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Frames of Reference in Spatial Memories Acquired From Language

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Four experiments examined reference systems in spatial memories acquired from language. Participants read narratives that located 4 objects in canonical (front, back, left, right) or noncanonical (left front, right front, left back, right back) positions around them. Participants' focus of attention was first set on each of the 4 objects, and then they were asked to report the name of the object at the location indicated by a direction word or an iconic arrow. The results indicated that spatial memories were represented in terms of intrinsic (object-to-object) reference systems, which were selected using egocentric cues (e.g., alignment with body axes). Results also indicated that linguistic direction cues were comprehended in terms of egocentric reference systems, whereas iconic arrows were not.

It is essential for human beings, as locomoting organisms, to represent in memory the locations of objects in the surrounding environment. People can learn locations of objects in the surrounding environment either from perception or from language. Learning the locations of landmarks in an unfamiliar city by one's own observation is an example of the former; learning them from a guidebook is an example of the latter. Because we are able to describe the locations of objects learned by perception to others and we can visualize the locations of objects described by others, it is plausible that spatial memories from perception and spatial memories from language share similar cognitive structures (e.g., Clark, 1973; Jackendoff, 1987; Talmy, 1983).

The location of an object cannot be specified or described without providing, at least implicitly, a frame of reference. To understand human spatial memory and cognition, it is useful to divide spatial reference systems into two categories (e.g., Pani & Dupree, 1994): *Egocentric* reference systems are those in which location is specified with respect to the observer. Examples include (but are not limited to) retinal, head, and body coordinates. *Environmental* reference systems are those in which location is specified with respect to objects in or features of the environment. Examples include the walls of a room, geographic landmarks, and parallels of latitude and meridians of longitude.

Growing evidence suggests that long-term memories of the locations of objects in the environment are organized in terms of environmental reference systems; in particular, the location of an object seems to be specified in terms of other objects (e.g., Easton & Sholl, 1995; Hintzman, O'Dell, & Arndt, 1981; Mou & McNamara, 2002; Shelton & McNamara, 2001; Sholl & Nolin, 1997; Werner & Schmidt, 1999). For example, Hintzman et al. (1981) found that participants' focus of attention on one object affected accessing spatial locations of other objects in spatial memories acquired from perception. Participants learned the locations of eight objects surrounding them in a room (~45° apart), were taken to a different room, and pointed to target objects relative to orientation cues (e.g., *The candle is in front of you; point to the hat. The television set is to your right, point to the book*). Response times varied according to the following pattern: The cued, or focused, object followed by the one opposite to it (but on the same axis) obtained the quickest responses; the objects adjacent to it obtained the slowest responses (focused < opposite < adjacent right = adjacent left). For example, when the focus was on the right, the pattern was right < left < front = back. The focused < opposite < adjacent right = adjacent left pattern suggests that spatial location from perception is coded with respect not to the observer's body, but to other objects.[1]

Recent evidence reported by Shelton and McNamara (2001) and by Mou and McNamara (2002) is also consistent with this conclusion. In one of Shelton and McNamara's experiments, participants learned the layout of objects in a cylindrical room from three points of view (0°, 90°, and 225°). Half of the participants learned the views in the order 0°, 90°, 225°, and half learned the views in the reverse order. Participants spent the same amount of time at each study view. Accuracy of judgments of relative direction (e.g., *Imagine you are standing at the book and facing the lamp; point to the clock*) indicated that only the first study view (0° or 225°)

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[1] Hintzman et al. (1981) did not report whether this pattern held for all focused objects (i.e., all orientations), but if we assume there was no interaction with focused object, their data suggest that participants represented the spatial relation between each object and the one opposite to it (e.g., 0°–180°, or 45°–225°). However, because participants were tested on more than 900 trials over 3 days, stimulus–response learning during the testing phase (e.g., Logan, 1988) could have influenced the results. Regardless, the findings are difficult to accommodate in an egocentric-representation model.

was mentally represented: Pointing judgments were accurate for imagined headings parallel to the first study view but no more accurate for headings parallel to the second and the third study views than for novel headings. Indeed, there was no behavioral evidence that participants had even seen the second and the third study views.

To explain these and other findings, Shelton and McNamara (2001) proposed that learning and remembering the spatial structure of the surrounding environment involve interpreting the layout in terms of a spatial reference system. They suggested that this process is analogous to determining the top of a figure (e.g., Rock, 1973); in effect, conceptual "north" is assigned to the layout, creating privileged directions in the environment (e.g., Tversky, 1981). The frame of reference for this interpretation is selected using egocentric and environmental cues, such as viewing perspective and alignment with walls, respectively. Egocentric cues are dominant because the spaces of human navigation rarely have directions or axes as salient as egocentric experience. An important claim of this theoretical framework is that spatial memories are organized in terms of environmental reference systems.

As an example, consider the cylindrical room experiment discussed previously. According to the theory, when observers studied the layout of objects from the first viewing position, they interpreted it in terms of a reference system aligned with their viewing perspective. When they were taken to the second and the third learning views, they continued to interpret the spatial structure of the layout in terms of the reference system defined by the first point of view, just as if they were viewing a (now) familiar object at novel orientations. This reference system remained the dominant one, even when participants moved to the next two points of view, because no other point of view was aligned with a salient axis in the environment.

Mou and McNamara (2002) extended Shelton and McNamara's (2001) theory by proposing that locations of objects were represented with respect to an intrinsic frame of reference defined by the collection of objects (e.g., rows and columns formed by chairs in a classroom). They instructed participants to learn the layout of a collection of objects along an intrinsic axis, which was different from or the same as their viewing perspective. After learning, participants made judgments of relative direction using their memories. Pointing judgments were more accurate for imagined headings aligned with the learning axis, even when it differed from the viewing perspective, than for other imagined headings, and there was no cost to learning a layout along a nonegocentric axis. Mou and McNamara proposed that when people learn the layout of objects in a new environment, they use egocentric and environmental cues to select an intrinsic frame of reference. These cues include viewing perspective, instructions, properties of the objects (e.g., they may be grouped on the basis of similarity or proximity), and the shape of the layout itself (e.g., it may appear square from a particular viewing perspective).

Although experimental evidence suggests that spatial memories acquired from perception are organized with respect to intrinsic frames of reference, the prevailing opinion in the literature on spatial memories acquired from language is that locations of objects around an observer are represented in egocentric frames of reference. Some of the strongest evidence in support of this view comes from the influential experiments conducted by Franklin and Tversky (1990).

