here, *zai*, *dao*, and *cong*) is intertwined with intra-speaker variation and that this variation hinges on the sense type used in context. Most but not all informants accepted prepositions occurring without localisers when carrying “axial” and “topological” senses in context, but they were split on “cardinal” senses and, to a lesser extent, the “relative” pair *zuo* and *you*. Furthermore, informants confirmed that simple localisers could carry senses restricted to these sense dimensions, though with some *provisos* (e.g., the *nei* and *wai* data). They also confirmed that compound localisers would further be restricted in the “part location type” that their senses cover. These facts entail that compound localisers may be monosemous and stand in hyponym relations with simple localisers, which display restricted forms of polysemy. These facts also seem to entail that hyponymy relations seem to hold among prepositions and localisers, though intra-speaker variation and context sensitivity are again key factors.

We can therefore conclude that we have reached our first goal: offering an overview of the regular spatial polysemy and hyponym relations of Mandarin spatial categories. We also have reached our second goal: show that a form of nuanced

intra-speaker variation exists, based on the sense dimensions defining this polysemy. Our third goal becomes an account of these data that must capture the following three facts in a systematic manner. First, prepositions can act as hyponym-like items to localisers, given their broader polysemy. Second, the hyponym-like relations between simple and compound localisers suggest that one may define a spatial taxonomy of senses. Third, the apparent monosemy that affixes trigger must also receive an account (i.e., *-mian*, *-bian*, *-fang*; *-bu*, *-tou*, and prefix *zhi-*). To this account, we turn.

## A SEMANTIC ACCOUNT OF THE DATA

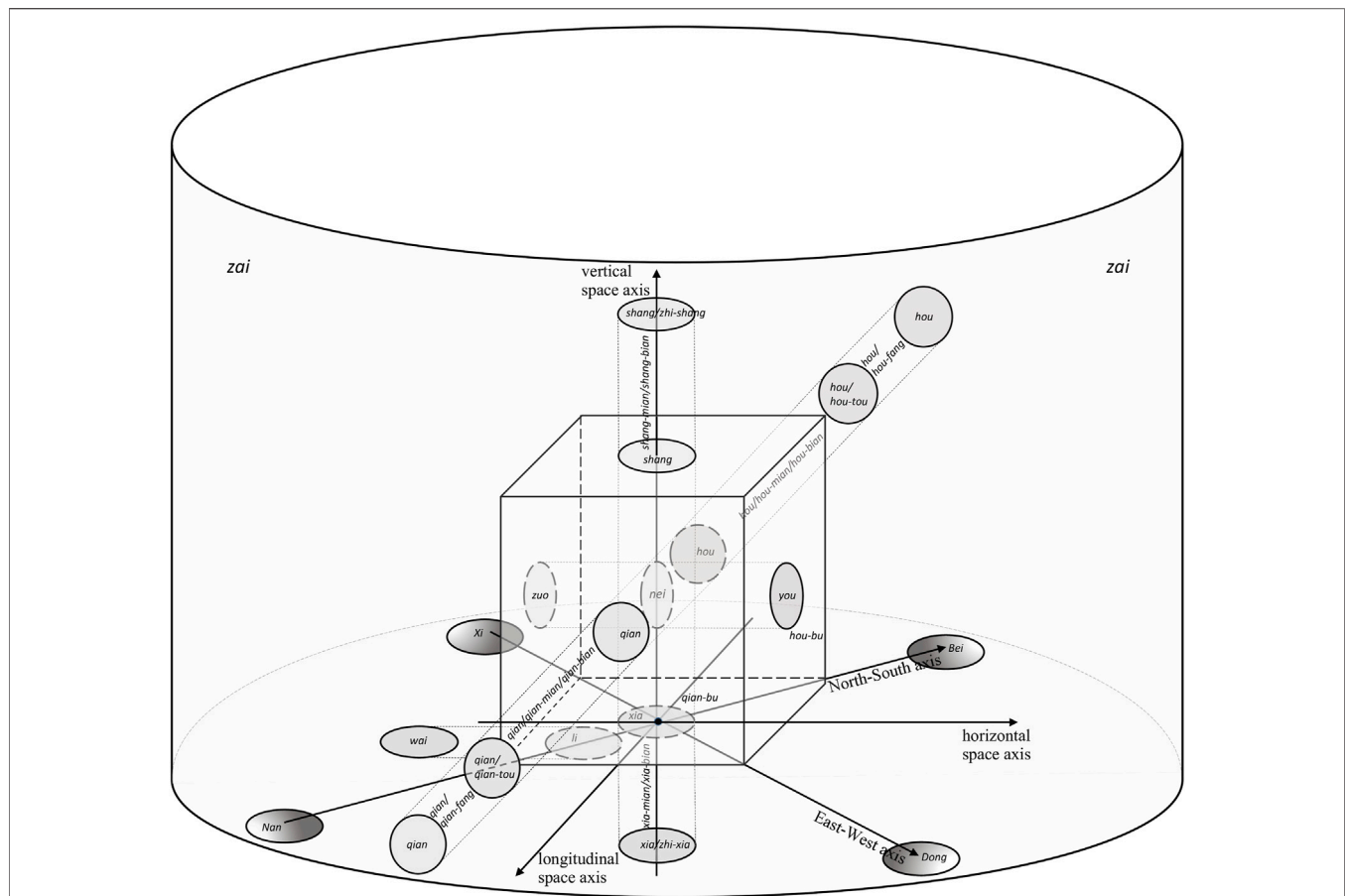
The goal of this section is to introduce our account of the data, based on the semantic maps approach (*Basic Assumptions and a Semantic Map for Zai*). We offer a model of the polysemy and sense relations in prepositions (*Prepositions and Their Schemas: Dao and Cong*) and localisers (*Localisers and Hyponym Relations*), paving the way for our general discussion.

