The Metrics of Spatial Situation Models

Mike Rinck and Andrea Hähnel
Technical University of Dresden

Gordon H. Bower
Stanford University

Ulrich Glowalla
University of Giessen

The authors investigated the metrics of spatial distance represented in situation models of narratives. In 3 experiments, a spatial gradient of accessibility in situation models was observed: The accessibility of objects contained in the situation model decreased with increasing spatial distance between the object and the reader’s focus of attention. The first 2 experiments demonstrated that this effect of spatial distance was purely categorical rather than Euclidean: Accessibility depended on the number of rooms located between the object and the focus of attention, not on the size of the rooms. Experiment 3 revealed, however, that participants were able to use information about Euclidean distance in a secondary task when necessary. The implications of these results for theories of narrative comprehension and hierarchical versus nonhierarchical theories of spatial memory are discussed.

Many theories of text comprehension assume that readers build situation models of the information described by texts (e.g., Johnson-Laird, 1983; Kintsch, 1988, 1992; van Dijk & Kintsch, 1983; Zwaan, Langaton, & Graesser, 1995). Situation models constitute a level of text representation associated with “deep” processing and serve to integrate the information stated in a text with general information supplied by the reader’s world knowledge (Glenberg, Meyer, & Lindem, 1987). The experiments reported here address the question of how readers use and update their situation models during reading to focus attention on the most relevant aspects of the described situation (see also de Vega, 1995; Morrow, Bower, & Greenspan, 1989).

Situation models can represent many different aspects of the situation described in a text, for example, time, space, causality, protagonists, and goals (Zwaan et al., 1995; Zwaan, Magliano, & Graesser, 1995). However, spatial relations are the type of information investigated most often, thus the term spatial situation models (see Morrow, 1994, for a review). Spatial relations represented in situation models would include information such as the protagonist’s present location, where the protagonist is moving, what the described locations look like, and where important objects and actors are located. In addition, many studies have shown that spatial situation models guide the allocation of attention because readers focus their attention on the protagonist of the narrative and on his or her location. As a result, a spatial gradient of accessibility occurs, that is, objects spatially close to the protagonist become more primed and accessible in memory than do spatially distant objects. The spatial gradient of accessibility has been demonstrated many times in studies that use a layout learning procedure before narrative reading (e.g., Haenggi, Germsbacher, & Bolliger, 1994; Haenggi, Kintsch, & Germsbacher, 1995; Morrow et al., 1989; Morrow, Greenspan, & Bower, 1987; Morrow, Leirer, Altieri, & Fitzsimmons, 1994; Morrow, Leirer, Andrassy, & Stine, 1994; Rinck & Bower, 1995; Wilson, Rinck, McNamara, Bower, & Morrow, 1993), as well as in studies using learning from text (Rinck, Williams, Bower, & Becker, 1996, Experiment 1) or no prior learning procedure (e.g., de Vega, 1995; Glenberg & Mathew, 1992; Glenberg et al., 1987; O’Brien & Albrecht, 1992).

Although the importance of spatial distance for the accessibility of situation model components has been demonstrated many times, the type of spatial distance involved in this phenomenon has not been investigated. Many authors seem to assume that spatial situation models represent Euclidean distance, that is, the models reflect the metrics of the real world, such as distance being measurable on an interval scale (e.g., in feet or meters). This assumption is rarely explicitly stated. However, expressions such as “accessibility of the objects tended to decrease as the distance from the location room to the probed room increased” (Morrow et al., 1987, p. 165) or “the accessibility of objects should gradually decrease with increasing distance from the propta-
There are at least four reasons to doubt this assumption. The first reason is a general one: Situation models have to be quite elaborate to represent Euclidean distance correctly, and it seems questionable whether readers would usually invest the effort necessary to build these elaborate models during narrative comprehension. These doubts are further strengthened by research that seems to indicate that readers often form only very vague situation models or none at all (Foertsch & Gernsbacker, 1994; McKoon & Ratcliff, 1992; Morrow, 1994; Zwaan & van Oostendorp, 1993, 1994). In a closely related series of experiments, Langston, Kramer, and Glenberg (1994) provided evidence that their participants constructed spatial situation models from descriptions of spatial arrangements; however, they failed to find evidence for Euclidean distance being represented in the situation models. These authors had their participants read (or listen to) texts that described the object-by-object construction of a spatial layout (e.g., the arrangement of objects in an aquarium). According to the text, a recently mentioned critical object ended up adjacent to a previously introduced target object or farther away from it. Of importance, the spatial distance between the critical object and the target object was never described explicitly. Langston et al. reasoned that—given that situation models represent Euclidean distances—the target object should be more accessible in memory and “noticed” by the participants if it is close to the focus of attention, that is, to the critical object. However, in a series of seven experiments, they failed to find consistent support for this noticing hypothesis.

Second, virtually all the evidence for a spatial gradient of accessibility cited above can be explained without referring to Euclidean distance. Instead, the more parsimonious assumption of a representation of categorical distance is sufficient to explain why closer objects are more accessible than distant objects. This is because the studies cited above usually confounded Euclidean distance between the focus of attention and a probed object (e.g., measured in inches) with categorical distance (e.g., measured by the number of rooms located between the focus and the object). Assuming that situation models represent categorical distance rather than Euclidean distance would be more parsimonious because the latter assumes distance represented on an interval scale, whereas an ordinal scale is sufficient for the former.

A review of the literature cited above also brings up the third argument against Euclidean distance: The only study that tried to find direct evidence for it failed. In their second and third experiments, Morrow et al. (1987) pitted Euclidean distance (“as the crow flies”) against route distance (“as the protagonist walks”). Unfortunately, they found no distance effect on the accessibility of objects located in the situation model at all, presumably because their experiment was not designed as a strong test of this specific topic. Thus, the question of exactly what type of distance affects accessibility remains unanswered.

Fourth, in different but closely related areas, very little evidence for a Euclidean metric in memory representations of spatial relations has been found. In his review of the literature on spatial priming and location judgments, McNamara (1991) concluded that “spatial representations are certainly not the former [i.e., preserving Euclidean properties of the world] and they may be even more extreme than the latter [i.e., abstract conceptual representations]; spatial representations may be purely nonmetric” (p. 147). However, Denis and Zimmer (1992) reported some evidence for Euclidean properties preserved in cognitive maps (measured by spatial priming, distance comparisons, and mental scanning).

It is worthwhile to investigate the type of distance represented in situation models for practical as well as for theoretical reasons. For successful research, it is important to determine the correct way to vary spatial distance in experiments. For instance, varying Euclidean distance may yield uninterpretable results if spatial situation models represent only categorical distance (and vice versa). From a theoretical point of view, conclusions regarding the representation of Euclidean distance will allow us to extend McNamara’s (1991) evaluation of theories of spatial representation. McNamara reviewed these theories with regard to how interobject spatial relations are represented in long-term memory. In addition, the results of the experiments reported here speak to how these representations are used during narrative comprehension.

The important distinction made by McNamara (1991) is between hierarchical versus nonhierarchical theories of spatial memory. According to hierarchical theories, spatial representations are structured by nested levels of detail (e.g., Hirtle & Jonides, 1985; McNamara, 1986; Stevens & Coupe, 1978). Relevant to the experiments reported here is the fact that these levels can be organized according to the relation of containment (e.g., objects are contained in rooms which in turn are contained in buildings). Furthermore, another important property of spatial environments reflected in hierarchical theories is region membership, where regions can be defined by physical (e.g., walls between rooms) or symbolic boundaries (e.g., state lines on a map). Among others, Stevens and Coupe (1978) have demonstrated the influence of boundaries: They organize the structure of spatial representations, sometimes even distorting the representation (see also Tversky, 1981). In addition, Franklin, Henkel, and Zangas (1995) have demonstrated that people tend to treat the space surrounding them as though it consisted of separate regions (i.e., front, back, right, and left).

In contrast to hierarchical theories, nonhierarchical theories—as the name implies—do not assume that spatial representations contain nested levels of detail or that boundaries affect the structure of the representations. The prototypical example of nonhierarchical theories are mental images (e.g., Kosslyn, Ball, & Reiser, 1978; Thorndyke, 1981). Mental images are nonhierarchical representations that represent Euclidean distance. It is important to note, however, that nonhierarchical theories do not have to assume analog representations, such as mental images. For instance, McNamara (1991) pointed out that both Thorndyke’s (1981) image-based theory and Byrne’s (1979) propositional theory are nonhierarchical.

