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Two principles of premise integration in spatial reasoning

ROBIN HÖRNIG, KLAUS OBERAUER, and ANDREA WEIDENFELD
University of Potsdam, Potsdam, Germany

We propose two principles that facilitate integration of two relational premises in spatial reasoning. Integration is easier if the anaphor in the second premise, P2, bears the role of the relatum (relatum = given). Moreover, integration is easier if, in P2, the anaphor is mentioned before the new element (given-new). In premises with canonical word order (grammatical subjects mentioned first), these principles always conflict with one another. In topicalized statements mentioning the prepositional phrase first, the two principles work in tandem. By varying word order, we tested the two principles by measuring P2 comprehension times. Comprehension times indicated that integration was easiest when P2 obeyed both principles and most difficult when both principles were violated. Canonical premises were of intermediate difficulty. This pattern emerged regardless of whether the anaphor was a definite description or a pronoun.

In the standard three-term spatial reasoning task, the reasoner receives a pair of spatial-relational premises, P1 and P2, in verbal form—for example, *The knife is to the left of the vase. The vase is to the left of the glass*. Then he/she is asked for the spatial relation not explicitly asserted; in the example above, that is the relation between the knife and the glass.[1] How do people accomplish this task? Huttenlocher (1968) suggested that people construct a spatial image of the described layout and then read off the unmentioned relation from that image. Accordingly, the main task is to construct an integrated representation of the spatial layout, a process that we refer to as *premise integration*: "In explaining the mental processes of the problem solver, one may deal only with the issue of how information from the two premises is combined. . . . This process is traditionally what is meant by reasoning, as separable from merely understanding the individual premises" (Huttenlocher & Higgins, 1971, p. 487). To characterize the reasoning task in this way—as language understanding beyond the level of single sentences—is to conceive of it as text comprehension. We would then expect premise integration to be guided by principles of language comprehension.

Huttenlocher's (1968) idea that the reasoner operates on a representation of the described layout rather than on a representation of the description of the layout has been further developed by Johnson-Laird (1983, 1996) in his mental model theory. Within this framework, an initial mental model is constructed on the basis of the first premise, and then the new element mentioned in the second premise is integrated into the initial model. Thus, premise integration should be especially sensitive to properties of the second premise. The present work is an attempt to bring ideas from reasoning and from language comprehension research within the mental model framework. In particular, we tested two linguistically motivated principles of premise integration, the *given–new* principle derived from work on discourse pragmatics, and the *relatum = given* principle developed in the tradition of model theories of reasoning.

The Given–New Strategy

On the basis of linguistic analyses (e.g., Chafe, 1970[2]; Halliday, 1968), Clark and Haviland (1977) postulated the given–new strategy for language comprehension. Integrating information of the current sentence with previous information is performed in three steps: (1) identifying the given information of the current sentence, (2) finding an antecedent for the given information, and (3) attaching the new information to the antecedent. Since the first two steps are carried out as soon as the given information is encoded, mentioning given information before new information speeds up integration. On the other hand, mentioning new information initially in a sentence increases memory load because it requires holding the new information in abeyance until the given information becomes available. On the basis of these assumptions, the given–new strategy states that a sentence is easier to comprehend if given information precedes new information. Yekovich, Walker, and Blackman (1979) empirically verified this hypothesis for target sentences with canonical word order—that is, for sentences with the grammatical subject in sentence initial position (e.g., *The shark attacked*

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Table 1
The Basic Design of the Experiment:
Antecedent × Anaphor × Word Order

Antecedent	Object	Subject	Object	Subject
Anaphor	Subject	Object	Object	Subject
Word Order				
Canonical	*A* is to the left of *B* *B* is to the left of *C*	*B* is to the right of *A* *C* is to the right of *B*	*A* is to the left of *B* *C* is to the right of *B*	*B* is to the right of *A* *B* is to the left of *C*
Topicalized	To the left of *B* is *A* To the left of *C* is *B*	To the right of *A* is *B* To the right of *B* is *C*	To the left of *B* is *A* To the right of *B* is *C*	To the right of *A* is *B* To the left of *C* is *B*

the diver near the reef). A canonical target sentence was read more quickly when its subject referred back to the element already introduced (given subject precedes new object) than when its object did (new subject precedes given object).