### Basic Assumptions and a Semantic Map for Zai

Within typology, a method to account semantic variation is that of *semantic maps* (Croft, 2001; Haspelmath 2003; Cysouw 2010; Cysouw et al., 2010). Semantic maps involve two components: conceptual spaces (“models” in Croft 2001) and lexical matrices. Lexical matrices present senses/functions attested in a language and then assigned to each item in a category. Conceptual spaces represent cognitive, possibly non-linguistic concepts that languages can express (e.g., colour; Regier, et al., 2013). They are generally represented as either connected graphs (Haspelmath 2003) or Euclidean spaces (Croft and Poole 2008). Cognitive Linguistics proposes similar but not identical models. Most proposals use *Idealized Cognitive Models*, graph-like maps representing sense networks of single vocabulary items (e.g., Lakoff, 1987; Lakoff and Turner 1989; Gibbs 1994; Tyler and Evans, 2003; Glynn 2012, 2014; Evans, 2015). A prototypical sense (e.g., “enclosure”) can be refined *via* the addition of further senses (e.g., “enclosure and support”). Networks, in turn, form radial categories: specific senses are derived from the prototypical sense *via* the addition or omission of semantic features.

The semantic maps model eschews the existence of prototypical senses; nevertheless, they represent polysemy *via* network senses-like graphs. Cognitive approaches do not specify the nature of relations between prototypical sense and other senses: senses are inherently distinct. Thus, each approach has its own *pros* and *cons*. We propose to overcome this theoretical *impasse* by using a combination of the two perspectives along the following points.

First, we base our model on *Image Schemas*, structured representations of perceptual information associated with senses and their relations (e.g., Johnson 1987; Lakoff 1987; Langacker 1987, 1991, 2008; Tyler and Evans, 2003: Ch. 2; Hampe 2005; Zwarts 2005; Kang 2012). Image schemas (or schemata, in some works) tend to represent such information in abstract terms. The “inclusion” schema, for instance, simply



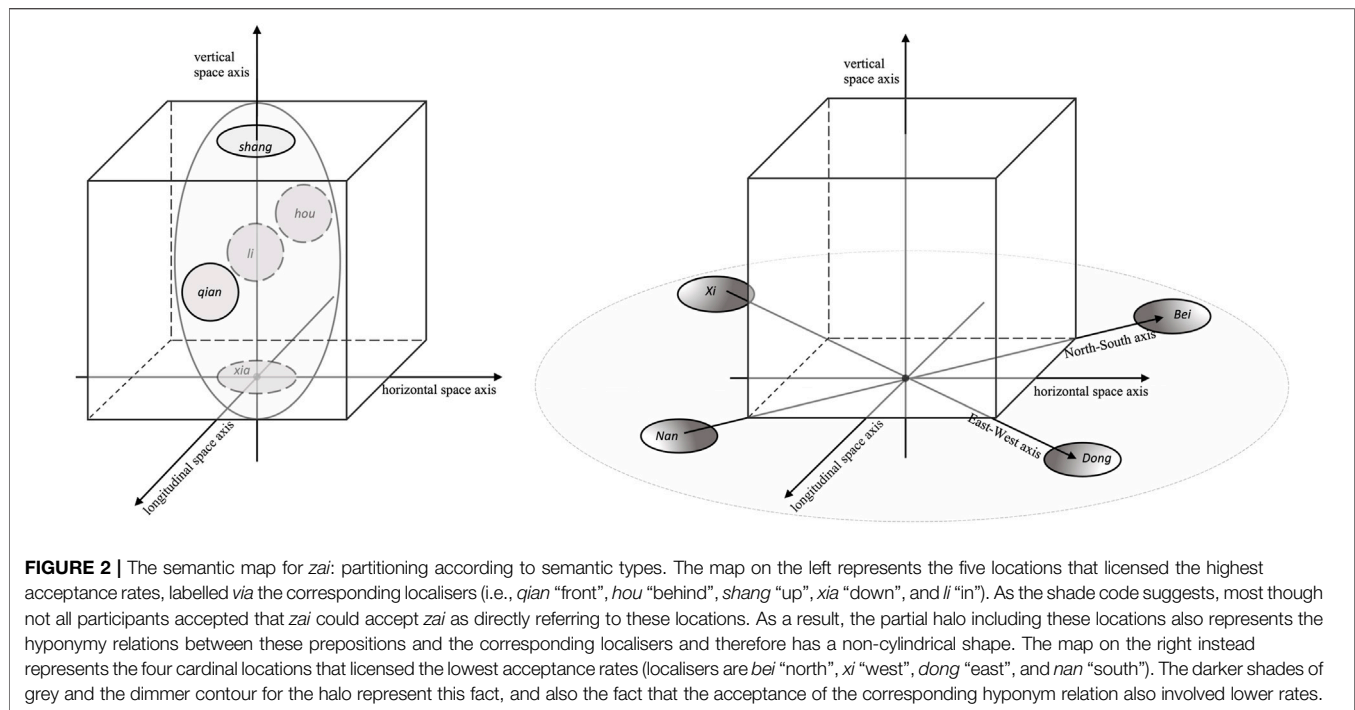
**FIGURE 1 |** The semantic map for *zai* and its range of possible locations. The map represents a ground as an idealised cube, abstracting away from the role of shape in determining the nature of the locations to which prepositions and localisers refer. *Zai*'s potential polysemy domain is represented as a cylinder-shaped (“halo”) region encompassing all the regions/locations that localisers refer to. For instance, the “front” location to which *qian-mian* refers is part of *zai*'s halo. Locations also carry different shades to represent the “strength” of hyponym relations. This figure represents this fact by having the four cardinal locations be in dark grey and other locations in light grey. A consequence of building semantic maps in this manner is that distinct categories may stand in hyponym-like relations. As our map shows, prepositions may refer to “general” regions, for speakers that accept their polysemy: localisers thus refer to more “specific” regions within these general regions. Categorical distinctions play a role at a grammatical level of organisation, but not at a conceptual level.