The experiments reported in this article speak directly to the appropriateness of hierarchical compared with nonhierar-
chical theories of spatial representations. According to nonhierarchical theories, Euclidean distance should be represented in spatial situation models and should affect the accessibility of entities in the situation model, whereas boundaries such as room walls should have no effect. In contrast, hierarchical theories predict effects of boundaries on the accessibility of objects within them but make no prediction regarding the effects of Euclidean distance. In general, a hierarchical representation would not even have to represent ordinal information (e.g., about the order of rooms in a building). We have to assume that at least ordinal information is represented, however, because of the spatial gradient of accessibility observed so often. In summary, effects of Euclidean distance would be most easily explained by nonhierarchical models, whereas effects of categorical distance would be compatible only with hierarchical models.

So far, there is little evidence that might be used to test these predictions. However, there is good reason to expect an effect of boundaries on accessibility because the effect has been demonstrated by using a number of other spatial tasks, such as distance estimations (Newcombe & Liben, 1982), judgments of spatial proximity (Allen, 1981), and judgments of relative location (Maki, 1981). Because boundaries serve to organize space into spatial categories (e.g., walls organize buildings into rooms), this expectation leads to the prediction that categorical distance should affect accessibility.

The experiments reported in this article were designed to assess the effects of Euclidean distance independently of categorical distance. We decided against varying route distance as Morrow et al. (1987) did because route distance (short vs. long route) cannot be varied independently of Euclidean distance (short vs. long distance "as the crow flies"); Crossing a long Euclidean distance on a short route is impossible (whereas the opposite is an everyday phenomenon in traffic detours).

In general, the three experiments followed the procedure introduced by Rinck and Bower (1995), which in turn is based on the experiments reported by Morrow et al. (1989). Participants first memorized the diagram of a building and a number of objects located in it, then read a series of narratives, each one describing a protagonist's activities in that building. The narratives contained critical motion sentences describing how the protagonist moved from one room (the source room) through a number of unmentioned path rooms into another room (the location room, also called "goal room" in previous studies); for example, "Then he walked from the storage room into the lounge" (see Figure 1). The experimental manipulations pertained to the path room: Euclidean distance was varied by making the room either short or long, and categorical distance was varied by dividing the room into two rooms or leaving it undivided. The accessibility of objects was probed by undistinguished anaphoric sentences that followed the motion sentences (called "target sentences" by Rinck & Bower, 1995). Each anaphoric sentence contained a definite noun phrase that referred to a memorized object in one of the building's rooms; for example, "He decided that the refrigerator should not be so dirty tomorrow" (see Figure 1). Reading times of anaphoric sentences were used as one of the dependent variables.

If Euclidean distance is represented in spatial situation models and used during narrative comprehension, the accessibility of objects referred to—and therefore, the reading times of anaphoric sentences—should be affected by the size of the path room. If, however, only categorical distance is represented and used, reading times should be affected by the path room division, that is, by the number of path rooms. A similar line of reasoning applies to motion sentences. If participants represent the protagonist's movement in their situation model, inferring the protagonist's complete path might take longer, the longer the path is. This prediction is in accord with the results observed by Kosslyn et al. (1978) in a mental scanning task. They found that scanning times increased with increasing distance between the starting point and the end point of a mental movement. Again, the question is whether "longer" should be thought of in terms of Euclidean distance, as in the Kosslyn et al. study, or in terms of categorical distance.

In Experiment 3, in addition to motion sentences and anaphoric sentences, test probes consisting of pairs of learned objects were presented during reading of the narratives. For each test probe, participants had to decide which one of two named objects was located closer to the current

![Figure 1. Sample building layout memorized by participants in Experiment 1.](image)
Figure 1 displays one of the eight layouts used in Experiment 1, translated from German. All layouts were approximately 12 × 24 cm in size and showed the research center with 32 objects located in 10 rooms (not necessarily the same 10 rooms for all participants). In the later narratives, four specific rooms served as source rooms or location rooms for all participants, namely, “reception room,” “library,” “storage room,” and “lounge.” These rooms were identical for all participants. Four other rooms always served as path rooms in the narratives, namely, “experiment room,” “office,” “laboratory,” and “repair shop.” The appearance of these path rooms was systematically varied. Each of them could be short or long. In addition, it could be depicted as a single, undivided room or divided into two rooms. For participants who studied the layout shown in Figure 1, the repair shop and the laboratory were depicted as single rooms, one being short, the other one being long. For the same participants, the experiment room and the office were divided into two rooms each. In this case, a second room name was used. For instance, the divided experiment room was depicted as the experiment room and the waiting room, and the divided office as the office and the outer office (see Figure 1).

In each diagram, two movement paths were over a short Euclidean distance, and two were over a long distance. For participants who studied Figure 1, for example, the path from the library through the laboratory to the storage room was long and undivided, and the path from the storage room to the lounge via the repair shop was short and undivided. The path from the lounge to the reception room was long and divided, leading through the waiting room and the experiment room. The path from the reception room to the library was short and divided, leading through the office and the outer office. The participants were not informed about these systematic variations. In particular, they did not know that what they perceived as two rooms (e.g., the office and the outer office) had been created by dividing a single room (e.g., the office) into two rooms. By these variations, each participant read anaphoric sentences referring to a path room object in each of the four combinations of Euclidean distance (short vs. long) and categorical distance (undivided, divided).

To counterbalance the materials and the experimental conditions, we used eight different layouts. Each path room was depicted equally often as undivided–short, undivided–long, divided–short, and divided–long. We varied room size by moving the wall that separated each path room from the adjacent room, for example, by moving the wall between the laboratory and the storage room to the left, the long laboratory could be turned into a short room (see Figure 1). Room division was varied by including a separating wall or by leaving it out. For instance, the experiment room could be divided into the experiment room and the waiting room, and the office divided into the office and the outer office (see Figure 1). Note that the paths when divided into two rooms were still of the same length as the undivided ones. Because for each single participant only two of the four path rooms were divided, he or she studied either the waiting room and the outer office (see Figure 1), or the assistants’ room and the supply room (not shown in Figure 1). Thus, each layout contained 10 rooms. Each room contained four objects, except for divided path rooms, which contained only two objects each (see Figure 1). The names of the four additional rooms (waiting room, outer office, assistants’ room, and supply room) are a bit awkward in English, but the original German names were perfectly plausible.

These counterbalancing procedures yielded four different layouts. We created another four to counterbalance the objects and rooms located in the two parts of each path room by switching the location of the objects and room names. For instance, in the layout depicted in Figure 1, the scales and the computer are located in the left part of the laboratory, whereas the work counter and the

location of the protagonist. Some of these relative distance judgments could be made correctly only on the basis of Euclidean distance, because the objects were located in the same room and therefore did not vary in categorical distance. For instance, if the protagonist was located in the lounge depicted in Figure 1, the object pair might consist of 'carr and plywood. Thus, such tests will indicate whether participants can use knowledge about Euclidean distance at all, and if so, whether Euclidean distance affects only relative distance judgments or anaphor resolution times as well. Identifying the effects of Euclidean distance and categorical distance should allow us to further evaluate hierarchical and nonhierarchical theories of spatial representation. Moreover, identifying how participants use their knowledge about Euclidean distance and categorical distance in different tasks, such as narrative comprehension compared with relative distance judgments, should allow conclusions regarding theories postulating “satisficing” strategies (Foertsch & Gernsbacher, 1994; Zwaan & Graesser, 1993). According to these theories, participants of reading experiments do only what is required to solve the experimental task successfully and no more.

Experiment 1

We designed Experiment 1 to determine the relative effects of Euclidean distance and categorical distance on the accessibility of situation model components. To this end, the size and number of rooms were varied independently of each other, and accessibility was measured by anaphoric sentences referring to objects contained in the situation model. In general, Experiment 1 was similar to the two-part experiments described by Rinck and Bower (1995). In the first part, participants studied the layout of a fictitious research center; and in the second part, they read narratives about protagonists who performed actions in the research center.

Method

Participants. Sixty-four students of the Technical University of Dresden served as participants in this experiment and were compensated by a small monetary payment equivalent to $7. The data of 3 additional participants were excluded from all analyses because 1 participant did not learn the building layout, and 2 participants gave incorrect answers to more than 30% of the comprehension questions following the narratives. The remaining 64 participants had an average error rate of 10% to these questions.