It is tempting to assume that the given–new strategy generalizes to premise integration in spatial reasoning. For premises with canonical word order, the given–new strategy predicts that integration will be easier when the sentence initial grammatical subject of P2 refers back to an element introduced by P1 (e.g., P1: *A is to the right of B*. P2: B_{given} *is to the right of* C_{new}) rather than if the sentence final prepositional object of P2 refers back to the given element (e.g., P1: *B is to the right of A.* P2: C_{new} *is to the right of* B_{given}) Since an *anaphor* is what refers back to an element introduced earlier, the given–new strategy predicts for canonical premises that integration is easier with a sentence-initial subject anaphor (together with a new prepositional object), as compared with a sentence-final object anaphor (together with a new subject). Ehrlich and Johnson-Laird (1982) attempted to confirm this prediction. Taking error rates as indicating the ease of premise integration, they obtained the opposite result in one experiment—namely, fewer errors for P2s with an object anaphor (new subject precedes given object) than with a subject anaphor (given subject precedes new object). In two subsequent experiments, they found no effect of the anaphor in P2 but did find an effect of the *antecedent* in P1, which is what the anaphor refers back to. Integration was easier when the grammatical subject of P1 was the antecedent for the anaphor of P2 (e.g., P1: *B is to the left of A.* P2: *B is to the right of C*) as compared with the prepositional object of P1 being the antecedent for the anaphor (e.g., P1: *A is to the right of B.* P2: *B is to the right of C*). Despite the inconsistency in these studies, Johnson-Laird (1983) was led to conclude that there is no given–new advantage for premise integration in spatial reasoning.

Baguley and Payne (2000) investigated premise integration in spatial reasoning by measuring P2 comprehension times. Their canonical premise pairs contained either a subject anaphor referring back to the object antecedent or an object anaphor referring back to the subject antecedent (cf. Table 1 below). Premise integration was faster with object anaphors (new–given) than with subject anaphors (given–new). Baguley and Payne (2000, p. 325) conclude that "in at least one domain it appears that people find the order new–given easier to read and understand." They conjectured that in the spatial domain, the given–new strategy might be in conflict with the demands of model construction. We will address such a conflict next.

The Role of the Relatum in Linguistic Localization

According to Miller and Johnson-Laird (1976), spatial-relational assertions are used to localize objects linguistically (for similar proposals see, e.g., Clark, 1973; Herskovits, 1986; Landau & Jackendoff, 1993; Talmy, 1983). In their terminology, the *referent* (the grammatical subject *the vase* in *The vase is to the left of the glass*) is the object that is localized linguistically relative to the *relatum* (the prepositional object *the glass* in *The vase is to the left of the glass*). The role of the relatum is to restrict the domain in which the referent is localized: "One purpose of locative descriptions is to narrow the domain of search for a referent. . . . it is helpful to distinguish two search domains. The first domain is the one in which to search for *the relatum y*; the second is a subdomain of the first in which to search for the referent *x*. The first search domain *is given* by the context in which the communication occurs" (Miller & Johnson-Laird, 1976, p. 384, our emphasis). We condense this citation to its essence: *the relatum is given*. If someone knows where the glass is, we can inform her about the location of the vase by asserting: *The vase is to the left of the glass*. It would sound rather odd to do so by telling her: *The glass is to the right of the vase*, although both assertions convey the same information. This is acknowledged by Baguley and Payne (2000, p. 325), who point out "in general, people introduce new spatial locations relative to known landmarks."

Huttenlocher and Strauss (1968) have reported empirical evidence for the advantage of a given relatum in linguistic localizations. They tested young children with a ladder-type apparatus with five shelves, in the middle of which a block of a certain color (e.g., a red one) was given. The children's task was to add a new block of another color (e.g., a blue one) to the shelf as instructed. The relatum of the instruction was either the given red block (*Make it so that the blue block is on top of/under the red block.*) or a new blue block (*Make it so that the red block is on top of/under the blue block*). The children were faster and more often correct in placing the new block when the relatum of the instruction was given than when it was new. Clark (1972) conducted a similar experiment with college students. They saw a given horizontal pink