In Franklin and Tversky's (1990) experiments, participants first studied a printed version of a second-person narrative describing a scene, where objects were located above the head and below the feet, in front and behind, and on the left or right of the character. In the second phase, participants were presented other portions of the narrative on a computer, each time reorienting their point of view to mentally face one of the objects in the horizontal plane. For each orientation, three sentences—a reorientation sentence, a description sentence, and a filler sentence—were presented. The reorientation sentence instructed the participant to mentally adopt a new point of view to face another object. The description sentence gave a visually detailed description of the object. The filler sentence followed the description sentence without mentioning any object explicitly, so as to remove any potential name-priming effects. Then, directional words (*front, back, left, right, above* or *below*) were presented, and participants were asked to name the object at the location indicated by the directional word.

The results showed that response times for reporting objects at different locations on the horizontal plane varied systematically: front, followed by back, obtained the fastest responses; left and right obtained the slowest responses (front < back < left = right). To explain these findings, Franklin and Tversky (1990) proposed that the spatial relations between a character and the surrounding objects described in a narrative were computed within a body-centered coordinate framework (also see Clark, 1973; Johnson, 1987; Lakoff, 1987).

There are reasons to question this interpretation, however. It is possible that the egocentric direction pattern might arise from processing the meanings of directional words (*front, back, left,* and *right*) rather than accessing egocentric representation of locations. At least two observations support this hypothesis. A series of studies in the late 1970s on the relative difficulty of "right versus left" judgments (e.g., differentiating right from left takes longer than differentiating above from below) showed that the egocentric direction pattern was specific to the directional words. Maki, Grandy, and Hauge (1979) showed that replacing words with arbitrary letters that had been paired with arrows eliminated the right–left effect. Furthermore, Maki (1979) showed that spatial judgments using arrows rather than words eliminated the right–left effect. Farrell (1979) reported that it is more difficult to deal with left and right than with up and down when differentiating between the two directions than when orienting to them. Verbally differentiating the visual presentation of left and right arrows was more difficult than verbally differentiating the visual presentation of up and down arrows. But the left–right effect was eliminated in the condition of making left or right manual movement when responding to the visual presentation of left and right arrows and making front or back manual movement when responding to the visual presentation of up and down arrows. Another reason to suspect that the egocentric direction pattern may be caused by the spatial words used as stimuli can be found in investigations of the effects of response modality. de Vega, Rodrigo, and Zimmer (1996) showed that the egocentric direction pattern was specific to the labeling modality but not to the pointing modality. Using a variant of Franklin and Tversky's (1990) paradigm, de Vega et al. required participants to name or to press an arrow key to report the location of a probed object around their bodies. Front/back was faster than left/right only when participants named the direction.

Our conjecture is that spatial memories acquired from language also may be represented using intrinsic reference systems. Following Mou and McNamara (2002) and Shelton and McNamara (2001), we assume that an intrinsic frame of reference is selected on the basis of egocentric cues, such as alignment with the front–back, right–left axes. Object-to-object spatial relations that are aligned with this intrinsic frame of reference are represented more strongly or with higher probability than are other object-to-object relations.

Consider, for example, the collection of four inanimate objects depicted in Figure 1. One possible intrinsic organization pairs *cannon* with *flag* and *antenna* with *lifeboat* in a +-shaped layout. An alternative organization, however, pairs *cannon* with *antenna*, *antenna* with *flag*, *flag* with *lifeboat*, and *lifeboat* with *cannon* in a diamond/square-shaped layout. Either of these intrinsic frames of reference could be used to specify the locations of the objects (other intrinsic organizations are also possible of course). For an observer oriented as illustrated in Figure 1, the first of these intrinsic frames of reference is aligned with the egocentric front–back and right–left axes and, therefore, is more salient. Hence, if a person read a second-person narrative describing the scene in Figure 1, he or she would represent interobject spatial relations in terms of this intrinsic reference system, so that the pairs *cannon–flag* and *antenna–lifeboat* would be more strongly associated than other pairs.

The relative strength of these object-to-object spatial relations produces the focused < opposite < adjacent left = adjacent right pattern observed by Hintzman et al. (1981). When attention is focused on one of the objects (e.g., by reading a sentence that describes it), the other objects are activated in memory, with the level of activation proportional to the strength of association between each of them and the focused object. This effect can be viewed as a spatial priming effect (e.g., McNamara, 1986; McNamara, Ratcliff, & McKoon, 1984). Returning to Figure 1, if participants focused their attention on *cannon*, the pattern of retrieval times would be *cannon* < *flag* < *antenna* = *lifeboat*. In Franklin and Tversky's (1990) experiments, the focused object

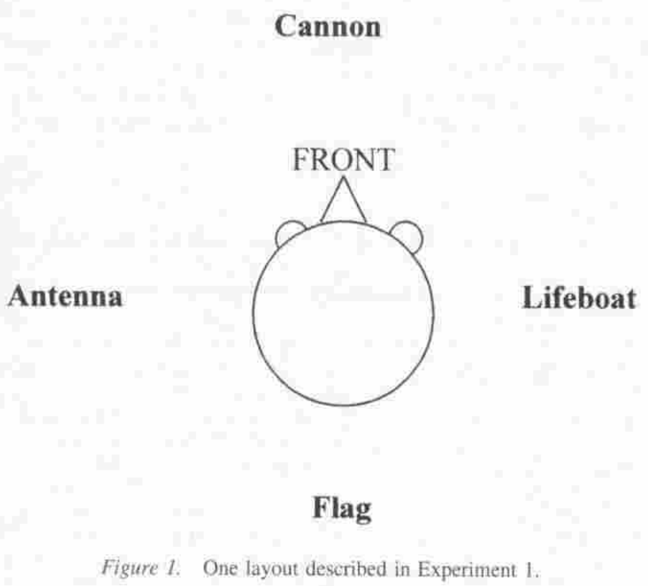

Figure 1. One layout described in Experiment 1.

was always in front, and therefore, if there was an attentional effect, it was perfectly confounded with the egocentric direction effect.