Layout learning. In the first part of the experiment, participants learned the layout of the research center. They studied it for 1 min, then they turned it over and were given a blank diagram containing only the walls and doors of the building. They were asked to recall by writing all the room names and object names they could remember at their correct locations on the diagram; they compared their work with the original layout and noted errors. Participants proceeded through such self-paced study–test cycles until they could perfectly reproduce all room and object names in their correct locations. Afterward, they answered eight questions about locations of rooms and objects in the building. Participants required approximately 40 min to learn the layout and answer the questions perfectly.
microscope are located in the right part. We switched this order in the corresponding reversed layout. Thus, altogether eight different layouts were created, and participants were randomly assigned to learn one of the layouts. This rather elaborate procedure was undertaken to reduce error variance. Thus, during later reading of the narratives, identical verbal materials could be used for anaphoric sentences in different experimental conditions because the experimental differences had been created during the preceding learning of the layouts. For instance, the same sentence referring to an object in the laboratory (e.g., the microscope) would thus refer to an object located in either the left or the right part of either an undivided—short, undivided—long, divided—short, or divided—long laboratory, depending on the layout studied before.

Narrative reading. In the second part of the experiment, participants read 15 narratives (1 practice narrative, followed by 11 experimental narratives and 3 filler narratives) presented one sentence at a time on the CRT screen of a microcomputer, controlled by the VTx software (Fezzardi, Hasebrook, & Glowalla, 1992). Presentation of the sentences was self-paced: Participants pressed both buttons of the computer’s mouse to advance from one sentence to the next. A translated example of the experimental narratives used in Experiment 1 is given in the Appendix. Each narrative was approximately 20 sentences long and described the actions of a protagonist who moved through the building trying to fulfill a goal, for example, to clean up the research center in preparation for important visitors. At the end of each narrative, three yes–no questions were presented to test comprehension of the narrative. These questions queried such details as the reason for certain actions, the location of certain activities, and the order of actions. To motivate careful reading, we gave participants a financial bonus equivalent to $7 for making at most four mistakes over the 14 narratives or a bonus equivalent to $3 for making a maximum of eight mistakes on these questions. Two participants who answered more than 30% of the questions incorrectly were excluded from all analyses. Participants answered yes or no to each question by pressing either the left or the right mouse button. After each answer, feedback about the correctness was provided on the screen. After a wrong answer, a message urging participants to read more carefully was displayed. Participants were instructed to read carefully but at their natural speed. Reading times, as well as question answering times and correctness of the answers were recorded by the computer.

We distributed a total of 16 “experimental blocks” of critical test sentences over the 11 experimental narratives. Each block consisted of a motion sentence, a motivating sentence, and an anaphoric sentence. Each motion sentence described a complete motion event, in which the protagonist walked from one room (source room) through one or two unmentioned rooms (path room) into the next room (location room). The following example is given in the Appendix: “Then he walked from the storage room into the lounge.” As mentioned, reception room, library, storage room, and lounge served as source rooms and location rooms, whereas the other rooms were used as path rooms. After each motion sentence, a motivating sentence was presented to motivate the mental event described in the following anaphoric sentence: “He rechecked his list of tasks to see what else needed to be done to make the research center decent looking” (see Appendix). The motivating sentence was followed by an anaphoric sentence containing a definite noun phrase that referred to some unique object in one of the rooms of the research center. As the Appendix illustrates, this object could be located in the location room (e.g., the refrigerator in the lounge), in the part of the path room that was spatially near to the protagonist (near path, e.g., the cart in the repair shop), in the far part of the path room (far path, e.g., the tools in the repair shop), or in the source room (e.g., the crates in the storage room). All anaphoric sentences described some type of mental event such as thinking, remembering, or deciding about some aspect of the referent object. After the anaphoric sentence, the protagonist did something in the location room before moving on into the next room along the route.

Each participant read 16 anaphoric sentences, that is, one sentence in each experimental condition, as defined by combination of target room type (location, near path, far path, source), path room division (undivided, divided), and path room size (short, long). Of course, at any given position in a narrative, each participant read only one of the four possible anaphoric sentences. We divided the anaphoric sentences into four sets of materials and presented each set to one quarter of the participants. We interspersed three filler narratives among the experimental ones. They served to mention explicitly those rooms that were only implicitly contained in the motion sentences of the experimental narratives, thus keeping these rooms from being forgotten during the course of the experiment. After reading all 15 narratives, participants completed a short questionnaire about their reading strategies and features of the narratives. It took participants about 45 min to read the narratives and answer the questions.

Design. For anaphoric sentences, a combination of the variables path room division, path room size, and target room type yielded a $2 \times 2 \times 4$ design. All variables were varied within subjects. The same was true for motion sentences, except that target room type was not of interest for motion sentence reading times. Following a suggestion by Pollatsek and Well (1995), we included the counterbalancing variable of layout type as an eight-level between-subjects variable in the by-subjects analyses. In the by-materials analyses, the counterbalancing variable of materials set was included where appropriate. The dependent variables of interest were the reading times of motion sentences and anaphoric sentences.

Results and Discussion

We analyzed reading times of motion sentences and anaphoric sentences after excluding outlier reading times (5% of the reading times) from the data. We determined outliers relative to each participant and each experimental condition. First, we computed difference scores by subtracting each participant’s median reading time from his or her reading times. Then, separately for each dependent variable and each experimental condition, the upper and lower 3% of the difference scores were determined, and the corresponding reading times were marked as outliers and replaced by the participant’s median reading time (Rinck, 1994). We computed all analyses twice, once by using the 64 participants as a random variable and once by using the 16 anaphoric sentence positions. Below, $F_1$ values relate to the by-subjects analyses, whereas $F_2$ values relate to the by-materials analyses. All effect sizes reported below (with the $f$ statistic) were determined from Cohen (1988). The reading times observed in Experiments 2 and 3 were treated the same way.

Anaphoric sentences. The mean anaphoric sentence reading times observed in Experiment 1 are displayed in Table 1. They were analyzed by analyses of variance (ANOVA), including the within-subjects variables of target room type, path room division, and path room size. The overall analyses yielded a highly significant effect of target room type, $F_1(3, 168) = 34.06, p < .001; F_2(3, 45) = 16.93, p < .001; f = .31$. References to location room objects were more quickly understood than references to near path room objects, $F_1(1, 56) = 43.83, p < .001; F_2(1, 15) = 10.44,$
p < .01; f = .26. Also, references to far path room objects were more quickly understood than were those to source room objects, \( F_1(1, 56) = 4.97, p < .05; F_2(1, 15) = 4.52, p = .05; f = .09. \) The most interesting pattern of results was related to the difference between the near and the far part of the path room: Access to objects in the near part was faster than to those in the far part but only if the path room was divided into two rooms, \( F_1(1, 56) = 9.46, p < .01; F_2(1, 15) = 10.70, p < .01; f = .20. \) It did not matter whether the path room was short or long. If the path room was undivided, the difference between the near and the far part was not significant (both \( F_s < 1.52, \text{ns}; f = .07)\), neither for short nor for long path rooms. Accordingly, the interaction of target room type and path room division was significant, both for the whole set of data, \( F_1(3, 168) = 4.51, p < .01; F_2(3, 45) = 3.01, p < .05; f = .10, \) and for the two parts of the path room, \( F_1(1, 56) = 10.70, p < .01; F_2(1, 15) = 6.57, p < .05; f = .14. \) These results indicate that the accessibility of objects was affected only by categorical distance: Differences in accessibility occurred only if the objects were located in different rooms, such as in the near and the far part of a divided path room. If the very same objects were not separated by a wall, their accessibility did not differ significantly, whether Euclidean distance between the objects was short or long.

**Motion sentences.** The mean motion sentence reading times observed in Experiment 1 are shown in the upper part of Table 2. They were analyzed by ANOVAs including the within-subjects variables of path room division and path room size. These analyses indicated that participants read motion sentences more slowly if the path room was divided and long. Otherwise, reading times were uniformly low. Accordingly, the interaction of path room division and size was significant, at least in the more powerful by-subjects analysis, \( F_1(1, 56) = 10.33, p < .01; F_2(1, 15) = 2.82, \text{ns}; f = .09. \) The same was true for the main effects of path room division, \( F_1(1, 56) = 8.44, p < .01; F_2(1, 15) = 1.53, \text{ns}; f = .08, \) and of path room size, \( F_1(1, 56) = 5.21, p < .05; F_2(1, 15) = 1.35, \text{ns}; f = .08. \) These reading times suggest that participants did infer the protagonist’s motion through the unmentioned path room(s). However, they do not indicate whether Euclidean distance, or categorical distance, affects the time participants take to “mentally move” the protagonist from the source room into the location room. Reading times were increased only if the path room was both long and divided.