line placed in the middle of a display and were asked to add a new blue line as instructed. Again, placements were faster and more often correct if the relatum was given (*Blue is higher than pink*) than if it was new (*Pink is lower than blue*). More recently, Oberauer and Wilhelm (2000) were able to demonstrate the advantage of the givenness of the relatum by using a picture verification task. Participants first read a single spatial relational assertion (e.g., *The triangle is to the right of the square*). Then one of the objects, relatum or referent, was pictured in the middle of the screen. With a 1,000 msec delay, the second object appeared on the screen at a position that either agreed or disagreed with the relative position asserted. Participants verified pictures faster when the relatum was presented first than when it was presented second, indicating that the relatum established the first search domain, as claimed by Miller and Johnson-Laird (1976).

We suggest that the advantage of a given relatum generalizes to premise integration in spatial reasoning and postulate that premise integration is easier with a given relatum (object anaphor) than with a new relatum (subject anaphor). We will call this the *relatum = given* principle, which is similar to, but not identical to end anchoring proposed by Huttenlocher (1968, p. 555) who claims that "it is easier to understand a premise that describes an end item as grammatical subject rather than grammatical object." If the end term of P2 is grammatical subject, its middle term—that is, the anaphor—is a prepositional object.[3] From Huttenlocher's appeal to the grammatical function of end terms, if restricted to P2, it follows that integration should be easier with an object anaphor (given relatum) than with a subject anaphor (new relatum). In the same way, however, end anchoring addresses the grammatical function of the end term of P1, predicting easier integration with an object antecedent than with a subject antecedent. No such prediction follows from relatum = given. In testing end anchoring with canonical premises, Huttenlocher actually found the predicted effect for P2 (anaphor), but not for P1 (antecedent).

Two Principles of Premise Integration in Spatial Reasoning

We propose two linguistically motivated principles of premise integration in spatial reasoning: (1) *relatum = given*, by which premise integration is easier with an object anaphor, and (2) *given–new*, by which premise integration is easier if the anaphor in P2 is mentioned first.

As is obvious from these formulations, a P2 with canonical word order always violates one of the two principles. A canonical P2 with a subject anaphor in its sentence initial position agrees with principle 2 (given–new) but violates principle 1 (relatum = given), since its relatum is new. A canonical P2 with an object anaphor (given relatum) agrees with principle 1 but violates principle 2, since the sentence-initial subject is new. Thus, canonical premise pairs, which so far have been exclusively used in experiments on spatial reasoning, cannot comply with both principles. This, we think, is responsible for some inconsistencies in the literature. Whereas Baguley and Payne (2000) speak of a new–given advantage in the domain of spatial reasoning, we think that in their experiment with English canonical premises the relatum = given principle has preponderated over the given–new principle. Along the same lines we interpret a finding reported by De Vooght and Vandierendonck (1998). They measured P2 comprehension times for canonical premise pairs with subject anaphors referring back to subject antecedents and object anaphors referring back to object antecedents (cf. Table 1 below). As in Baguley and Payne's study, premise integration was faster with object anaphors (given relatum) than with subject anaphors (new relatum). De Vooght and Vandierendonck, however, explain their results in terms of the antecedent. They argue that the relatum of P1 is focused in the initial mental model, which requires the focus to shift in case of a subject antecedent. This explanation, in turn, conflicts with the finding of Baguley and Payne, where object anaphors referring back to subject antecedents were easier to process than were subject anaphors referring back to object antecedents. It seems more convincing to us to explain both of these findings in terms of the anaphor.

The goal of our study is to disentangle the effects of the given–new principle and the relatum = given principle by utilizing the comparatively free word order in German. In order to establish the preferred given–new order, the constituent conveying the given information can be *topicalized*—namely, this constituent can be placed in sentence initial position. In a verb-second language with variable word order like German, such a constituent can simply be preposed. Given–new order of a P2 with an object anaphor is obtained by preposing its prepositional phrase:

Rechts von B_{given} *ist* C_{new}.
Right of *B* is *C*.
To the right of B_{given}, *there is* C_{new}.

The topicalized variant of a P2 with its given relatum preposed obeys both principles, relatum = given and given–new, and should be easiest to integrate. In contrast, a topicalized P2 with a preposed new relatum violates both principles and should be especially hard to integrate.