represents a figure as being within the location occupied by a ground, with both referents possibly idealised to points in space. Our maps follow a similar philosophy but take a more fine-grained, paradigmatic approach to the representation of locations, as we explain in the remainder of this section.

Second, we determine the locations and axes that are part of these maps by using the sense dimensions that we have individuated in the *Results* section. Axial localisers refer to different types of locations along a given axis. For instance, *qian* refers to the possible locations along the “front” semi-axis and *hou* to the “back” semi-axis (cf. **Figure 1**). Similar reasoning extends to pairs *shang* “up” and *xia* “down,” and *zuo* “left” and *you* “right.” Compound localisers can partition this complex location into more specific locations: for instance, *qian-mian* refers to the “front side” location of a ground and *qian-bu* the (intrinsic) “front part”. Topological localisers refer to internal (e.g., *li* “in” and *nei* “within”) or external (e.g., *wai* “out”) locations; cardinal localisers (e.g., *bei* “north”) refer locations

defined *via* the cardinal system. Compound localisers involving suffix *-fang* and prefix *zhi-* refer to locations at a “distal” distance from the ground. Other compound localisers refer to locations that may be “proximal” to the ground, whether they be “internal” (e.g., *-tou*) or external (e.g., *-bian*).

Third, we use the following visual conventions to represent these locations. We use circles to represent undirected locations and directed and continuous lines (“vectors”) to represent axes/projections, i.e., directed locations. We label sets of connected locations as “regions” and sets of connected projections as “axes”. We then use sequences of segmented, directed lines (“paths”) to represent directions. Hence, paths represent motion “to” and “from” the ground; vectors represent axes/directions defined *via* specific locations (e.g., Jackendoff 1983, 1990; Lakoff and Núñez, 2000: Ch. 2; Zwarts and Winter 2000: 209; Zwarts 2005; Langacker 2008: 340–380; Kang 2012; a. o.). Our maps thus represent regions, locations, paths, and axes as distinct spatial referents that can nevertheless be defined with respect to the ground.



Fourth, we represent a ground as a three-dimensional object and the centre of a semantic map. From this centre, we define a set of spatial referents *via* the semantic dimensions that localisers can cover. We can represent the polysemy of simple localisers *via* their ability to refer to regions or axes, i.e., sets of connected locations or projections that monosemous compound localisers can independently individuate. We therefore represent hyponymy relations *via* mereo-topological (i.e., spatial “part-of”) relations. For instance, the specific “front part” region that *qian-bu* refers to is part of the “front axis” that *qian* refers to. We thus represent the conceptual relation between polysemy and hyponymy by showing that the semantic range of one vocabulary item can be part of the semantic range of another vocabulary item.

Fifth, we represent intra-speaker variation with respect to their acceptance of prepositions’ polysemy *via* a shading code. Circles with a light grey shade represent locations for which most speakers accepted sentences with and without localisers (e.g., the “front” location). Circles with a dark grey shade represent locations for which acceptance rates were statistically significant (e.g., the “North”) location. For these locations, participants rejected sentences without localisers more than our original predictions, whence the darker shade. We illustrate this point *via* the proposed map for *zai*.