Taken together, the results of the first experiment suggest that the accessibility of objects represented in the situation model depended on categorical distance, that is, on the number of rooms located between the object and the focus of attention. Euclidean distance, however, had no effect on accessibility: The size of the path room did not affect accessibility as measured by reading times of anaphoric sentences. In addition, the somewhat more equivocal reading times of motion sentences do not provide convincing evidence for an effect of Euclidean distance either.

These conclusions are hampered, however, by several shortcomings of the first experiment related to the shape, position, and size of the path rooms. As Figure 1 shows, the path rooms could be located in a corner of the building (e.g., the laboratory) or along the long axis of the building (e.g., the repair shop). Both diagrams are somewhat infelicitous in that the protagonist can move on a straight or on a bent path through undivided path rooms, thus rendering its division into a near part and a far part ambiguous. Moreover, an effect of Euclidean distance may have failed to appear because our manipulation was not strong enough: Even though our layouts’ long rooms were twice as long as short rooms, this relation might not be extreme enough. Finally, perhaps participants did not show an effect of Euclidean distance because they forgot about the details of the learned layout during the course of the experiment. Although this possibility seems improbable to us in light of earlier results (Rinck & Bower, 1995; Rinck et al., 1996), it cannot be excluded because a test of participants’ layout knowledge was not

### Table 1
**Mean Reading Times (in Milliseconds) and Standard Deviations of Anaphoric Sentences in Experiment 1**

<table>
<thead>
<tr>
<th>Path room division and size</th>
<th>Location</th>
<th>Near path</th>
<th>Far path</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>M</td>
<td>SD</td>
<td>M</td>
</tr>
<tr>
<td>Divided-long</td>
<td>4,163</td>
<td>2,057</td>
<td>4,732</td>
<td>1,540</td>
</tr>
<tr>
<td>Divided-short</td>
<td>4,073</td>
<td>1,742</td>
<td>4,866</td>
<td>1,554</td>
</tr>
<tr>
<td>Undivided-long</td>
<td>4,058</td>
<td>1,486</td>
<td>5,182</td>
<td>1,642</td>
</tr>
<tr>
<td>Undivided-short</td>
<td>4,285</td>
<td>1,758</td>
<td>5,230</td>
<td>1,505</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Experiment and path room division</th>
<th>Short</th>
<th>Long</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experiment 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Divided</td>
<td>3,712</td>
<td>2,077</td>
</tr>
<tr>
<td>Undivided</td>
<td>3,728</td>
<td>2,298</td>
</tr>
<tr>
<td>Experiment 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Divided</td>
<td>3,704</td>
<td>2,032</td>
</tr>
<tr>
<td>Undivided</td>
<td>3,479</td>
<td>1,990</td>
</tr>
<tr>
<td>Experiment 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Divided</td>
<td>3,205</td>
<td>1,711</td>
</tr>
<tr>
<td>Undivided</td>
<td>3,076</td>
<td>1,628</td>
</tr>
</tbody>
</table>
administered at the end of Experiment 1. Thus, we designed Experiment 2 as a replication of Experiment 1 with methodological improvements as well as additional dependent variables.

Experiment 2

Experiment 2 replicated and extended the results of the first experiment by using improved layouts and an additional type of anaphoric sentence. Of importance, none of the path rooms was located in a corner of the building, and all movements through any path room followed a straight path. In addition, the Euclidean difference between short and long rooms was increased to the maximum amount that was still plausible. To investigate an even larger difference in Euclidean distance, we introduced a new type of anaphoric sentence. These sentences referred to an object in a room “across the building,” which could be separated from the protagonist either by only a wall or by at least 6 in (15.24 cm) on the layout. We ensured that participants did not forget the learned layout during the course of the experiment by testing their knowledge at the end of the experiment. Again, the important question investigated in Experiment 2 was whether Euclidean distance or categorical distance would influence the accessibility of objects represented in the participants’ situation model.

Method

Because this experiment was very similar to Experiment 1, we limit our description to its differences.

Participants. Forty-eight undergraduates of the Technical University of Dresden, Germany, and the University of Giessen, Germany, participated in the experiment, either to fulfill a course requirement or for monetary compensation (equivalent to $10). The data of 5 additional participants were excluded from all analyses because their high error rates on the comprehension questions after each narrative indicated careless reading. The remaining 48 participants had an average error rate of 11%.

Layout and narratives. Two of the eight layout versions used in Experiment 2 are depicted in Figure 2 and Figure 3. In these layouts, none of the path rooms (experiment room, repair shop, laboratory, office) was located in a corner of the building. Moreover, the protagonist’s path always led straight through the path room, whether it was short or long, divided or undivided. In addition, the difference between short and long rooms was increased considerably; long rooms were 2.4 times as long as short ones. We varied the size of the path rooms by presenting the layouts either in a horizontal orientation (Figure 2) or in a vertical orientation (Figure 3). In the vertical orientation, the experiment room and the laboratory were short, whereas the office and the repair shop were long. The opposite was true for the horizontal orientation.

Compared with Experiment 1, the range of rooms referred to by anaphoric sentences was limited to the most important ones. In Experiment 2, these sentences always referred to an object located in the near or in the far part of the path room. Because the first experiment had yielded clear results regarding the accessibility of objects in the near and far room, we decided not to retest these. Instead, we doubled the number of references to objects in the near and far part of the path room. Because all of these references related to some part of the path room, they are called path room anaphoric sentences in the following. Each participant read 2 different path room anaphoric sentences in each of the eight experimental conditions, that is, 16 sentences altogether.

In addition, we introduced the across building anaphoric sentences mentioned above. If the protagonist was located in the experiment room, repair shop, laboratory, or office, the sentence would refer to an object in the room on the opposite side of the building (i.e., the laboratory, office, experiment room, or repair shop, respectively). Each participant read four of these across building anaphoric sentences, that is, one for each possible room across the building, distributed over four of the experimental
narratives. For these sentences, the mean route distance between the protagonist and the object referred to was identical in all conditions (viz., five rooms), whereas Euclidean distance varied greatly. For instance, in one of the narratives, when the protagonist was located in the experiment room, the protagonist “recalled that she had spoken to somebody working at the scales,” across the building (see Figure 2 or 3). For participants who had learned horizontal layouts, such as that in Figure 2, the scales were very close in Euclidean distance to the protagonist, that is, “right behind the wall.” For participants who had learned vertical layouts, such as that in Figure 3, the scales were far away in Euclidean distance to the protagonist, that is, “in the laboratory.”

We also introduced a manipulation check on layout recall in Experiment 2. After participants had finished reading the narratives, we asked them to draw the learned layout from memory on a blank sheet of paper. We could thus ascertain whether participants still knew the rooms and the objects by the end of the experiment. Moreover, we introduced a number of minor modifications in Experiment 2. To make the number of objects located in each room unmistakable, we changed objects consisting of multiple components and denoted by plural terms, such as shelves and speakers, into single objects denoted by singular terms, such as shelf and speaker. The number of objects located in the source and location rooms was reduced to two or three objects to increase the variety in the number of objects located in each room and to reduce the overall number of learned objects to a total of 26. Also, we reduced the number of filler narratives to two texts to speed up the second part of the experiment. Finally, we included room names in all anaphoric sentences (e.g., “the clock” was expanded to “the clock in the experiment room”) to facilitate comprehension of the anaphoric references (see Rinck & Bower, 1995, Experiment 1).

Design. Reading times of path room anaphoric sentences, across building anaphoric sentences, and motion sentences were recorded as dependent variables. For path room anaphoric sentences and motion sentences, all combinations of the variables path room division (undivided, divided), path room size (short, long), and target room type (near path room, far path room) yielded a $2 \times 2 \times 2$ design. For across building anaphoric sentences, we used only the variable Euclidean distance (close, far) in analyses. In each case, the variables were completely crossed and varied within subjects. Again, we included the counterbalancing variables of map type and materials set in the analyses where appropriate. As in Experiment 1, perfect counterbalancing was achieved. We used every path room anaphoric sentence and motion sentence exactly six times in each experimental condition by having each of the eight different layouts studied by 6 participants. Also, all of the four across building anaphoric sentences referred to a close object for half of the participants and to a far object for the other half, depending on the orientation of the layout they had studied.