Basic Design and Two Main Hypotheses

In order to test the validity of the two principles of premise integration in spatial reasoning, we crossed three factors for the basic design (see Table 1): antecedent (subject or object), anaphor (subject or object), and word order (canonical or topicalized). As the dependent variable, we recorded comprehension times for P2 to measure the difficulty of premise integration.

Our first main hypothesis concerns principle (1), relatum = given, predicting a main effect of anaphor. Premise integration should be easier—that is, P2 should be read faster—with an object anaphor (given relatum) than with a subject anaphor (new relatum).

Our second main hypothesis addresses principle (2), given–new, predicting an interaction of anaphor and word order. Topicalized word order should yield a large effect of anaphor: Preposing a given relatum (object anaphor) complies with both principles, and preposing a new relatum (subject anaphor) violates both principles. Thus, topicalization should lead to short P2 comprehension times for object anaphors but to long P2 comprehension times for subject anaphors. Comprehension times for canonical P2s should be intermediate because one principle is always violated, while the other is obeyed. We expect that a violation of either relatum = given or given–new will lead to a comparable delay in P2 comprehension times relative to topicalized object anaphors because we found no difference for German canonical P2s in a previous experiment (Oberauer, Hörnig, Weidenfeld, & Wilhelm, in press).

Focusing in the Initial Mental Model

Our experiment also provides an opportunity to investigate other factors, that various authors have hypothesized to affect sentence integration, and that could operate in addition to or in place of the two principles we propose. It is a widely held assumption that anaphor assignment is affected by focusing in the mental model constructed from previous discourse (Garnham, 1987, 2001; Grosz, Joshi, & Weinstein, 1995). However, nominal anaphors—that is, definite descriptions—might not be sensitive enough to reliably identify the focused antecedent. Pronouns, which are more sensitive to the accessibility of their antecedents (cf. Sanford & Garrod, 1981), are the more convenient anaphoric expressions to test for focusing in the initial mental model. Therefore, we included pronominal as well as nominal anaphors in our material. We expect our two main hypotheses to apply to either of them. However, an impact of the antecedent could be limited to pronouns.

Antecedent accessibility could vary, depending on its position and/or grammatical function. As a functional hypothesis, we have mentioned De Vooght and Vandierendonck's (1998) assumption that the relatum is focused in the initial model. The opposite expectation derives from studies on assigning ambiguous pronouns, which are preferably assigned to subject antecedents (*subject assignment*; e.g., Crawley, Stevenson, & Kleinman, 1990), a preference explained by the higher accessibility of subjects, as compared with objects. An instance of a positional hypothesis is Gernsbacher's (1989; Gernsbacher & Hargreaves, 1988) principle of *first mention*. The probe verification paradigm used in her experiments revealed that antecedents were more accessible if mentioned first. With canonical word order, subject assignment and first mention both predict higher accessibility of the first mentioned subject. Their predictions diverge, however, for topicalized word order. Indeed, Gernsbacher and Hargreaves (Experiment 6) failed to observe a first mention advantage for topicalized sentences. The important point here is that all of the hypotheses considered thus far—functional or positional—might indicate focusing in the initial mental model. An assignment preference like *parallel function* differs crucially in this respect since the preferred assignment depends on the grammatical function of the anaphor. Parallel function states that an ambiguous pronoun is likely to be understood as assigned to the antecedent with the same grammatical function as itself (Sheldon, 1974; Smyth, 1994; Stevenson, Nelson, & Stenning, 1995).

There is as yet no evidence which of the hypotheses considered, if any, applies to premise integration in spatial reasoning. The predictions of the various approaches discussed are summarized in Table 2.

METHOD

Participants

Twenty-two undergraduate students at the University of Potsdam, 15 female and 7 male, between 17 and 30 years of age (*M*: 22.4), took part in the experiment. They fulfilled either course requirements or were paid 10 DM (about US $5). Data from 2 other participants were lost due to a technical error.