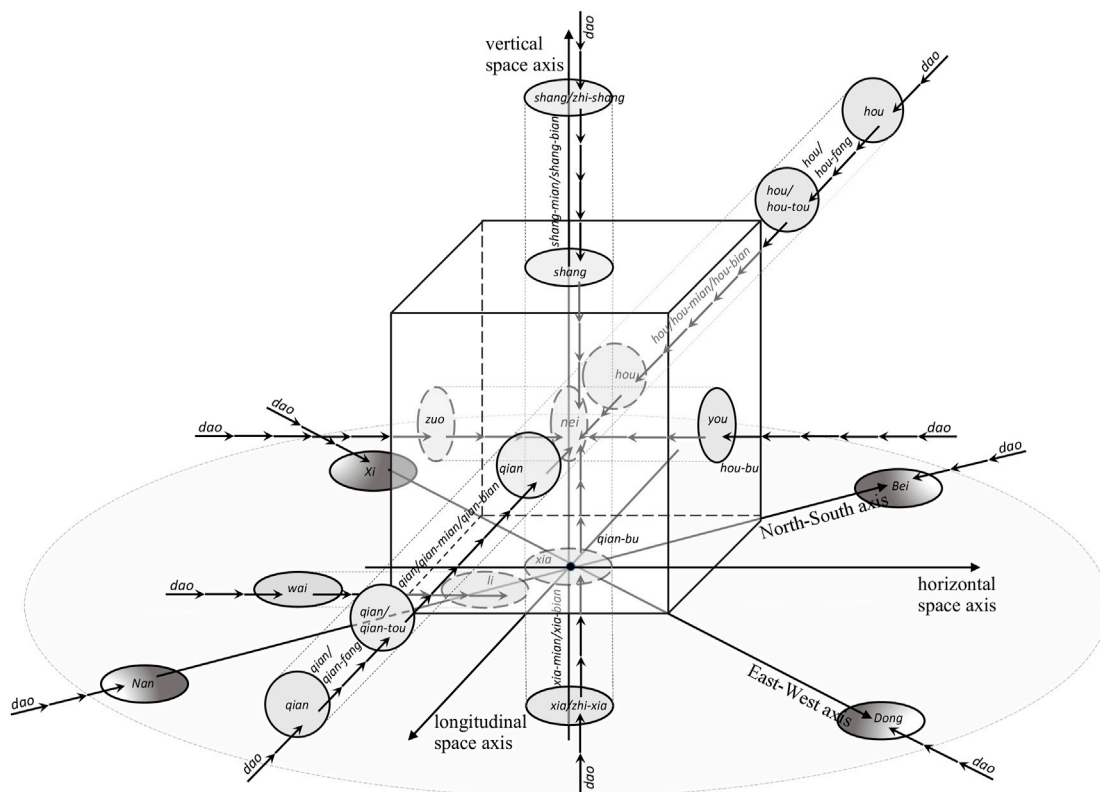
The map in **Figure 1** suggests that *zai* may refer to a “halo” region that can include the regions and axes that localisers can refer to (i.e., the halo includes all the circles; cf. Asher and Sablayrolles 1995). This is also a visual representation of the cumulative hyponymy relations holding between *zai* and localisers. *Zai* can potentially act as a hyperonym to localisers, since its halo-like region includes other regions and locations as its distinctive parts. The shading principle shows that not all participants may consider *zai* and a localiser potentially referring to the same location/region.

For some speakers, such locations must be excluded from *zai*’s halo, which can thus have “holes” in its semantic domain. The four locations expressed *via* the cardinal localisers *dong*, *xi*, *nan*, and *bei* (respectively, “east”, “west”, “south”, and “north”) represent such holes in *zai*’s map. To illustrate these differences in acceptance patterns, we present a map in which we differentiate locations according to their shading code in **Figure 2**.

The maps in **Figure 2** may be read from left to right as presenting snapshots or comic-like panels that show how *zai*’s halo may extend in covering different location types, but may also “weaken” as a result. Participants accepted that *zai* could refer to locations more directly connected to the ground and its parts, but the extension of *zai*’s semantic halo to cardinal locations was considered weaker. In this regard, the map in **Figure 1** can be conceived as integrating the two maps into **Figure 2** into a more inclusive since **Figure 1** also includes the four other tested locations (i.e., *nei* “within”, *wai* “out”, *zuo* “left”, and *you* “right”). Once we have a clear definition of the model, we can explain how data are represented. We thus introduce **Figures 3, 4** in the next section to explain the representation of *dao* and *cong*’s senses.