This conceptual framework makes a novel prediction when objects are located in noncanonical locations, as in Figure 2. In this case, the front–back axis is aligned with *cannon–antenna* and with *lifeboat–flag*, and the right–left axis is aligned with *lifeboat–cannon* and *flag–antenna*. Assuming that these intra-axis spatial relations are stronger than interaxis spatial relations, our proposal makes the novel prediction that response times will follow a focused < adjacent right = adjacent left < opposite pattern. For example, if participants focused on *cannon*, the pattern of retrieval times would be *cannon* < *antenna* = *lifeboat* < *flag*. It is not clear what an egocentric-representation model such as that of Franklin and Tversky (1990) would predict in the situation depicted in Figure 2. In their paradigm, typically front is faster than back, but right and left do not differ. Hence, one possible prediction is that retrieval times might be ordered left front = right front < left back = right back.

Experiments 1 and 2 were designed to test these predictions. Using Franklin and Tversky's (1990) paradigm, we set participants' focus of attention on each object in turn and had participants report the object in each cued direction (i.e., *front, back, left,* and *right*). Attentional focus and cued egocentric direction were manipulated independently. The object-to-object coding hypothesis predicted that the attention effect would appear to be focused < opposite < adjacent left = adjacent right when objects were located in canonical positions (see Figure 1) and focused < adjacent left = adjacent right < opposite when objects were located in noncanonical positions (see Figure 2). The results were consistent with the object-to-object coding hypothesis. Egocentric direction effects were also obtained, but they had different forms in the two situations. When objects were located in canonical positions, the standard egocentric pattern, front < back < left = right, was observed, but when objects were located in noncanonical positions, the pattern left front = right front = right back < left back was observed.

The purpose of Experiment 3 was to determine whether the standard egocentric direction pattern was produced by processes involved in accessing an egocentrically defined spatial representation or by processes involved in apprehending the directional words. This experiment replicated Experiment 1 (objects in canonical positions) but used iconic arrows instead of words to cue directions. The attention effect in this experiment was the same as that in Experiment 1; namely, focused < opposite < adjacent left = adjacent right. However, the standard egocentric direction effect was not obtained. Instead, response times were ordered front = right < left = back. Collectively, the results of Experiments 1, 2, and 3 indicated that spatial memories acquired from language were represented in intrinsic reference systems.

Finally, Experiment 4 was designed to test a possible alternative explanation of the results of Experiment 3, namely, that the standard egocentric direction effect was not obtained with iconic arrows because they were ambiguous. The results of this experiment indicated that the arrows were not ambiguous and also showed that egocentric effects were obtained even when participants were not searching imagined spaces. This latter finding provided additional evidence that the egocentric effects observed in investigations of spatial memories acquired from language were

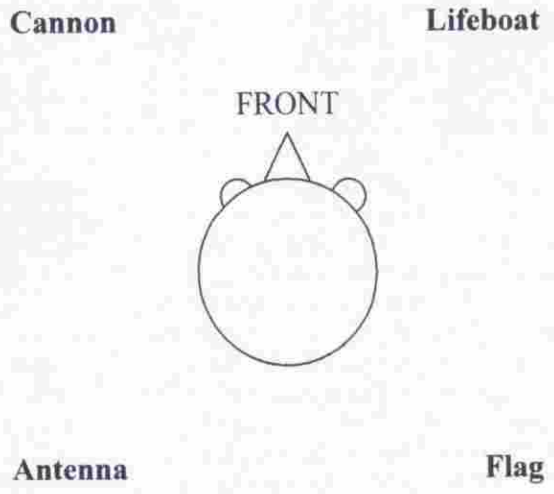

Figure 2. One layout described in Experiment 2.

not produced by egocentric representations of the locations of objects. In the General Discussion section, we propose a possible explanation of the various egocentric direction patterns.

Experiment 1

In Experiment 1, participants' focus of attention was set on front objects, back objects, left objects, or right objects (relative to their bodies) before they searched for objects in the paradigm developed by Franklin and Tversky (1990). We set participants' focus of attention before each trial by presenting a description sentence, which provided a visual detail about the focused object.

Method

Participants. Twenty university students (10 men and 10 women) participated in return for monetary compensation. In this experiment and all of the following experiments, participants were native speakers of Mandarin.

Narratives and design. We used eight narratives presented in Mandarin. Each of them involved four landmarks located front, back, left, and right of a central observer. An additional narrative was used for practice only (see Table 1). Each narrative described an environment from the perspective of the central observer, who was identified in the second person (e.g., *You are currently looking at*. . .). A list of the four objects preceded each narrative. The ship narrative follows as an example (translated from Mandarin):

> You got on the sailing navy ship on the last day of your military life. Now you are standing on the deck and looking around curiously. Behind you, you see a flag flying in the breeze. The name of the navy is written on it. In front of you, you see a cannon that has been wiped bright by the soldiers. The gun is directed to the sky. It seems like a brave hero who is defending the navy. Lying to your right there is a lifeboat that is painted white and black. There are two small special windows on the sides. To your left, there is an antenna with a white circle. The shape of it is not the same as that of a television antenna. Perhaps it is used for receiving some special signals.

In the second part of each narrative, participants read three kinds of sentences: reorientation sentences, description sentences, and filler sentences. The reorientation sentence required participants to physically turn 90° (left or right) by describing the participant as turning and looking over the objects in a new perspective, for example, *Turn left 90° and imagine the landmarks around you.* The description sentence described a visual detail about one object (front object, back object, left object, or right object) to set the focus of attention on it. The filler sentence did not describe any object in particular.

For each narrative, participants turned four times to face each of the objects around them (right in four narratives and left in four narratives). In each orientation condition, they focused on each object by reading a unique description sentence about it. Each direction (front, back, left, right) was probed once for each focus object, creating 16 test trials per orientation condition. Trials were presented in a random order. Each test trial consisted of a single directional word (*front, back, left,* or *right*). In the subsequent data analysis, we coded these trials as 16 categories corresponding to the combination of the 4 probed directions (front, back, left, or right) and the 4 positions of the target object in relation to the focused object (focused, opposite, adjacent left, or adjacent right). Participants received a total of 512 trials, arranged in superblocks (narratives), blocks (orientation condition), and subblocks (conditions of focus), with probed direction varied randomly without replacement within subblocks.