Table 2
Summary of Predicted Effects by Various Approaches for the Basic Design

	Predicted Effect(s)	Premise integration is easier with …
Premise Integration Approaches		
Focus shift (De Vooght & Vandierendonck, 1998)	antecedent	… object antecedent
New–Given (Baguley & Payne, 2000)	anaphor × word order	… canonical word order, object anaphor … topicalized word order, subject anaphor
End anchoring (Huttenlocher, 1968)	antecedent anaphor	… object antecedent … object anaphor
Relatum = Given	anaphor	… object anaphor
Given–New	anaphor × word order	… object anaphor if topicalized word order
(Pronominal) Anaphor Assignment Approaches		
Subject assignment	antecedent	… subject antecedent
First mention (Gernsbacher, 1989)	antecedent × word order	… canonical word order, subject antecedent … topicalized: object antecedent
Parallel function	anaphor × antecedent	… anaphor and antecedent of same grammatical function

Materials

One hundred twenty-eight 3-term items were constructed along the following lines. The three terms of an item named animals (e.g., snake, donkey, deer), fruits or vegetables (e.g., raspberry, apple, carrot), vehicles (e.g., van, carriage, bike), musical instruments (e.g., trumpet, piano, violin), or other common objects of everyday life (e.g., pipe, pencil, key). The two premises of half of the items had canonical word order; and the premises of the other half had topicalized word order. Care was taken to ensure that items of both word order conditions were equally distributed across object categories (e.g., animals). Half of the items of each word order condition described a determinate one-dimensional, linear arrangement; and the other half described a two-dimensional layout. Dimensionality of layouts was balanced because the principles of premise integration under investigation should apply regardless of whether a layout extends in one or two dimensions. Therefore, we used both kinds of layouts to make sure that the theoretically relevant findings are not specific to a particular kind of layout.

The layout of each item was held constant, whereas its description was varied with respect to antecedent (subject vs. object) and anaphor (subject vs. object), as well as type of anaphor (noun vs. pronoun), resulting in eight variants of each item (cf. Table 3). These item variants were assembled in eight different versions of the material such that each version consisted of eight items for each cell of the four-factorial experimental design of word order × anaphor × antecedent × type of anaphor (half of them describing a one-dimensional layout and the other half describing a two-dimensional layout). The pool of 128 items was grouped into four blocks of 32 items each, two blocks with nouns and two blocks with pronouns. Each block comprised four items from each of the eight conditions of the basic design, antecedent × anaphor × word order.

Nominal anaphors were definite descriptions with determiners marked for gender and case. Pronouns were marked for gender and case, too.[4] For the unambiguous assignment of pronouns, one of the two potential antecedents of P1 was marked for feminine gender, and the other one was marked for masculine or neuter gender. Relational expressions of P2—*rechts von* (right of), *links von* (left of), *über* (above), and *unter* (below)—were counterbalanced within conditions.

Procedure

The participants were tested individually on a PC. They were told that they would read descriptions of layouts of three pictures each, hanging on a wall either beneath each other, beside each other, or a combination thereof. The session began with four training trials, followed by the four test blocks. Block order was either noun–pronoun–noun–pronoun or the reverse. Items within each block were randomized for each participant. Blocks were separated by a display announcing the opportunity to pause. After the participants started a trial by pressing the space bar, the first premise appeared in the middle of the screen, centered on a single line. The participants were instructed to press the space bar as soon as they could imagine the layout described (P1 comprehension time). Then, P1 was replaced by P2, again in the middle of the screen, centered on a single line. The participants were told to press the space bar as soon as they could imagine the whole layout (P2 comprehension time). After pressing the space bar again, the participants were tested by a picture verification task as follows.[5] First, the object denoted by one of the end terms (the nonantecedent of P1, *A*, or the new element of P2, *C*) was pictured in the middle of the screen. After a delay of 1,000 msec, a picture of the object denoted by the other end term was added to the first picture. The relative position of the second picture was either valid with regard to the premise pair or invalid (*A* and *C* interchanged). For 1-D layouts, the distance (30 pixels) between the two pictures was too short to allow a third picture of the same size (120 × 120 pixels) to be place between them. The participants were explicitly told in advance that they should base their judgments on the relative positions of the pictured objects. By pressing the *yes* button or the *no* button, the participants judged whether the layout conformed to the description given by the two premises (valid layout) or not (invalid layout). The time from the onset of the second picture until the pressing of the button was measured as verification time. After judging the layout, a display announced that pressing the space bar would start the next trial.