Results and Discussion

Path room anaphoric sentences. The means and standard deviations of these reading times are shown in Table 3. The overall ANOVAs, including the within-subjects variables of path room division, path room size, and target room type, yielded a highly significant interaction of path room division and target room type, $F_1(1, 40) = 8.36, p < .01$; $F_2(1, 30) = 8.89, p < .01; f = .08$. The nature of this interaction was very easy to identify: For both short and long divided path rooms, objects in the near part of the path room, that is, one room back from the protagonist’s location, were more accessible than objects in the far part, that is, two rooms back: divided–long, $F_1(1, 40) = 7.79, p < .01; F_2(1, 30) = 6.30, p < .05; f = .17$; divided–short, $F_1(1, 40) = 5.43, p < .05; F_2(1, 30) = 6.28, p < .05; f = .14$. For undivided path rooms, the accessibility of objects in the near

<table>
<thead>
<tr>
<th>Path room division and size</th>
<th>Near path</th>
<th>Far path</th>
</tr>
</thead>
<tbody>
<tr>
<td>Divided–long</td>
<td>5,543</td>
<td>2,647</td>
</tr>
<tr>
<td>Divided–short</td>
<td>5,591</td>
<td>2,515</td>
</tr>
<tr>
<td>Undivided–long</td>
<td>5,371</td>
<td>2,480</td>
</tr>
<tr>
<td>Undivided–short</td>
<td>5,336</td>
<td>2,158</td>
</tr>
</tbody>
</table>

Table 3

Mean Reading Times (in Milliseconds) and Standard Deviations of Path Room Anaphoric Sentences in Experiment 2
and far part was practically identical, for both short and long path rooms (all Fs < 1, all fs < .02). This very clear pattern of results strongly suggests that—just as in Experiment 1—the accessibility of objects was exclusively affected by categorical distance and not by Euclidean distance.

Across building anaphoric sentences. The upper part of Table 4 displays the means and standard deviations of these reading times for references to objects either close or far in Euclidean distance from the focus of attention. Although references to close objects were read slightly slower than references to far objects, the difference between these two conditions was not significant (both Fs < 1, fs = .05). Hence, these data do not provide any evidence for an effect of Euclidean distance on accessibility either. Even though the objects were separated from the protagonist by either a large distance or just a wall, their accessibility did not differ, possibly because the number of rooms along the route separating them was identical.

Motion sentences. The mean motion sentence reading times are shown in the middle part of Table 2. Again, the within-subjects variables path room division and path room size were included in the ANOVAs of these reading times. The only significant effect was observed in the by-subjects analysis, namely, the main effect of path division, $F_1(1, 40) = 5.34, p < .05; F_2(1, 30) = 1.58, ns; f = .05$. The main effect of path room size and the interaction did not approach statistical significance (all Fs < 1, all fs < .03). Interpreted cautiously, the pattern of these reading times fits well with the reading times of anaphoric sentences. Participants seemed to infer the protagonist’s path through the unmentioned path room(s), and this inference (or imagined walk) took longer if two rooms rather than one room were involved. The size of the path room(s), however, did not matter at all.

Postexperimental drawings. Overall, the room and object names, as well as the object locations, were reproduced quite accurately in the drawings, averaging 97% correct recall. Thus, there was no evidence of participants’ forgetting the appearance of the layout during the course of the experiment. Moreover, in contrast to the reading times presented so far, participants’ drawings clearly reflected the Euclidean distances of the building diagrams they had studied. On average, long rooms were drawn twice as long as short rooms. This relation is very close to reality; in the

<table>
<thead>
<tr>
<th>Table 4</th>
<th>Mean Reading Times and Reaction Times (in Milliseconds) and Standard Deviations of Across Building Anaphoric Sentences and Test Probes in Experiments 2 and 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Euclidean distance</td>
<td></td>
</tr>
<tr>
<td>Experiment and dependent variable</td>
<td>Close</td>
</tr>
<tr>
<td><strong>Experiment 2</strong></td>
<td></td>
</tr>
<tr>
<td>Anaphoric sentences</td>
<td>5,581</td>
</tr>
<tr>
<td><strong>Experiment 3</strong></td>
<td></td>
</tr>
<tr>
<td>Anaphoric sentences</td>
<td>5,189</td>
</tr>
<tr>
<td>Test probes</td>
<td>4,735</td>
</tr>
</tbody>
</table>

learned layouts, long rooms were 2.4 times as long as short ones. The difference in reproduced length between short and long rooms was highly significant, $F_1(1, 40) = 211.60, p < .001, f = 1.26$. Categorical distance had a slight effect on the drawings as well: Two divided rooms were drawn slightly longer than the corresponding undivided one (1.04 times as long), $F_1(1, 40) = 114.48, p < .01, f = .06$.

Taken together, the results of Experiment 2 indicate that the time for readers to access a referent object was affected exclusively by its categorical distance in participants’ situation models. Objects located in the near part of the path room were accessed more readily than were objects in the far part only if the path room was divided into two rooms. Moreover, time to read and fill in inferences regarding the protagonist’s path took longer only if the number of inferred path rooms increased. However, no evidence at all could be found for any effect of Euclidean distance on anaphor resolution or on reading time. Objects located at varying Euclidean distances in the same undivided path room did not differ in accessibility, objects located five rooms away at varying Euclidean distances did not differ either, and inferences of the protagonist’s path took no longer when the inferred path was longer in Euclidean distance.

These results are in accord with the hypotheses that spatial situation models used during narrative comprehension do not contain information about Euclidean distances of the spatial environments they represent. However, the results are also compatible with another hypothesis, namely that participants formed an independent memory representation for the learned layout itself distinct from the situation model they constructed by combining the layout with the narrative and prior knowledge. The layout might be represented in a nonhierarchical, possibly image-like format that preserves its Euclidean metric. The situation model, however, might be hierarchical, with rooms being the critical spatial units that organize spatial features of the situation model. A third hypothesis is that participants did represent information about Euclidean distance in their situation model but did not use it during narrative comprehension because that level of detail was unnecessary. All of these hypotheses would predict that participants retrieve or compute knowledge about Euclidean distance only when necessary during narrative comprehension or any other task. This view coincides with recent results reported by Langston et al. (1994) and with suggestions by Foertsch and Gernsberger (1994) and by Zwaan and Graesser (1993), who argued that participants in reading experiments use a satisfying strategy. We designed Experiment 3 to test this prediction.

Experiment 3

Experiment 3 was a replication of the second experiment with a secondary task added to narrative reading. As in the original Morrow et al. (1987, 1989) experiments, reading of the narratives was periodically interrupted by test probes naming two objects contained in the learned layout. Unlike the Morrow et al. task, however, we asked our participants to make relative distance judgments: For each pair of objects, participants were to decide which one was located closer to
the current location of the protagonist. For some test probes, the objects were located in different rooms, so the judgment could be based on either Euclidean distance or categorical distance. For other test probes, however, both objects were located in the same room although their Euclidean distance from the protagonist varied. In these cases, the judgment could only be based on Euclidean distance.

We included the relative distance judgments for several reasons. First, they should allow us to determine whether participants represent Euclidean distance at all in their situation model: If they do not, they should be unable to judge object pairs that differ only in Euclidean distance. Second, we expected to find an effect on judgment time of the distance between the two probe objects in a manner analogous to the symbolic distance effect observed in judgments within linear orders (see Moyer & Dumais, 1978, for a review) and spatial distance effects reported elsewhere (Rinck et al., 1996; Wagener-Wender & Wender, 1990). The farther apart the two probe objects are in the situation model, the easier it should be to determine which one is closer to the protagonist. Again, the critical question is whether the distance between the probe objects, or their distance from the protagonist, should be thought of in terms of Euclidean distance or categorical distance.

One might expect to find that Euclidean distance affects the ease of these judgments because participants are practically forced to use it to judge the same-room test probes. Thus, if they must use this type of information, it might then affect the cognitive processes involved in the decisions. However, the literature on the symbolic distance effect provides little evidence for effects of distance measured on an interval scale, such as is Euclidean distance. In most such studies, the items were only ordered along an ordinal scale, and ordinal distance and interval distance were typically confounded (Moyer & Dumais, 1978). In one of the rare studies investigating both types of distance, Griggs and Shea (1977) found that participants did not include interval information in their representation of a linear order unless forced to do so by the experimental task.

Third, inserting the relative distance judgments into our task will tell us whether Euclidean distance will now affect anaphor resolution. One possibility is that, once the information representing Euclidean distance is retrieved from memory to identify the closer object of the pairs, participants might find it difficult to “turn off” this knowledge during narrative comprehension, thereby causing the metric distance information to spill over into retrieving referents for the target anaphors. According to this hypothesis, adding the judgment task should cause an effect of Euclidean distance on both the judgments and the sentence reading times.