Four monitors were set up on four tables surrounding a swivel chair, on which the participants sat. The same text was displayed on each monitor using a VGA multiplier, allowing participants to continue reading the same material after turning to a new orientation. The monitors were rotated back 60° and mounted in special tables so that the bottom edge of the monitor was flush with the table top; in other words, from the participant's perspective, the angle formed by the table surface and the monitor screen was 150°. Participants thus looked down at the screen as much as they would look at a sheet of paper lying on the table, and arrow stimuli (used in Experiment 3) indicated in front of and behind rather than up and down. Only text was used in Experiment 1.

Procedure. There were two parts to each narrative. The first part was on a single sheet of paper and described the environment from the perspective of an upright observer as he or she looked at the surrounding objects (see the ship narrative). Participants learned the locations of the objects from this printed description. They were told that the second part of the narrative would contain questions about the objects at these locations. Participants studied the first part as long as they wanted, but after returning it to the experimenter, they were not allowed to read it again.

The second part appeared on a computer as a continuation of the narrative from the printed part. Participants read one sentence at a time in a loud voice. The experimenter pressed the space bar on a computer to advance to the next sentence once the participant had finished reading the sentence. There were four orientation conditions in this part. Each orientation condition began with a reorientation sentence, asking the participant to turn 90°. The message on the screen was, *Turn left (right) 90°, and imagine the landmarks around you.* After the participant had reoriented, a description sentence was presented. Each description sentence presented a

Table 1
Objects Located Within Eight Test Scenes and One Practice Scene

Scene	Objects
Opera theater (practice)	Bouquet, loudspeaker, sculpture, lamp
Work shed	Hammer, saw, toolbox, fan
Hotel lobby	Fountain, gift shop, barbershop, tavern
Construction site	Bucket, wheelbarrow, ladder, shovel
On a navy ship	Cannon, lifeboat, flag, antenna
Space museum	Satellite, space suit, meteorite, map
Lagoon	Bottle, snorkel, frisbee, paddle
Laboratory	Chart, cabinet, camera, microscope
Toy factory	Doll, plane model, hairy bear, sailboat

detail about the focused object. For example, *The cannon on your right is. . . .* Then a filler sentence was presented. Following the filler sentence, a directional word (e.g., *front*) was presented. The participant was asked to report the name of the object at the location indicated by the word in a loud voice as soon as possible but without sacrificing the accuracy of the judgment. A microphone that was held by the participant and connected to the computer recorded the response. The time from onset of the directional word to onset of the oral response was measured. Sixteen trials (4 focused objects × 4 probed directions) were presented in each reorientation condition. After completion of 16 trials, the next orientation condition began with another reorientation sentence. In a similar way, all four orientations were tested, and the last orientation situated the participant again in the position that was initially described by the narrative (i.e., the original orientation was tested last).

Before the test narratives, participants read a practice narrative. For the practice narrative, feedback was provided after each oral response; but for the test narratives, no feedback was provided.

Previous studies using Franklin and Tversky's (1990) paradigm did not typically require participants to rotate. We required participants to rotate so that they would be better able to update their orientation with respect to the layout of objects (e.g., Rieser, 1989). To ensure that physical rotation did not influence the original effects observed by Franklin and Tversky, we replicated the experiment using imagined rotation. The results were identical to those observed here.

Results

Outliers were removed using the upper and lower outer fences (25% − 1.5 [75% −25%]; 75% + 1.5 [75% −25%]; Tukey, 1977). Approximately 6.72% of the data were removed. Incorrect responses (2.19% of the data) also were removed. Mean response time as a function of probed direction and relative position is plotted in Figure 3. The major findings were as follows: First, both the front < back < left = right pattern of the egocentric direction effect and the focused < opposite < adjacent left = adjacent right pattern of the attention effect were observed. Second, these two effects were independent.

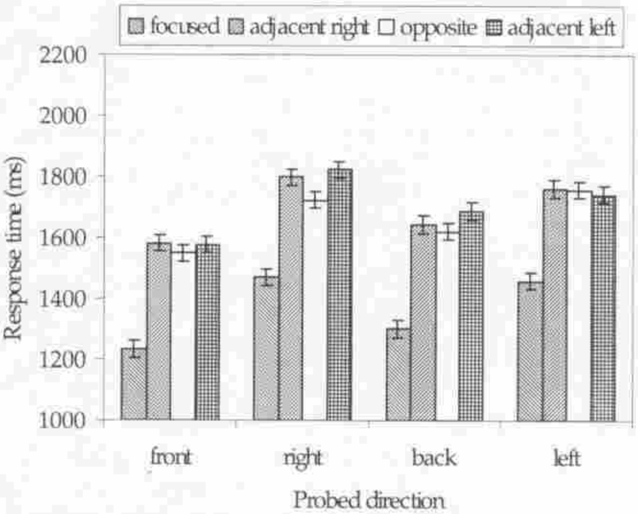

Figure 3. Response time in searching for objects as a function of probed direction and position of the target object with respect to participants' focus of attention in Experiment 1. (Error bars are confidence intervals corresponding to ±1 standard error, as estimated from the analysis of variance.)

Mean response time was computed for each participant and each condition and analyzed in repeated measures analyses of variance (ANOVAs), with variables corresponding to probed direction (front, back, left, or right) and the target object's position relative to the focused object (focused, opposite, adjacent left, or adjacent right).

The main effect of probed direction was significant, $F(3, 57) = 26.66$, $p < .01$, $MSE = 31{,}212$. The overall mean response times (in milliseconds) were 1,486 (front), 1,564 (back), 1,680 (left), and 1,703 (right). Planned comparisons showed that response times for the front condition were shorter than those for any of the other conditions, $Fs(1, 19) > 35.2$, $ps < .001$; response times for the back condition were shorter than those for the left and right conditions, $Fs(1, 19) > 15.2$, $ps < .001$; and response times for the left and right conditions did not differ, $F(1, 19) = 2.19$, $p = .16$. Response times for the front–back dimension were shorter than for the left–right dimension, $F(1, 19) = 29.19$, $p < .01$. The ordering, therefore, was front < back < left = right.