## Prepositions and Their Schemas: *Dao* and *Cong*

Let us address *dao* and *cong* and their potential polysemy. Recall that these prepositions involve a notion of “directedness”: “to” the ground for *dao* and “from” the ground for *cong*. As our data show, most participants accepted the possibility that these prepositions can be polysemous in a manner similar to *zai*. A minimal sense difference with *zai* is that *dao* and *cong* would refer to these locations as “goals” and “sources” of moving grounds,



**FIGURE 3** | The semantic map for *dao*. The map represents *dao*'s halo indirectly: all the paths reaching the ground, or locations/regions defined with respect to the ground, are part of the region/halo that *dao* covers. This entails that when sentences describe forms of directed movement, they can lack localisers. This is the case because *dao* can refer to the location that a figure reaches as one of the possible “goals” of the figure.

respectively. We thus adopt the same shading code that we use for *zai*. We offer the corresponding maps in **Figures 3, 4**.

Overall, our maps show that these prepositions are potentially polysemous: all participants accepted that they could refer to some locations that localisers would also refer to. Participants would differ on the polysemy range assigned to each preposition, as the “cardinal type” data show. In the proposed maps, this fact is captured by the shading code. The fewer speakers would accept, e.g., *zai* to refer to a location (e.g., “north”), the darker such location is shaded, hence resembling a “hole” in the map (cf. again **Figures 1–4** and the shades associated with cardinal localisers). Halos thus represent the potential regions that prepositions can refer to, in sentences lacking a localiser. However, intra-speaker variation emerges when one looks at what “location types” are part of this polysemy. We can thus conclude that the quantitative results discussed in *Results* regarding the “strength” of the polysemy of these prepositions also find a visual representation in the maps.

### Localisers and Hyponym Relations

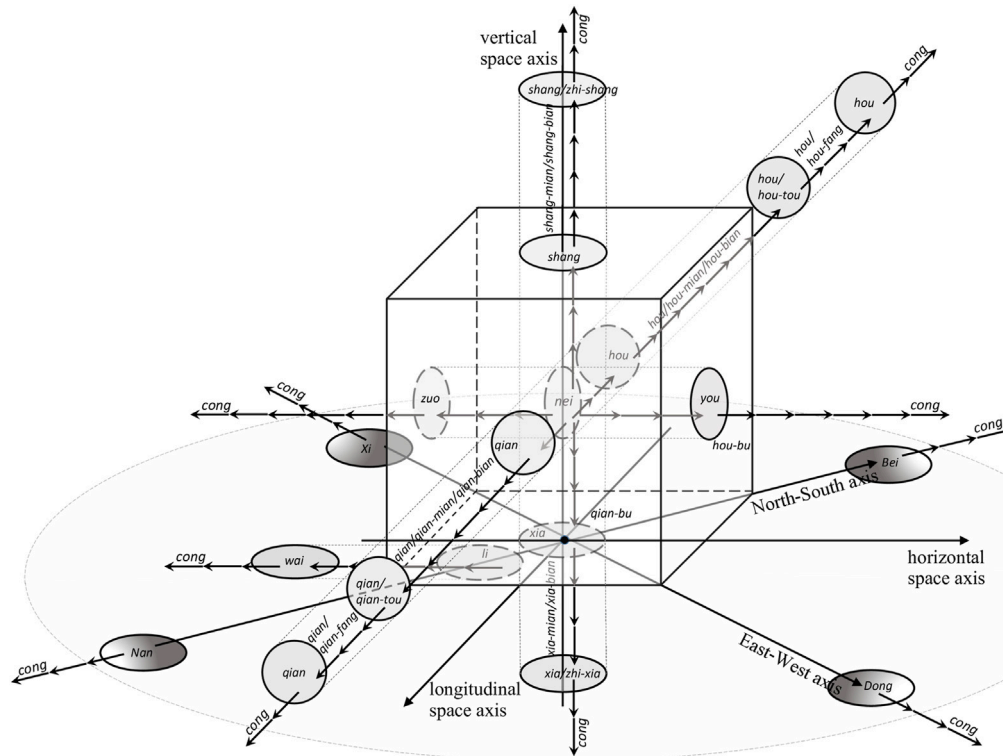
We turn our attention to localisers and their restricted forms of polysemy. For this purpose, we introduce the map that we associate to *qian* and its hyponym localisers in **Figure 5**.

As the figure shows, a localiser can refer to a set of locations defined along a given axis. The “location types” involved in this form of polysemy can be defined *via* the senses of the suffixes

attaching to each localiser. This type of analysis may be extended to the other localisers (e.g., *hou* “back”, *xia* “down”, and *shang* “up”) to define localiser-specific maps that can be combined into the general maps offered in **Figures 1–4**. The restricted regions of space that these localisers refer to can also be conceptualised as paths (cf. again **Figures 3, 4**). Thus, the path reaching the “front side” location and the path leaving this location respectively represent this location as a “goal” and a “source” that a figure reaches or leaves. The hyponym relations between pairs of simple and compound localisers that emerge from our data also receive a visual representation. For instance, the “front side” location that *qian-mian* refers to becomes part of the larger region that *qian* refers to, i.e., the set of circles also marked *via* the *qian* label. The white shading represents the fact that all participants accepted these relations in context, due to the restricted polysemy of *qian*.

Since the map in **Figure 5** does not allow us to discuss the semantic contribution of prefix *zhi-*, we offer one map dedicated to this task in **Figure 6**.