A contrary hypothesis would state that retrieving information about Euclidean distance is sufficiently effortful that participants will only do so when it is necessary, hence, metric information would not be expected to be used during narrative comprehension and would not affect reading times of anaphoric sentences.

A third possibility is that the relative distance judgment task will impair narrative comprehension: If participants mainly concentrate on judging the test probes correctly, they may expend effort in keeping track of the location of the protagonist and the objects at the expense of attending less to the contents of the narrative and the anaphoric sentences. In this manner, the judgment task might even weaken the effect of categorical distance on accessibility rather than strengthen the effect of Euclidean distance. We tried to prevent participants from concentrating primarily on the judgment task by reinforcing them for careful reading as well as for accurate judgments. Previous research does not provide any evidence for or against these hypotheses because the studies used either a probe judgment task (e.g., Morrow et al., 1987, 1989; Rinck et al., 1996; Wilson et al., 1993) or anaphoric sentences (Morrow, Leirer, Andrassy, & Stine, 1994; Rinck & Bower, 1995) to measure accessibility, but not both.

These alternative hypotheses predict different patterns of results for relative distance judgments and reading times of anaphoric sentences, each pattern leading to different theoretical conclusions. In the most extreme case, if Euclidean distance does not affect reading times, and participants are unable to judge objects that differ solely in Euclidean distance, we would conclude that situation models participants construct for narratives do not preserve the Euclidean metric at all—a finding consistent with hierarchical models of spatial memory, such as that proposed by Stevens and Coupe (1978). If Euclidean distance has an effect on the distance judgment task and not on the spatial gradient of accessibility observed in the anaphoric sentences reading times, we would conclude that although participants represent Euclidean distances in their situation model, they use it selectively only when necessary, following the satisfying strategy of comprehension suggested recently (Foertsch & Gernsbacher, 1994; Zwaan & Graesser, 1993). If we find that Euclidean distance affects performance in both tasks, we would be able to claim that Euclidean distance is not only represented in spatial situation models but is also widely used as soon as it becomes activated.

**Method**

Because Experiment 3 was similar to Experiment 2, we describe only its new features.

**Participants.** Forty-eight undergraduates of the Technical University of Dresden, Germany, and the University of Giessen, Germany, participated in the experiment, either to fulfill a course requirement or for monetary compensation (equivalent to $10). The data of 3 additional participants were excluded from all analyses because of error rates higher than 30%. The remaining 48 participants had an average error rate of 8%.

**Materials and procedure.** Except for a few minor stylistic changes, the layouts and narratives we used in Experiment 3 were identical to those of Experiment 2. The major difference in procedure was the introduction of the relative distance judgments. A total of 26 test probes was presented to each participant, distributed over the 13 narratives that followed the practice narrative, which contained 4 practice test probes. As in the previous experiments, participants read the narratives sentence by sentence by pressing both mouse buttons. At unpredictable times, a test probe was presented instead of the next sentence. Each test probe consisted of the question line “Which object is closer to (protagonist name)?” Simultaneously, and below this line, the names of two objects learned as part of the layout were presented side by side in
the middle of the screen. For instance, in the text shown in the Appendix after the sentence “With a deep sigh, he sat down on the couch, and started to write down some notes for his presentation,” the question “Which object is closer to Thomas?” was presented. Simultaneously, the two object names shelf—garbage can were presented below the question. Participants had to indicate the closer object—in this case, the shelf—by pressing the left or right mouse button for the left or right object, respectively. The answers and their latencies were recorded by the computer. After their judgment, participants received the same feedback as after their answers to the comprehension questions at the end of the narrative. After another button press, the next sentence of the narrative was presented. Test probes were presented in locations different from the ones already occupied by anaphoric sentences. To ensure accurate relative distance judgments as well as careful reading of the narratives, participants received an extra financial bonus if they kept their error rate below 15% on both the test probes and the comprehension questions.

We used four different types of test probes, of which path room test probes were the most important. These eight test probes were presented after motion sentences equivalent to the ones presented before anaphoric sentences. The path room probes consisted of two objects located in the unmentioned path room. One object always came from the near part of the path room (closer to the protagonist) and the other one from the same side of the room but from the far part. For instance, after the protagonist had moved from the library into the storage room (see Figure 2 or 3), the test probes computer—microscope or work bench—scales would be presented. Depending on the studied layout, one object or the other was located closer to the protagonist. For example, for participants who had studied the layouts in Figure 2 and Figure 3, the work bench would be closer than the scales and the microscope closer than the computer. In analogy to the anaphoric sentences, the path rooms involved in these test probes were undivided—short, undivided—long, divided—short, or divided—long, depending on the layout studied before. Each participant judged two path room probes in each of these four experimental conditions. The critical questions were whether a distance effect would occur with these probes, that is, faster and more accurate decisions for object pairs that differ more in distance, and whether the relevant distance between them would be Euclidean or categorical distance.

Across building test probes were the second type of test probes. Eight of these were presented to each participant. In analogy to the across building anaphoric sentences, they consisted of one object located at the innermost wall of the protagonist’s current location room and another object located just behind that wall or farther away. For example, when the protagonist was located in the experiment room (see Figure 2 or 3), the test probe might consist of the clock and the scales. For half of the participants (the ones who studied layouts in horizontal orientation as in Figure 2), these two objects were located close to one another in Euclidean space, separated only by a wall. For other participants who studied layouts in vertical orientation (see Figure 3), these two objects were located far from one another. In terms of route distance, however, all across building probes were equated. Each participant received four across building probes containing close objects and four probes containing far objects. If Euclidean distance contributes to the distance judgments, the far probes should have been easier to judge than the near probes. Please note that for both path room probes and across building probes, the difference in distances from the protagonist to the two probe objects is critical, with smaller differences causing more difficult decisions. For the anaphoric sentences, distance between the single referent object and the focus of attention (the protagonist) is critical, with shorter distances causing faster access in memory.

Finally, corner—corner test probes and location—other test probes were the two other probe types we used in Experiment 3. Judgments of these test probes were not included in the statistical analyses. The four corner—corner probes always contained objects from opposite corner rooms of the building (reception room, lounge, storage room, library). These probes were presented when the protagonist was located in one of the other two corner rooms. For instance, when the protagonist was located in the storage room, the corner—corner probe might have contained the couch from the library and the refrigerator from the lounge. Judgments of these test probes depended mainly on differences in Euclidean distance. They were presented to induce attention to Euclidean distance, to include the corner rooms in the judgment task, and to have a probe type that was difficult but still unambiguous. The six location—other probes expanded the range of difficulty in the other direction. They always contained an object from the current location room and an object from some other room farther away. In these cases, it should be very easy to identify the object that is closer to the protagonist. In addition to using a variety of test probes, we constructed two sets of all probes by switching the left—right presentation order of the two object names for half of the participants.

Design. We conducted independent analyses for path room anaphoric sentences, across building anaphoric sentences, motion sentences, path room probes, across building probes, and participants’ postexperimental drawings. For motion sentences and both types of anaphoric sentences, the design was identical to that of the second experiment. For all test probes, latencies of correct responses to the probes and error rates of the responses served as dependent variables. For path room probes, all combinations of the variables path room division (undivided, divided) and path room size (short, long) yielded a 2 X 2 design. For across building probes, the only variable was Euclidean distance (close, far). As before, all variables were varied within subjects. Experimental conditions and materials were perfectly counterbalanced, and the counterbalancing variables of map type and materials set were included in the analyses where appropriate.