Presentation sequence (*A* or *C* displayed first) was varied to assess whether *C–A* sequences were verified faster than *A–C* sequences. We expected a *C–A* advantage because in a previous experiment on linear layouts (Oberauer et al., in press) we had found that verbally presented conclusions could be reliably verified faster if the endterm *C* of P2 was mentioned before the endterm *A* of P1.

RESULTS

Speed of Premise Integration

Analysis is based on the natural logarithm of P2 comprehension times for trials in which the picture verification task was judged correctly. This was the case in 88% of all trials, ranging from 98% to 72% per participant. The log-transformation was conducted in order to achieve more normal distributions. Except where indicated otherwise, analyses of untransformed data yielded the same effects as did the analyses of log-transformed data. For each participant, comprehension times three standard deviations larger than their mean were classified as outliers and discarded from the analysis. After data were aggregated per participant per condition, no values were missing, and data of all 22 participants were entered into the four-factorial analysis. Mean values of aggregated untransformed and log-transformed data are shown in Table 4.

As predicted by relatum = given, there was a main effect of anaphor [$F(1,21) = 54.359$, $p < .001$, $\eta^2 = .721$]. P2s with object anaphors (given relatum; 4,425 msec; *ln*: 8.233) were read about 1,000 msec faster than P2s with subject anaphors (new relatum; 5,468 msec; *ln*: 8.436). Likewise, the interaction of anaphor and word order, as predicted by given–new, proved to be significant [$F(1,21) = 105.036$, $p < .001$, $\eta^2 = .833$; see Figure 1]. Canonical P2s with object anaphors (4,757 msec; *ln*: 8.315) were read only slightly faster than with subject anaphors [4,968 msec; *ln*: 8.339, $t(21) < 1$]. However, topicalized P2s with object anaphors accelerated comprehension substantially (4,093 msec; *ln*: 8.151), whereas topicalized P2s with subject anaphors (5,967 msec; *ln*: 8.533) led to a marked increase in comprehension times. On average, P2s with given–new order (4,531 msec) were read about 830 msec faster than were those with new–given order (5362 msec). Thus the results support both principles, relatum = given and given–new (see Figure 1).

The anaphor × word order interaction entered into a further significant three-way interaction with type of anaphor [$F(1,21) = 7.358$, $p = .013$, $\eta^2 = .259$], indicating that the given–new advantage was more pronounced with nouns than with pronouns (see Table 4; this three-way interaction was not reliable for untransformed data). No further effect emerged in this analysis.

In a separate analysis of log-transformed P1 comprehension times we examined the pure word order effect. Canonical P1s (5,384 msec; $ln = 8.557$) were read 260 msec faster than topicalized P1s (5,644 msec; $ln =$

Table 3
Two Examples (One With Canonical Word Order, One With Topicalized Word Order) of the Eight Variants of Original German Items

Premise 1	Premise 2 With [Noun]/[Pronoun]
Subject Antecedent	**Subject Anaphor**
Der Igel ist rechts von der Gemse.	[Der Igel]/[Er] ist links vom Frosch.
The$_{masc}$ hedgehog is to the right of the$_{fem}$ chamois.	[The$_{masc}$ hedgehog]/[It$_{masc}$] is to the left of the$_{masc}$ frog.
Object Antecedent	
Die Gemse ist links vom Igel.	
The$_{fem}$ chamois is to the left of the$_{masc}$ hedgehog.	
Subject Antecedent	**Object Anaphor**
Der Igel ist rechts von der Gemse.	Der Frosch ist rechts [vom Igel]/[von ihm].
The$_{masc}$ hedgehog is to the right of the$_{fem}$ chamois.	The$_{masc}$ frog is to the right of [the$_{masc}$ hedgehog]/[it$_{masc}$].
Object Antecedent	
Die Gemse ist links vom Igel.	
The$_{fem}$ chamois is to the left of the$_{masc}$ hedgehog.	
Subject Antecedent	**Subject Anaphor**
Rechts von der Schlange ist der Hirsch.	Links vom Esel ist [der Hirsch]/[er].
To the right of the$_{fem}$ snake is the$_{masc}$ deer.	To the left of the$_{masc}$ donkey is [the$_{masc}$ deer]/[it$_{masc}$].
Object Antecedent	
Links vom Hirsch ist die Schlange.	
To the left of the$_{masc}$ deer is the$_{fem}$ snake.	
Subject Antecedent	**Object Anaphor**
Rechts von der Schlange ist der Hirsch.	Rechts [vom Hirsch]/[von ihm] ist der Esel.
To the right of the$_{fem}$ snake is the$_{masc}$ deer.	To the right of [the$_{masc}$ deer]/[it$_{masc}$] is the$_{masc}$ donkey.
Object Antecedent	
Links vom Hirsch ist die Schlange.	
To the left of the$_{masc}$ deer is the$_{fem}$ snake.	