Compound localisers can possibly refer to only one of these regions and can thus be monosemous. Our maps show that, for instance, *-bu* individuates the “parts” of an object as a cluster of not necessarily contiguous but nevertheless connected locations (cf. *qian-bu* in **Figure 5**). When this suffix combines with a localiser, the locations that both elements can refer to become the locations that a compound localiser can refer to. For instance, if *li* refers to an



**FIGURE 4 |** The semantic map for *cong*. The map represents *cong*'s halo indirectly: all the paths leaving the ground, or locations/regions defined with respect to the ground, are part of the region that *cong* covers. This entails that when sentences describe forms of directed movement, they can lack localisers. This is the case because *cong* can refer to the location that a figure reaches as one of the possible “sources” of the figure.

“in (ner)” region and *-bu* “part” a region (type), then *li-bu* refers to an “in (ner) part” region. Instead, the suffix *-tou* refers to a single region at a certain distance and axis/direction from the ground (e.g., *qian-tou* denoting a “front edge” location). The maps also show that affixes seem to refer to location types, i.e., locations individuated *via* given properties. Thus, *zhi-* localisers refer to locations that are at a “distal” distance from the ground, as the *zhi-shang* and *zhi-xia* locations show (cf. again **Figures 1, 3, 4**).

Overall, we can represent the fact that these affixes partition a spatial semantic domain involving the “distance”, “reference system”, and “location type” sense dimensions. *Via -bu*, compound localisers only refer to “parts”. *Via -mian* and *-bian*, they only refer to external “sides.” *Via -tou*, they only refer to “edges”; *via -fang* but also *via zhi-*, they only refer to “distal” locations, and *-fang* also selects “axes.” Cardinal localisers such as *bei* “north” capture these distinctions but involve an “absolute” reference system. The triplet of topological localisers *li*, *wai*, and *nei* instead defines regions’ clusters that can be conceived as either internal or external with respect to figure’s position to the ground but that lack other senses.

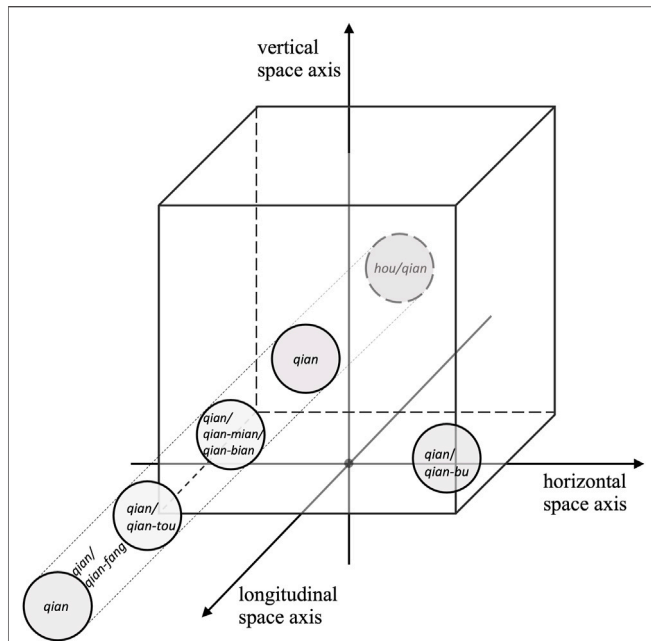
We can therefore conclude that our maps can capture the regular spatial polysemy and hyponymy patterns attested in Mandarin localisers. In so doing, they capture the hyponym relations that emerge among these items in a systematic manner. Our maps can also capture the nuanced forms of intra-speaker variation associated with the potential regular polysemy of spatial prepositions *via* a shading code, and the

potential hyponymy relations with localisers. Our maps thus represent that polysemy seems sensitive to categorial distinctions (e.g., prepositions vs. localisers), to semantic distinctions (e.g., “axial” and “part type” location types), and to the role of context. We have now reached our third goal: a formal account of the data. We can move to the general discussion.

## GENERAL DISCUSSION

We believe that six key results emerge from our account that are worth discussing in detail.

First, our maps offer an account of the potential regular polysemy of Mandarin spatial categories. We have shown that Mandarin prepositions *zai*, *dao*, and *cong* can be polysemous for participants who accepted their use without localisers in context. Such uses seem to depend on the “location type” at stake and may even involve the item-specific semantic properties of individual items (e.g., *nei* “within” and *you* “right”). Localisers presented a more transparent picture: simple localisers (e.g., *qian*) cover sense types that compound localisers cover on an even more specific basis (e.g., *qian-mian* and *qian-bian*). Therefore, these data show that regular polysemy seems a paradigmatic property in localisers and a property subject to intra-speaker variation for prepositions (cf. Huang et al., 2017). Though nuanced, this picture however sheds new light on regular polysemy in these categories. Most previous



**FIGURE 5 |** The semantic map for *qian*. The map represents *qian*'s more restricted polysemy. This simple localiser can refer to the “intrinsic front” of a ground or its “relative front” (i.e., a ground’s “back”, thus overlapping with *hou* in reference). It can also refer to the (external) “front side” of a ground, although the compound localisers *qian-mian* and *qian-bian* can only refer to this location. The compound localiser *qian-bu* refers to a “front part”, i.e., the portion of a ground that may define the front axis. We only mark a portion of this part as *qian-bu* to maintain the same size for all circles. *Qian-fang* refers to a “front axis”, whence its position is at a “distal” distance from the ground. Prefixation *via zhi-* is blocked for this localiser; hence, we do not include them in the map.