The main effect of relative position was significant, $F(3, 57) = 72.38$, $p < .01$, $MSE = 28{,}954$. The overall mean response times (in milliseconds) were 1,367 (focused), 1,663 (opposite), 1,708 (adjacent left), and 1,696 (adjacent right). Planned comparisons revealed that response times for the focused condition were shorter than those for any of the other conditions, $Fs(1, 19) > 73.7$, $ps < .001$; response times for the opposite condition were shorter than those for the adjacent-left and adjacent-right conditions $Fs(1, 19) > 6.8$, $ps < .05$; and those for the adjacent-left and adjacent-right conditions did not differ ($F < 1$). Response times for the focused-opposite dimension were shorter than those for the adjacent dimension, $F(1, 19) = 84.51$, $p < .01$. The predicted ordering, focused < opposite < adjacent left = adjacent right was obtained. The interaction between the egocentric direction effect and the attention effect was not found to be significant when we used a conventional alpha level, $F(9, 171) = 1.83$, $p = .07$, $MSE = 6{,}574$.

Discussion

The results of Experiment 1 indicated that participants' focus of attention did influence the process of searching imagined spaces from narratives. We dissociated the attention effect from the egocentric direction effect successfully. Participants were faster on the front–back dimension than on the left–right dimension and were faster on the front dimension than on the back, producing the front < back < left = right pattern of the egocentric direction effect reported by Franklin and Tversky (1990). However, participants were also faster on the objects in the focused-opposite dimension than on those in the adjacent dimension and were faster on the focused object than on the opposite object, following the focused < opposite < adjacent left = adjacent right pattern of the attention effect. Furthermore, the attention effect was independent of the egocentric direction effect statistically. These results indicated that participants' focus of attention affected the retrieval of object names from spatial representations acquired from narratives.

Experiment 2

In Experiment 2, objects were located in noncanonical positions with respect to the observer's body (left front, right front, left back, and right back; see Figure 2). As explained in the introduction, we predicted that the attention effect would have the pattern, focused < adjacent left = adjacent right < opposite. The predictions of an egocentric-representation model are not entirely clear. But as described previously, one possible outcome is left front = right front < left back = right back.

Method

Participants. Twenty university students (10 men, 10 women) participated in return for monetary compensation.

Narratives, design, and procedure. The narratives were similar to those used in Experiment 1 except that the objects were described in noncanonical positions (left front, right front, left back, and right back). The design was identical to that used in Experiment 1. The procedure was similar to that used in Experiment 1 except participants were probed with noncanonical directional words (i.e., *left front, right front, left back,* and *right back*). Participants reoriented in steps of 90° and therefore never directly faced one of the objects.

Results

Outliers were removed using the upper and lower outer fences (Tukey, 1977). Approximately 5.65% of the data were removed. Incorrect responses (1.68% of the data) also were removed. Mean response time as a function of probed direction and relative position is plotted in Figure 4. The major findings were as follows: First, egocentric and attention effects were found, but both differed from Experiment 1. In particular, the predicted attention effect, focused < adjacent left = adjacent right < opposite was obtained. Second, these two effects were independent. Mean response time was computed for each participant and each condition and analyzed in repeated measures ANOVAs, with variables corresponding to probed direction (left front, right front, left back, and right back) and the target object's position relative to the focused object (focused, opposite, adjacent left, and adjacent right).

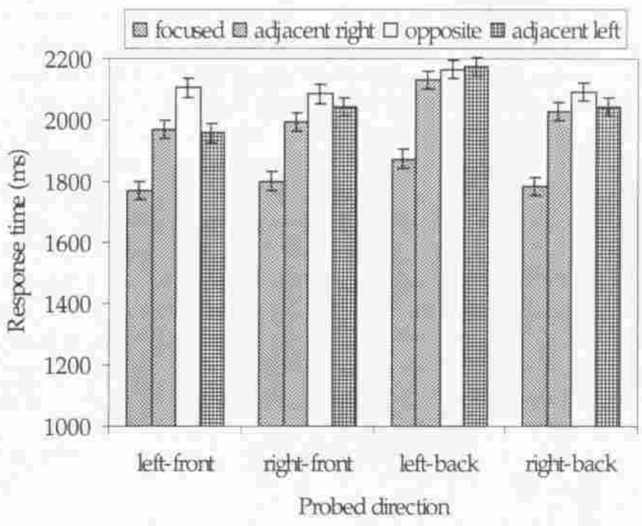

Figure 4. Response time in searching for objects, as a function of probed direction and position of the target object with respect to participants' focus of attention in Experiment 2. (Error bars are confidence intervals corresponding to ±1 standard error, as estimated from the analysis of variance.)

The main effect of probed direction was significant, $F(3, 57) = 9.87$, $p < .01$, $MSE = 28{,}672$. The overall mean response times (in milliseconds) were 1,951 (left front), 1,981 (right front), 2,088 (left back), and 1,988 (right back). Planned comparisons showed that response times for the left front, right front, and right back conditions were shorter than for the left back condition, $Fs(1, 19) > 9.1$, $ps < .01$, but that none of the other pairs differed significantly, $Fs(1, 19) < 2.49$, $ps > .13$. The statistical ordering, therefore, was left front = right front = right back < left back.

The main effect of relative position was significant, $F(3, 57) = 41.06$, $p < .01$, $MSE = 34{,}696$. The overall mean response times (in milliseconds) were 1,808 (focused), 2,056 (adjacent left), 2,032 (adjacent right), and 2,112 (opposite). Planned comparisons revealed that response times for the focused condition were shorter than those for each of the other conditions, $Fs(1, 19) > 40.2$, $ps < .001$; adjacent left and adjacent right conditions did not differ, $F(1, 19) = 2.65$, $p = .12$; and response times for the opposite condition were longer than those for any of the other three conditions, $Fs(1, 19) > 9.2$, $ps < .01$. The predicted ordering, focused < adjacent left = adjacent right < opposite, was therefore obtained. No significant interaction between the egocentric direction effect and the attention effect was observed, $F(9, 171) = 1.77$, $p = .08$, $MSE = 9{,}875$.

Discussion

In Experiment 2, we placed objects in noncanonical positions and had participants respond to noncanonical directional words. As predicted, the results revealed the pattern, focused < adjacent left = adjacent right < opposite. The adjacent objects were more accessible than the opposite objects. This finding is consistent with the hypothesis that the locations of objects learned from narratives are represented in terms of intrinsic frames of reference.

As discussed previously, egocentric-representation models do not make unambiguous predictions in this situation, but one possible prediction is that the directional cues should be ordered left front = right front < left back = right back. The observed ordering, based on statistical analysis, was left front (1,951 ms) = right front (1,981 ms) = right back (1,988 ms) < left back (2,088 ms). The numerical ordering of means is consistent with the hypothesized egocentric effect, although the difference between right front and right back is quite small, whereas the difference between right back and left back is substantial.