Results and Discussion

**Path room anaphoric sentences.** The means and standard deviations of these reading times are given in Table 5. The pattern of reading times observed in this experiment resembled the one of Experiment 2; however, the effects were much weaker. In the overall ANOVAs including the within-subjects variables of path room division, path room size, and target room type, the only effect that approached significance in the by-subjects analysis was target room type, $F(1, 40) = 3.32, p < .10; F(2, 30) < 1; f = .04$. In the by-materials analysis, the only effect approaching signifi-

<table>
<thead>
<tr>
<th>Path room division and size</th>
<th>Near path</th>
<th>Far path</th>
</tr>
</thead>
<tbody>
<tr>
<td>M</td>
<td>SD</td>
<td>M</td>
</tr>
<tr>
<td>Divided—long</td>
<td>2,521</td>
<td>2,082</td>
</tr>
<tr>
<td>Divided—short</td>
<td>2,496</td>
<td>2,661</td>
</tr>
<tr>
<td>Undivided—long</td>
<td>5,277</td>
<td>1,945</td>
</tr>
<tr>
<td>Undivided—short</td>
<td>5,398</td>
<td>2,462</td>
</tr>
</tbody>
</table>

Table 5: Mean Reading Times (in Milliseconds) and Standard Deviations of Path Room Anaphoric Sentences in Experiment 3.
cance was path room division, $F_1(1, 40) = 2.07, ns; F_2(1, 30) = 3.14, p < .10; f = .04$. Separate analyses of divided and undivided path rooms yielded a significant effect of target room type for divided rooms in the by-subjects analysis, $F_1(1, 40) = 5.50, p < .05; F_2(1, 30) = 1.52, ns; f = .07$. For undivided path rooms, the difference between objects from the near and the far part of the path room never approached significance (both $F_1 < 1, f_s = .01$). However, the interaction of target room type and path room division did not reach significance, $F_1(1, 40) = 1.89, ns; F_2(1, 30) < 1; f = .03$. This pattern of results provides only weak evidence for an effect of categorical distance on the accessibility of situation model components and no evidence at all for an effect of Euclidean distance.

**Across building anaphoric sentences.** The middle part of Table 4 displays the means and standard deviations of these reading times for references to objects either close or far in Euclidean distance from the focus of attention. Replicating the results of the preceding experiment, we found no significant difference between these two conditions (both $F_1 < 1, f_s = .04$). Thus, as before, these data provide no evidence for an effect of Euclidean distance on accessibility.

**Motion sentences.** The lower part of Table 2 displays the mean reading times of anaphoric noun phrases. In the ANOVAs including the within-subjects variables path room division and path room size, the only significant effect on the reading times, $F_1(1, 40) = 6.22, p < .05; F_2(1, 23) = 6.55, p < .05; f = .06$. As in the previous experiment, the main effect of path room size and the interaction were not significant (all $F_1 < 1, all f_s < .03$). The pattern of these reading times clearly indicates that participants took longer to represent the protagonist’s path if it included two unmentioned path rooms rather than one. Once more, the Euclidean distance traveled by the protagonist did not matter at all.

**Path room probes.** Mean reaction times of correct judgments of these test probes are shown in Table 6. Contrary to the sentence reading times collected before, these reaction times revealed an effect of Euclidean distance. Judgments were faster if the two probe objects were far from one another in Euclidean distance, that is, located in long path rooms. Accordingly, in the overall ANOVAs including the within-subjects variables path room division and path room size, the only statistically significant effect was path room size, $F_1(1, 40) = 34.60, p < .001; F_2(1, 7) = 24.69, p < .001; f = .21$. Much to our surprise, neither path room division nor the interaction of path room size and division were significant (all $F_1 < 1.12, ns, all f_s < .04$). Also, no significant differences between error rates were observed: They were uniformly low and averaged 5%, indicating excellent knowledge of the layout and its components.

**Across building probes.** Mean reaction times of correct judgments of these test probes are given in the lower part of Table 4. In accord with the path room test probes, and in contrast to the across building anaphoric sentences, an effect of Euclidean distance on judgment speed was observed. Faster judgments of object pairs that were located far from each other, rather than close to each other, indicated an effect of Euclidean distance, $F_1(1, 40) = 5.30, p < .05, f = .12$. As with the path room probes, error rates for across building probes averaged 5% and did not differ significantly across conditions.

**Postexperimental drawings.** The results regarding these drawings were similar to those of Experiment 2. The room and object names and their locations were reproduced quite accurately, averaging 95% correct recall. Also, long rooms were again drawn twice as long as short rooms (exactly 1.97 times as long, compared with the actual ratio of 2.4 times), yielding a highly significant difference between short and long rooms, $F(1, 40) = 239.59, p < .001, f = 1.18$. An effect of categorical distance was also observed again: Divided rooms were drawn slightly longer than undivided ones (1.04 times as long), $F(1, 40) = 17.65, p < .001, f = .08$.

In summary, the results observed for sentence reading times and probe judgment times were completely opposite. In accord with the previous experiments, reading times of anaphoric sentences revealed no effect of Euclidean distance on accessibility of the referent, whereas the relative judgment task produced faster judgments for greater Euclidean distance. The effect of Euclidean distance arose even though the test probes for the judgment task contained exactly those objects that we used as referents for the anaphoric noun phrases. Thus, path room probes were equivalent to critical path room anaphoric sentences, and across building probes were equivalent to across building anaphoric sentences. Hence, it seems obvious that the specific situation model components involved were not of critical importance to the type of distance effects observed. Rather, the effects depended on the tasks in which participants engaged. Reading and comprehending anaphoric noun phrases that taxed the accessibility of situation model components in memory yielded effects of categorical distance, whereas relative distance judgments yielded an effect of Euclidean distance. Besides opposite effects in reading times and judgment times, we found that the effect of categorical distance on the reading times of anaphoric sentences was much weaker than in previous experiments. The weak effect observed in Experiment 3 indicates that, contrary to our instructions, participants did indeed concentrate their energies more on the difficult test probes than on reading the easy anaphoric sentences. By itself, this result might seem troublesome. Together with the consistent findings of the first two experiments, however, the weak effect still provides converging evidence for the impact of categorical distance. In addition, it suggests that follow-up studies should use either anaphoric sentences or test probes—not both of them—to
measure accessibility of situation model components. The fact that categorical distance affected motion sentences somewhat more than in the previous experiment is compatible with this explanation. To give correct relative distance judgments, participants would focus on the protagonist’s motions and locations, thereby processing motion sentences more thoroughly while processing anaphoric sentences unrelated to motions somewhat less carefully.

General Discussion

The three experiments reported in this article indicate that the spatial gradient of referent accessibility observed in many previous studies of anaphor resolution is based on categorical distance rather than on Euclidean distance. This finding goes contrary to implicit assumptions shared by the authors of these studies, including ourselves. The accessibility of objects referred to by anaphoric noun phrases decreased with the number of rooms between the object and the focus of attention, not with the size of the rooms. In addition, when Euclidean distance was varied while holding route distance constant, no differences in accessibility between close and far referents occurred. These results are in accordance with those reported by Langston et al. (1994), whose failure to find a noticing effect based on spatial proximity provides indirect evidence against the representation of Euclidean distance in situation models.

Analogous results were observed for implied motions of the protagonist through unmentioned path rooms. Participants took longer to infer the protagonist’s path if he or she crossed two rather than one room, but the size of the rooms did not matter. These motion sentences bear some resemblance to the mental scanning task used by Kosslyn et al. (1978), who found that scanning times of mental images increased with increasing distance between the starting point (equivalent to our source room) and the end point (equivalent to our location room) of a mental movement. However, three important differences are noteworthy. First, Kosslyn et al. (1978) interpreted their results in terms of Euclidean distance, whereas the distance effects observed in our experiments were clearly categorical. This difference supports the distinction between spatial mental models and mental images made by several authors (Bryant & Tversky, 1995; Denis, 1996; Johnson-Laird, 1996). Second, Kosslyn et al. investigated a number of different distances, whereas our manipulations were restricted to the near and far part of the path room. Finally, Kosslyn et al.’s conclusions have been criticized (e.g., by Pylyshyn, 1981) as due to experimenter demand artifacts inherent in the mental scanning task. Our interpretation of the motion sentence reading times seems less prone to an explanation by demand artifacts because no reference to any type of distance was made. Instead, our participants were instructed to simply read each sentence for comprehension at their normal speed.

Despite the null effects of Euclidean distance on accessibility, however, it would be premature to conclude that the metrics of spatial situation models are restricted to an ordinal level, representing only categorical distance. As Experiment 3 demonstrated, participants were able to give correct relative distance judgments even if the two objects differed in Euclidean distance only. Moreover, the distance effect observed with both path room probes and across building probes was a pure Euclidean distance effect: the size, rather than the number, of rooms located between the two probe objects affected decision times.

This seemingly paradoxical pattern of results—categorical but not Euclidean distance effects on accessibility versus Euclidean but not categorical distance effects on relative distance judgments—has interesting theoretical implications. Regarding the distinction between hierarchical and nonhierarchical models of spatial memory suggested by McNamara (1991), our results indicate that participants’ spatial representation was clearly hierarchical, otherwise no effect of categorical distance induced by room divisions would have occurred. However, contrary to McNamara’s suggestion, the representation could not have been purely nonmetric either, because Euclidean distance did affect the speed of relative distance judgments.