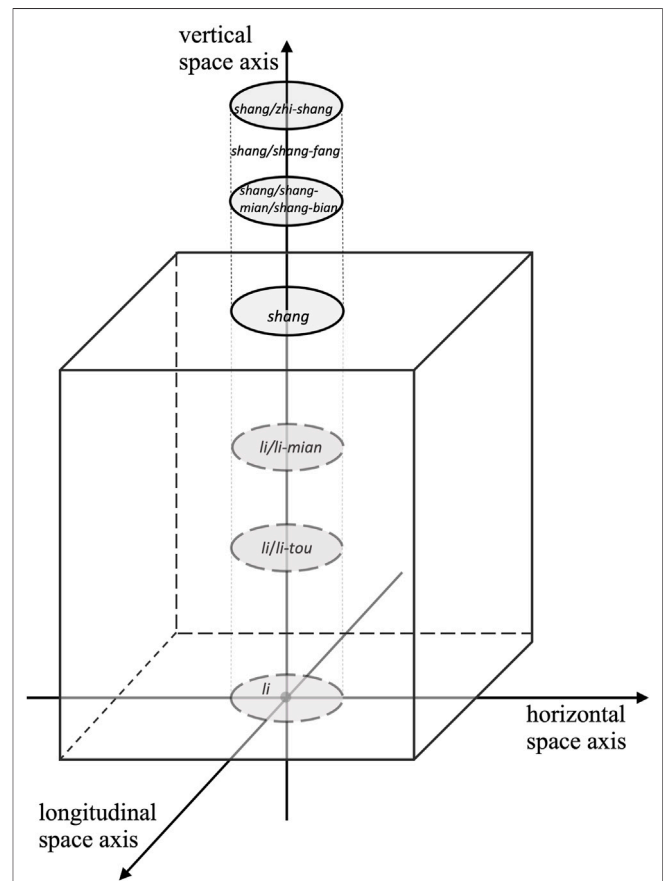
works only investigate prepositions and localisers’ logical polysemy (e.g., spatial vs. temporal senses; Wu and Muchinei, 2018).

Second, our maps capture the fact that informants can accept the restricted polysemy forms of localisers and the hyponymy relations emerging from these forms of polysemy. Crucially, our study makes explicit the range of senses that localisers can cover. Thus, we can say that simple localiser *qian* covers different location type senses because it can be used in the same contexts of compound localisers (e.g., *qian-mian*, *qian-bian*, *qian-fang*, and *qian-bu*). Similar reasoning extends to other localisers and their potential affixation *via -tou* (e.g., *li-tou*) and *zhi-* (e.g., *zhi-xia*). The first and second results therefore support the conclusion that polysemy acts as an inherently multi-dimensional property. What counts as a grammatical/lexical property for some speakers (e.g., *zai* covering cardinal senses) may become a pragmatic inference for other speakers (cf. Cruse 2004; Murphy 2010; Glynn 2012, 2014, 2016; Carston 2020).

Third, our maps capture the semantic dimensions that seem to partition the semantic domain of space. Simple localisers seem to select senses based on “topological”, “axial”, and “reference system” dimensions (cf. Jackendoff 1983, 1990; Tai 1993; Tai, 2005). Compound affixes can select senses restricted to the dimensions of “distance” (cf. *zhi-* forms) and “part type” (e.g., *-bu* forms). This result is consistent with works on the lexical typology of spatial prepositions (e.g., Sinha and Kuteva 1995; Zwarts and Winter 2000; Levinson and Wilkins 2006; Aurnague

and Vieu 2015). Thus, our study displays a strong degree of consistency with previous models in the literature. It however adds a general “location type” dimension *via* the study of compound localisers, as part of a general model of this domain.