The results presented so far do not provide direct evidence against the egocentric coding of locations because egocentric direction effects were also observed. In the next two experiments, we tested whether the egocentric direction effect obtained in Experiment 1 arose from accessing an egocentrically defined spatial representation or from comprehending the directional word cues.

Experiment 3

The purpose of Experiment 3 was to investigate whether the egocentric effect would be removed when participants responded to iconic arrows rather than to directional words. If the locations of the objects are specified in an egocentric spatial representation, as argued by Franklin and Tversky (1990), and this representation is responsible for the egocentric direction pattern, then the same pattern would appear if directions were cued with iconic arrows.

However, if the egocentric direction pattern was caused by processes involved in understanding and using directional word cues, it would be reduced or eliminated for iconic arrow cues.

Method

Participants. Twenty university students (10 men, 10 women) participated in return for monetary compensation.

Materials, design, and procedure. The narratives, design, and procedure were the same as those used in Experiment 1 except that the directional cues were iconic arrows (↑, ↓, ←, →) rather than direction words. Objects were located in canonical positions relative to the observer. Because the monitors were tilted backward 60°, the arrow stimuli were nearly on the horizontal plane.

Results

Outliers were removed using the upper and lower outer fences (Tukey, 1977). Approximately 5.65% of the data were removed. Incorrect responses (1.68% of the data) also were removed. Mean response time, as a function of probed direction and relative position, is plotted in Figure 5. The major findings were as follows: First, whereas the predicted attention effect was obtained, a new egocentric pattern appeared: front = right < left = back. Second, these two effects were independent.

Mean response time was computed for each participant and each condition and analyzed in repeated measures ANOVAs with variables corresponding to probed direction (front, back, left, or right) and the target object's position relative to the focused object (focused, opposite, adjacent left, or adjacent right). The main effect of probed direction was significant, $F(3, 57) = 5.86$, $p < .01$, $MSE = 7{,}784$. The overall mean response times (in milliseconds) were 1,299 (front), 1,345 (back), 1,332 (left), and 1,298 (right). Front and right did not differ ($F < 1$); front differed from each of back and left, $Fs(1, 19) > 7.0$, $ps < .02$; the difference between right and left was marginally significant, $F(1, 19) = 4.10$, $p = .06$; right and back differed, $F(1, 19) = 14.6$, $p = .001$; and left and back did not differ ($F < 1$). The front–back dimension was not significantly faster than the left–right dimension ($F < 1$). The ordering of conditions was approximately, front = right < left = back.

The main effect of relative position was significant, $F(3, 57) = 25.22$, $p < .01$, $MSE = 100{,}905$. Overall mean response times (in milliseconds) were 1,052 (focused), 1,391 (opposite), 1,420 (adjacent left), and 1,411 (adjacent right). Response times for the focused condition were shorter than those for any of the other conditions, $Fs(1, 19) > 23.9$, $ps < .001$; those for the opposite condition were shorter than those for the adjacent left condition, $F(1, 19) = 8.6$, $p = .008$; those for the opposite condition were shorter than those for the adjacent right condition, $F(1, 19) = 4.2$, $p = .054$; and those for the adjacent left and adjacent right conditions did not differ ($F < 1$). The ordering of conditions was therefore the same as in Experiment 1, focused < opposite < adjacent left = adjacent right. No significant interaction between the egocentric direction effect and the attention effect was observed, $F(9, 171) = 1.51$, $p = .15$, $MSE = 4{,}227$.

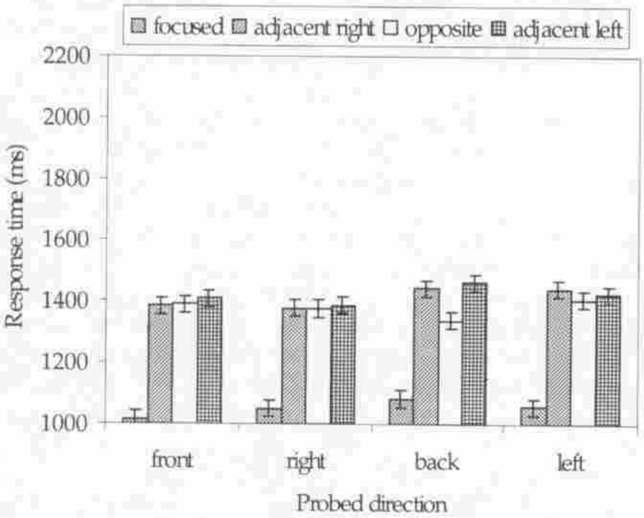

Figure 5. Response time in searching for objects as a function of probed direction (indicated by iconic arrows) and position of the target object with respect to participants' focus of attention in Experiment 3. (Error bars are confidence intervals corresponding to ±1 standard error, as estimated from the analysis of variance.)

Discussion

The egocentric effect observed in Experiment 1 was not observed when people responded to iconic arrows. Moreover, the pattern that was observed was not predicted in any obvious way by egocentric coding of location. This finding suggests that the egocentric effect observed in Experiments 1 and 2 arose from processing the directional words *front*, *back*, *left*, and *right* rather than from accessing spatial memories organized in terms of an egocentric frame of reference.

Experiment 4

Because the monitors were not tilted all of the way back (i.e., 90°), there is the possibility that the front and back arrows were ambiguous. This ambiguity might have eliminated the standard egocentric direction effect in some way. In Experiment 4, we tested whether the arrows were ambiguous by requiring participants to match visually presented iconic arrows with auditorily presented directional words. Another goal of Experiment 4 was to determine whether egocentric effects would appear in comprehending direction words or arrows even when participants were not searching spaces learned from narratives. On each trial, a directional word was presented auditorily, and then a direction word or an iconic arrow was presented visually. Participants responded vocally "yes" if the two matched or "no" if they did not.

Method

Participants. Twenty university students (10 men, 10 women) participated in return for monetary compensation.