What kind of spatial representation would be able to predict both findings? Unfortunately, several different answers are possible, and our experiments were not designed to discriminate them. For instance, one might assume that nonhierarchical representations of each room—possibly an analog mental image of it—are hierarchically organized into a representation of the complete building. However, to explain our data, a purely propositional and categorical representation of Euclidean distance would suffice. The levels of Euclidean distance investigated here would be encompassed if participants merely categorized each room as either small, medium, or large. To study Euclidean distance beyond such simple categorizations, one needs to investigate more levels of Euclidean distance, as in the study by Kosslyn et al. (1978). This was well beyond the scope of this article and must be left to future investigations.

The pattern of results we observed in the three experiments reported here seems best accommodated by the satisficing strategy suggested by Zwaan and Graesser (1993) and Foertsch and Gernsbacher (1994). In their view, participants of experiments carry out only those cognitive processes that are necessary to complete a given experimental task—in this case, narrative comprehension and relative distance judgments. This was the case even though our materials were longer and more interesting than those used by Foertsch and Gernsbacher, and our participants were financially rewarded for thorough work. For the experiments reported here, the satisficing strategy implies that participants use only the type of information needed for a given task, even though other and more specific information may be available in their memory representation. Clearly, to comprehend the narratives and give correct answers to the comprehension questions, participants did not have to retrieve knowledge about Euclidean distances from memory. More surprisingly, knowledge about categorical distances did not affect the relative distance judgments, even though such information would have been helpful whenever the two probe objects were located in a divided path room. It seems that participants completely disregarded their knowledge about categorical distance because the instructions for the
judgment task made clear that the judgments had to be given on the basis of Euclidean distance.

In the discussion of Experiment 2, we proposed three different hypotheses that might be compatible with the pattern of results observed in Experiment 3. According to the first hypothesis, participants do not represent Euclidean distances in their situation model but compute it selectively when necessary. This hypothesis seems implausible to us for several reasons. First, we find it difficult to see how detailed information such as Euclidean distances could be computed from a less detailed representation, for example, one that represents only ordinal distance information. Second, information about Euclidean distance was contained in the layouts and therefore easily available to the participants. Thus, it is hard to believe that the information would be ignored first just to be computed later. Third, it remains unclear how the observed distance effect in probe judgment times would be explained by this hypothesis. Finally, the hypothesized selective computation of Euclidean distance information was necessary only if two objects located in an undivided path room had to be compared. Therefore, comparisons of these objects should take longer than those of objects located in divided path rooms. This was definitely not the case.

According to the second hypothesis, people set up different representations for the situation model versus the building layout, namely a nonhierarchical metric representation for the layout and a nonmetric one for the situation model. This assumption seems implausible because correct judgments of relative distance require that participants integrate layout information (the object locations) with information acquired from the current text (the protagonist's location). Thus, the observed effects of Euclidean distance arose from an integrated representation, not from isolated knowledge restricted to the layout. This integrated representation acquired from the text and other sources is exactly what the term situation model refers to (Glenberg et al., 1987; Morrow, 1994). Therefore, the third hypothesis seems most appropriate and parsimonious to us: Euclidean distance can be represented in situation models but is used only when needed. We strongly expect this conclusion to generalize to situations in which readers do not study a layout prior to narrative reading. This is the case because previous research has demonstrated comparable spatial gradients of accessibility for learning from layouts and texts (Rinck et al., 1996). Note that the third hypothesis does not imply that readers will always build situation models that represent information as specific as Euclidean distances. Often, the information supplied by the text and the reader's prior knowledge will be too inefficiently specified to construct situation models precise enough to reflect the Euclidean metric of the world. In our experiments, such precise metric information was provided by the layouts; thus, it is even more interesting that the information was used only when necessary.

Studies of knowledge representation have occasionally turned up other instances in which some knowledge is available in memory as revealed in one task performance, but yet it has little or no influence on performance of a closely related task that could have shown its influence. One instance is a study by Marsh (1993), whose participants learned to name the owners of objects that varied independently in two quantitative attributes (tombstones varying in size and shading). Later comparative judgments asking for the larger or darker of two named objects yielded symbolic distance effects to the names along each of the tested linear orders, effects that were largely (though not entirely) independent of one another. So, in this case, the comparative adjective (“Which is larger?” “Which is darker?”) sufficed to retrieve mainly information about the associated objects’ location on the queried attribute, with only slight cross-talk from the objects’ distance on the untested attribute.

In other cases, a nonoptimal organization of memorized material may be transformed or replaced by the participants during repeated testing by a more satisfactory organization to facilitate test performance. Such maneuvers were observed by Franklin and Bower (1988) whose participants first learned a deeply embedded goal–subgoal–action hierarchy and then proceeded to answer many questions of the form “Must one do action X in order to do action Y sometime later?” With repeated questioning, participants eventually replaced the goal hierarchy by a simple linear temporal order of the actions (a “squashed hierarchy”). This linear order then created a “symbolic distance” effect in terms of the temporal distance between the queried actions in the order. Yet, these participants were able to reproduce perfectly the goal hierarchy (and between-action dependencies) they had learned originally. So, again there is a paradoxical disparity between two different indices of the organization of participants’ knowledge about a domain.

One take-home message from these several demonstrations is that human adults are remarkably flexible and adaptive in how they retrieve and use their knowledge. They reveal substantial adaptability in selecting for use mainly that information that is relevant to the immediate task at hand and ignoring that which is momentarily irrelevant. Thus, when our participants in Experiment 3 were asked “Which is closer?” they retrieved metric information; when implicitly asked during reading to find a referent, they used at most information about categorical (“room”) distance. In light of participants’ exquisite adaptability, we are left to wonder not why Euclidean distance has no effect on anaphoric reference, but rather more seriously, why categorical distance does have an effect. Certainly, participants need not know what room a referent is in, or its distance from the protagonist, to verify that it exists somewhere in their mental map. So, the real puzzle is, why do readers show any distance effect whatsoever when resolving anaphoric references?

References


Langston, W., Kramer, D. C., & Glenberg, A. M. (1994, November). Mental models are not (very) spatial. Paper presented at the 35th Annual Meeting of the Psychonomic Society, St. Louis, MO.


Appendix

Translation of Sample Narrative Used in Experiment 1

Original materials were presented in German; explanations are given in the text.

Thomas wasn’t so sure he wanted to be head of the center anymore. He had just been informed that the board of directors would be making a surprise inspection tomorrow. He immediately called all the center’s employees together in the library and told them they had less than 24 hr to clean up the center. He explained about the visit and said that all of their jobs were at stake. He told the employees to clean and organize every single room. He went into the laboratory and made sure it was being cleaned and then headed off to check the rest of the rooms. He walked from the laboratory into the storage room. To devise a list of necessary tasks, he tried to think of everything that looked dirty or messy in the building. The crammed garbage can caught his attention, and he put it on top of his list immediately. He was very pleased, however, to see the storage room’s sparkling clean floor. He knew very well that the directors were more impressed by cleanliness than by good research.

Motion Sentence
Then he walked from the storage room into the lounge.

Motivating Sentence
He rechecked his list of tasks to see what else needed to be done to make the research center decent looking.

Anaphoric Sentence Alternatives
Location room: He decided that the refrigerator should not be so dirty tomorrow.
Near path room: He decided that the cart should not be so dirty tomorrow.
Far path room: He decided that the tools should not be so dirty tomorrow.
Source room: He decided that the crates should not be so dirty tomorrow.

He walked on and told the scientists in the experiment room that they’d better be busy conducting studies tomorrow. The directors should see how industrious they were. As he went into the reception room, he thought about the presentation he was planning to make to the directors. He definitely wanted it to be interesting and entertaining.

Motion Sentence
Next he walked from the reception room into the library.

Motivating Sentence
He didn’t want to let any uncleanliness distract the directors from his presentation, so he checked his list for things that needed to be cleaned.

Anaphoric Sentence Alternatives
Location room: He decided that the copier needed to be cleaned as soon as possible.
Near path room: He decided that the picture needed to be cleaned as soon as possible.
Far path room: He decided that the desk needed to be cleaned as soon as possible.
Source room: He decided that the rug needed to be cleaned as soon as possible.

With a deep sigh, he sat down on the couch and started to write down some notes for his presentation. He imagined himself giving a high-powered talk and began to feel the visit might go well after all.

Question 1: Did Thomas call all of the employees together in the library?
Question 2: Did Thomas decide that the storage room’s floor should not be so dirty tomorrow?
Question 3: Did Thomas tell the scientists to be busy conducting studies tomorrow?

Received November 13, 1995
Revision received August 22, 1996
Accepted August 22, 1996