8.605), $F(1,21) = 7.660$, $p = .012$, $\eta^2 = .267$; see Figure 1).

Accuracy of Premise Integration

For each participant error rates were computed for each cell of the four-factorial design. Analysis of error rates exhibited a main effect of anaphor [$F(1,21) = 11.680$, $p = .003$, $\eta^2 = .357$]. Items with object anaphors (relatum = given) led to fewer errors (10%) than did subject anaphors (relatum = new; 14%). Errors reflected no given–new advantage, as shown by the absence of an interaction between anaphor and word order [$F(1,21) = 1.384$, $p = .253$, $\eta^2 = .062$].

A further main effect emerged for type of anaphor [$F(1,21) = 5.162$, $p = .034$, $\eta^2 = .197$]. Items with pronouns (10%) were judged erroneously less often than

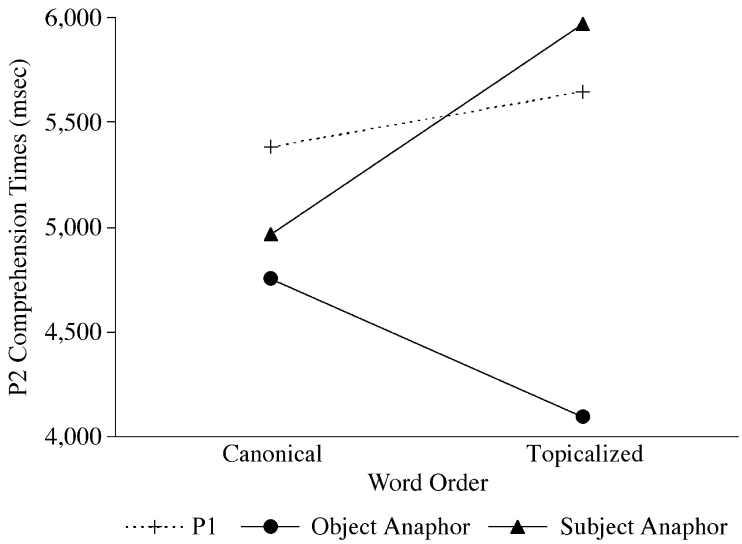

Figure 1: Mean untransformed comprehension times for first premise P1, second premise P2 with object anaphor (relatum = given), and second premise P2 with subject anaphor (relatum = new), as a function of word order.

Table 4
Mean Premise 2 Comprehension Times in Milliseconds (log-transformed data in parentheses) for Anaphor × Word Order, separately for Nominal and Pronominal Anaphors

	Word Order			
	Canonical		Topicalized	
Anaphor Type	Subject Anaphor	Object Anaphor	Subject Anaphor	Object Anaphor
Nouns	4,625 (8.288)	4,493 (8.290)	5,967 (8.552)	3.787 (8.084)
Pronouns	5,311 (8.389)	5,021 (8.340)	5,967 (8.514)	4,399 (8.218)

were items with nouns (14%). Moreover, type of anaphor entered into a three-way interaction with word order and antecedent [$F(1,21) = 4.597$, $p = .044$, $\eta^2 = .180$]. This interaction is due to a varying positional effect of antecedent, dependent on type of anaphor. When pronouns were assigned to the antecedent mentioned first in P1, participants made fewer errors (9%) than when pronouns were assigned to the antecedent mentioned second in P1 (12%), independent of its grammatical function. In contrast, when nouns were assigned to the antecedent mentioned first in P1, participants made more errors (15%) than when nouns were assigned to the antecedent mentioned second in P1 (12%).