Material, design, and procedure. The experimental environment was similar to that in Experiment 3 except only one monitor was used. Each trial consisted of an auditorily presented word (*front, back, left,* or *right*) and a visually presented word (*front, back, left,* or *right*) or an auditorily presented word and a visually presented arrow (↑, ↓, ←, →). There were 12 blocks of trials. The frequency of each auditory–visual combination is shown in Table 2. In this design, half of the trials required a "same"

Table 2
Frequency of Each Visual-Auditory Combination Used in Experiment 4

	Auditorily presented word			
Visual	*Front*	*Back*	*Left*	*Right*
Arrow ↑	4	2	1	1
Arrow ↓	2	4	1	1
Arrow ←	1	1	4	2
Arrow →	1	1	2	4
Word *Front*	4	2	1	1
Word *Back*	2	4	1	1
Word *Left*	1	1	4	2
Word *Right*	1	1	2	4

response, and each auditory–visual combination appeared at least once. The trials in each block were presented randomly.

Each trial began with a word (e.g., *front*) presented over a speaker. Participants named the word aloud. Presentation of the second word or the arrow was initiated by the experimenter after participants named the first word. Participants were required to say "yes" loudly if the visually presented word or arrow matched the auditorily presented word and "no" otherwise. Speed and accuracy were emphasized. The time from onset of the visual stimulus (a word or an arrow) to onset of the oral response was measured.

Only the data in the matching condition were of interest. There were 192 trials in this category for visually presented arrows and 48 trials for each iconic arrow. There were also 192 trials in this category for visually presented words, 48 trials for each word (*front, back, left,* or *right*).

Results

Outliers were removed using the upper and lower outer fences (Tukey, 1977) computed separately for each type of test stimulus (arrows vs. words). For the arrows, 11.4% of the data were removed as outliers, and an additional 2.2% of errors were eliminated. For direction words, 7.87% of the data were removed as outliers and 1.64% were removed as errors.[2] Mean response times computed for each participant and each condition were analyzed in an ANOVA with variables corresponding to stimulus type (arrows vs. words) and direction (front, back, left, right).

All three effects were statistically significant: Stimulus type, $F(1, 19) = 31.86$, $p < .01$, $MSE = 4{,}827.95$; direction, $F(3, 57) = 9.36$, $p < .01$, $MSE = 485.22$; and their interaction, $F(3, 57) = 3.73$, $p = .016$, $MSE = 483.43$. Overall mean response times (in milliseconds) for arrows were 636 (front), 645 (back), 647 (left), and 639 (right). Mean response times for words were 678 *(front)*, 710 *(back)*, 716 *(left)*, and 711 *(right)*. Simple effects showed that the direction effect was not statistically reliable for arrows, $F(3, 57) = 1.02$, $p = .39$, but was statistically reliable for words, $F(3, 57) = 12.06$, $p < .01$. Pairwise comparisons of the word conditions showed response times for *front* were shorter than those for all of the other direction words, $F(1, 19) > 14.3$, $ps < .001$, and that none of the response times for the other direction words differed ($Fs < 1.$).

In error rates, none of the effects were statistically reliable: Stimulus type, $F(1, 19) = 3.20$, $p = .09$, $MSE = 4.11$; direction, $F(3, 57) = 0.80$, $p = .49$, $MSE = 3.80$; and their interaction, $F(3, 57) = 0.37$, $p = .78$, $MSE = 4.41$. Means (%) for words were 0.9 *(front)*, 1.8 *(back)*, 2.0 *(left)*, and 1.9 *(right)*; means (%) for arrows were 2.1 (front), 2.3 (back), 2.3 (left), and 2.2 (right).

Discussion

In Experiment 4, participants matched direction arrows or direction words to previously presented direction words. Participants were equally good at matching arrows to words for all directions; there was little evidence of an egocentric effect. These results indicate that the apparatus and mode of arrow display used in Experiment 3 were not responsible for the absence of an egocentric effect. In addition, matching times for direction words were shorter for *front* than for the other direction words, which did not differ. The fact that this effect occurred only for words indicates that it is produced by processes involved in language comprehension, not processes involved in accessing egocentric spatial relations. Facilitation for *front* also may be related to the fact that the symbols in Chinese for *left, right,* and *back* are visually similar to each other but different from the symbol for *front*.

General Discussion

The goal of this project was to investigate whether spatial memories acquired from language were represented in terms of intrinsic (object-to-object) frames of reference or egocentric (self-to-object) frames of reference. On the basis of findings from studies of spatial memories acquired from perception (e.g., Hintzman et al., 1981; Mou & McNamara, 2002; Shelton & McNamara, 2001), we hypothesized that people would use egocentric cues to select an intrinsic frame of reference for representing spatial relations among objects, even when the locations of objects were described in narratives. An intrinsic frame of reference aligned with the body axes of front–back and right–left would be preferred over other possible intrinsic organizations. We further assumed that object-to-object spatial relations aligned with the intrinsic frame of reference would be stronger than would other object-to-object relations.

This conceptual framework predicted that when objects were described as being in canonical positions with respect to the observer (e.g., Figure 1), spatial relations between the front and the back objects and between the right and the left objects (e.g., cannon–flag and antenna–lifeboat) would be stronger than those between other pairs of objects (e.g., antenna–cannon and flag–lifeboat). However, when objects were described as being in noncanonical positions with respect to the observer (e.g., Figure 2), spatial relations between neighboring objects (e.g., cannon–antenna, lifeboat–flag, cannon–lifeboat, antenna–flag) would be stronger than those between other pairs of objects. In this situation, the left front and the left back objects and the right front and the right back objects are aligned with the egocentric front–back axis, and the left front and the right front objects and the left back and the right back objects are aligned with the egocentric left–right axis.

These predictions were tested using the paradigm developed by Franklin and Tversky (1990). Participants read second-person nar-

[2] The percentage of data removed as outliers was high in this experiment, especially for the arrow stimuli. Analyses of untrimmed data (with only errors removed) produced identical patterns of results. Analyses of trimmed data are reported to maintain consistency with the previous experiments.

ratives that located objects around the participants in various fictional settings. Participants periodically reoriented by 90° and then retrieved the names of objects in cued directions. The focus of attention was manipulated by presenting a sentence that described a visual feature of one of the objects (e.g., *The cannon in front of you...* or *The flag to your right...*). Unlike in Franklin and Tversky's original experiments, the focus of attention could be on any of the four objects, not just the one in front. As predicted, when objects were located in canonical positions (Experiments 1 and 3), retrieval times were ordered, focused < opposite < adjacent left = adjacent right, whereas when objects were located in noncanonical positions (Experiment 2), retrieval times were ordered, focused < adjacent left = adjacent right < opposite.