Fourth, our study is also consistent with Levinson and Meira’s (2003) conceptual hierarchy, although in a subtle manner. Two aspects offer proof of this theoretical consistency. First, our maps suggest that senses related to “cardinal” (e.g., *bei* and its sense) and “relative” (e.g., *zuo* and its sense) dimensions represent a semantic boundary among speakers (cf. also Palmer et al., 2017b). Second, our maps suggest that prepositions and localisers’ grammatical division of labour stem from this conceptual tension. Therefore, hyponymy relations among prepositions and localisers can emerge when localisers refer to regions that are “part of” the regions that “general” *zai*, *dao*, and *cong* cover. This result suggests that Mandarin prepositions and localisers partition the semantic domain of space in hierarchical manners that are reflected at a grammatical level. These partitions, in turn,



**FIGURE 6 |** The semantic map for *shang* and *li*. The map illustrates the locations that compound localisers *li-mian* and *li-tou* refer to. As the maps shows, *li-tou* refers to a perhaps more specific location, an “internal edge”. Instead, *li-mian* refers to the “internal side” of an object. On the vertical axis, *shang* “up” refers to a cluster of locations (i.e., a region), *zhi-shang* “far up, above” to an upper location distant from the ground, and *shang-mian/shang-bian* to an “up (per) side”. Participants mostly considered *zhi-shang* and *shang-fang* as near-synonymous, as the map suggests.

reflect cross-linguistic semantic dimensions of variation that, crucially, are not explored in Levinson and Meira's (2003) work.

Fifth, *via* our maps, we offer an approach to polysemy that is mostly semantic but with a pragmatic component. Again, the fact that participants accepted sentences including prepositions without localisers offers evidence confirming hyponymy relations (e.g., *zai* and *hou*). This evidence also suggests that multiple senses must be part of items' representations for these relations to be accessible. However, one can model these relations once their use in context is analysed. Hence, our view appears symmetrical to but perhaps compatible with pragmatically oriented views of polysemy (Falkum 2011; Falkum and Vicente 2015; Carston 2020). Our view places a greater emphasis on the role of grammar and lexicon in polysemy.

Sixth, the perspective that the maps bring about also attempts to connect two parallel but compatible approaches to the modelling of sense and sense relations. The first involves lexical typology and semantic maps (e.g., Cysouw et al., 2010), and the second involves Cognitive Linguistics schemas (e.g., Tyler and Evans 2003; Langacker 2008). Our proposal models spatial senses in Mandarin prepositions and localisers and their polysemy by representing how they refer to locations defined with respect to a ground. In our account, semantic maps and cognitive models become integrated conceptual tools capturing how speakers use spatial categories and their relations in context (Glynn 2012, 2014; for a similar point). Therefore, they define the space of Mandarin spatial categories in a systematic and yet flexible manner. With this point in mind, we can turn to the conclusions.

## CONCLUSION

The first goal of this paper has been to offer empirical evidence of the spatial polysemy and hyponymy relations in Mandarin spatial categories. We have shown that Mandarin prepositions (e.g., *zai*) and simple and compound localisers (e.g., respectively, *qian* "front" and *qian-mian* "front-side") can cover increasingly specific sets of spatial senses, thus displaying decreasing forms of polysemy. These results support the view that these categories operate a distribution of labour on how they capture the spatial relations between figure and ground, and how they cluster spatial senses into cohesive sub-domains. The second goal has been to show that these relations can involve nuanced forms of intra-speaker variation, which in turn can inform an account of these data. The third goal has been to offer a formal account based on semantic maps that can also capture the attested intra-speaker variation. The account shows that a visual rendition of these patterns can be offered that models sense types and sense relations as spatial relations among location types.

The paper has reached each goal by offering a novel extension of the semantics maps model based on the collected data. The suggested generalisations can thus shed light on how the semantic domain of space is conceptualised in Mandarin and how sense properties such as polysemy emerge from this organisation. Let us remind the reader, however, that our work has focused on three prepositions (*zai*, *dao*, and *cong*) and 13 localisers (e.g., *qian*, *li*, and *bei*: cf. again 6), among the dozens of vocabulary items that belong to each category. We conjecture that our account can be extended to other prepositions

and localisers. However, whether this type of analysis can be extended to all (spatial) prepositions and localisers in Mandarin is a question that we must leave for future work.

A final observation is that our account opens at least three interesting theoretical questions. The first question is whether and how the account is consistent with analyses of logical polysemy in spatial categories, i.e., analyses investigating temporal and metaphorical senses (e.g., Tyler and Evans 2003; Kang 2012). After all, we only have addressed spatial senses. A second complementary question is whether and how the account can also offer insights that can be "translated" into formally oriented accounts of spatial categories. This appears a possibility if one uses the logic of semantic maps to develop such formalisms (cf. Zwarts and Winter 2000; Zwarts 2005, 2017). The third question is whether and how the account can inform syntactic analyses of Mandarin spatial categories (e.g., Chappell and Peyraube 2008; Djamouri et al., 2013; Wu 2015). We believe that these questions can be answered in the positive. However, we must leave such tasks for future research.

## DATA AVAILABILITY STATEMENT

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

## ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the General Ethics Committee, Sun Yat-Sen University. The patients/participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

## AUTHOR CONTRIBUTIONS

F-AU designed the study, wrote the manuscript, and performed the figures' design. QR designed the study, collated the literature review, and performed the data analysis. YZ ran the experimental portion of the study and prepared the figures and the reference list.

## FUNDING

This work was supported by the MOE (Ministry of Education in China) Project Foundation of Humanities and Social Sciences (21YJC740042) and the China Postdoctoral Science Foundation (2019T120674).

## SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fcomm.2021.724143/full#supplementary-material>



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