Egocentric effects were also obtained, but they depended on the form of the direction cue. When objects were located in canonical positions, word cues produced the standard egocentric direction effect, front < back < left = right (e.g., Franklin & Tversky, 1990), whereas iconic arrow cues produced a different pattern, front = right < left = back. When objects were located in noncanonical positions, word cues produced a third egocentric direction pattern, left front = right front = right back < left back. The results from all four experiments indicated that egocentric direction effects depended more on the types of cues than on the locations of the cued objects.

These findings provide the foundations for a new model of searching spaces learned from narratives. In this model, searching spaces involves two main steps: (a) using a spatial cue to determine where to search and (b) identifying the object at the cued location (see also Carlson-Radvansky & Irwin, 1994; Carlson-Radvansky & Logan, 1997; Garnham, 1989; Herskovits, 1986; Landau & Jackendoff, 1993; Levelt, 1984; Logan & Sadler, 1996).

In Step a, when locations are cued by egocentric directional words, people use the body axes of front–back and right–left as a frame of reference in apprehending the words (also see Logan & Sadler, 1996). For example, *front* is interpreted as "in front of my imagined position," and *back* is interpreted as "behind my imagined position." Various functional asymmetries of the human body (as explained, e.g., by Franklin & Tversky, 1990) account for the egocentric direction pattern, front < back < left = right, obtained in Experiment 1. This egocentric direction effect is produced not by the representation of object location, but rather by the processes involved in interpreting the directional cues.

When locations are cued by iconic arrows, as in Experiment 3, people can determine the location directly, without reference to body axes, and the standard egocentric direction pattern is not obtained. There may be residual effects of egocentric frames of reference even when iconic arrows are used as direction cues, as front and right were faster than left and back. However, this pattern also appeared in Experiment 4 when participants matched arrows to direction words (although the effect was not statistically significant). The fact that this pattern seemed to appear in an experiment in which participants were not searching remembered spaces indicates that it may be produced by processes other than those involved in determining location. Forward facing arrows may be processed more efficiently because they correspond to our typical direction of locomotion. The facilitation for right-facing arrows may be related to handedness. We did not survey participants on their dominant hand, but based on normative data, we can estimate that the vast majority was right handed. Facilitation for right-facing arrows would have to occur in perceptual or conceptual processing, not the motor response system, as participants responded vocally.

Similar considerations may explain the pattern obtained in Experiment 2 when objects were located in noncanonical positions. The slowest direction, left back, is neither to the front nor to the right. Additional experiments are needed to determine the causes of the egocentric patterns obtained in Experiments 2, 3, and 4. The unambiguous conclusion from these experiments is that the findings are not consistent with models in which the locations of objects are represented egocentrically.

In Step b, the time to identify the target object at the cued location is influenced by the spatial relation between the target object and the focused object because the locations of objects are specified with respect to other objects (see also Easton & Sholl, 1995; Mou & McNamara, 2002; Sholl & Nolin, 1997). This effect can be viewed as a spatial priming effect (e.g., McNamara, 1986; McNamara et al., 1984). As described previously, according to this model, intrinsic frames of reference are selected using egocentric cues. In the current paradigm, in which objects are located around a central observer, the front–back and right–left body axes are particularly salient egocentric cues. Spatial relations aligned with an intrinsic axis are assumed to be stronger than spatial relations misaligned with an intrinsic axis. This model predicts the focused < opposite < left = right pattern when objects are located in canonical positions (as in Figure 1) but the focused < adjacent left = adjacent right < opposite pattern when objects are located in noncanonical positions (as in Figure 2). The former pattern was obtained in Experiments 1 and 3, and the latter was obtained in Experiment 2. More important, the attention effect pattern did not differ between Experiments 1 and 3 even though different direction cues were used.

Additional experiments are needed to determine how the focused object is processed and used. Participants may use the focused object as a landmark for keeping track of their orientation with respect to the layout of objects as they respond to direction cues. The attentional demands of monitoring one's orientation with respect to a single object would be minimal. Either allocentric or egocentric reference systems might be used (e.g., "the cannon is northwest of me" vs. "the cannon is to my left front"). Recent investigations of spatial updating suggest that as people locomote in a familiar environment, they keep track of their location and orientation with respect to the same intrinsic reference system used to represent the spatial layout of that environment (Mou, McNamara, Valiquette, & Rump, in press). Regardless of the reference systems involved, given knowledge of one's orientation with respect to one of the objects and knowledge of the spatial relations among the objects, one could determine the identity of any of the other objects given a direction cue.

Finally, according to this model, the effects produced in Steps a and b would not interact because they occur in different stages. The interaction between direction and relative position was never statistically significant using a conventional criterion, although it approached significance in Experiments 1 and 2. The marginally significant interactions in these experiments suggest that the processes involved in determining location and in identifying objects may affect each other in ways not predicted by the model in its current form.

This model can explain the present results but is also consistent with Franklin and Tversky's (1990) findings. One of their most important findings was that participants searched for objects in imagined spaces according to the pattern, above < below < front < back < left = right. We replicated their pattern on the horizontal plane (front < back < left = right) in this study. Additional experiments that include the above–below dimension as well as front–back and left–right dimensions are needed to test our model in three-dimensional spaces.

This model is also consistent with Hintzman et al.'s (1981) findings, as described in the introduction. An important difference between these two models is that the object-to-object system is selected by egocentric experiences (e.g., body axes) in our model but determined by the topological structure of the layout of objects in theirs. Hintzman et al. conjectured that the objects opposite to the focused objects had stronger connections with the focused object than did the adjacent ones because the focused object and the opposite object were located in the same topological dimension. However, this conjecture is not easily reconciled with the focused < adjacent left = adjacent right < opposite pattern observed in Experiment 2 when objects were located noncanonically.

Although these experiments raised several important questions, they also provided answers to the major issues raised in the introduction. The results indicate that the locations of objects described in narratives are mentally represented in terms of intrinsic reference systems, so that the locations of objects are specified in terms of other objects. Egocentric cues influence spatial coding in two ways: First, people select an intrinsic reference system aligned with the body axes of front–back and right–left, and second, people use the body axes as a frame of reference for comprehending egocentric directional words. These results, in conjunction with recently published findings by Mou and McNamara (2002), suggest that spatial memories acquired from perception and from language may be more similar than previously believed.

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