Speed of Picture Verification

Analysis is based on the natural logarithm of verification latencies for correct responses (88%). For the four-factorial analysis, anaphor × word order × presentation sequence × validity, data were aggregated over antecedent and type of anaphor. Again, there was a relatum = given advantage [$F(1,21) = 6.194$, $p = .021$, $\eta^2 = .228$]. Object anaphors led to faster verification times (2,397 msec; $ln = 7.597$) than did subject anaphors (2,529 msec; $ln = 7.637$). Anaphor did not interact with word order ($F < 1$), indicating that verification did not speed up with given–new order of P2.

There was one further significant effect-namely, a main effect of validity [$F(1,21) = 6.016$, $p = .023$, $\eta^2 = .223$; not significant for untransformed data]. Verifications of valid arrangements took less time (2,339 msec; $ln = 7.571$) than did falsifications of invalid arrangements (2,587 msec; $ln = 7.663$).

The predicted *C–A* advantage was not confirmed by the analysis ($F < 1$).

DISCUSSION

Our results provide strong evidence for two principles of premise integration in spatial reasoning, relatum = given and given–new. According to relatum = given, premises are more easily integrated when the anaphor in P2 is its relatum (prepositional object) rather than its referent (grammatical subject). This was confirmed by shorter comprehension times for P2s with a given relatum (object anaphor) than with a new one (subject anaphor). P2s with a given relatum even enhanced performance in the subsequent picture verification task, in which judgments were more often correct and were given faster. Hence, relatum = given improved performance in three ways: it speeded up model construction, led to more reliable models, and, on the basis of such models, judgment of pictures was faster. In addition, there was an advantage for P2 reading times when the anaphor was in the first position, thus complying with the given–new principle. The two effects could be disentangled by contrasting topicalized with canonical sentences.

The relatum = given principle has been derived from the conception of linguistic localization (Miller & Johnson-Laird, 1976). Linguistically localizing an object—communicating its location—is achieved by narrowing the search domain by relating its location to that of an object already known to the hearer/reader. This, in turn, demonstrates that premises in spatial reasoning are understood as acts of linguistic localizations—that is, P2 is intended to tell the reasoner how to place the new object relative to the known place of an object that is already part of the current mental model. That is why we have observed the same relatum = given advantage as was found previously for placement instructions by Huttenlocher and Strauss (1968) and by Clark (1972). This conception of premise integration fits nicely with the mental model theory as a framework for both language comprehension and reasoning (Johnson-Laird, 1983), although other theoretical frameworks might also be compatible with the principles of premise integration that we identified.

The close connection of premise integration with language comprehension has been shown further by the impact of the second principle, given–new, a derivative of Clark and Haviland's (1977) given–new strategy. Premises are integrated faster when the given information (the anaphor) is mentioned before the new element *C* is introduced in P2. Previous failures to demonstrate a given–new advantage in integrating spatial premises (Baguley & Payne, 2000; Ehrlich & Johnson-Laird, 1982) can be explained by the exclusive use of premises with canonical word order in these studies. Canonical premise pairs obeying given–new always violate relatum = given, and vice versa. In our present experiment, as well as in a previous one (Oberauer et al., in press), P2 comprehension times were about the same for both kinds of canonical premises; thus, violation of either principle delayed premise integration to a comparable degree. This might not generalize to other languages, however. Canonical premise pairs were found to be integrated faster with a given relatum (but new–given order) than with given–new order (but a new relatum), as reported by De Vooght and Vandierendonck (1998) for Dutch and by Baguley and Payne (2000) for English. We attribute both of these findings to a relatum = given advantage outweighing the new–given disadvantage. This interpretation is substantiated by the interaction of anaphor and word order if the

two principles are teased apart by a variation of word order (canonical vs. topicalized). Premise integration is easiest when a given relatum is preposed, but it is rendered most difficult by preposing a new relatum.

Consistent with Clark and Haviland (1977), we hypothesize that a preposed given relatum promotes premise integration by allowing the hearer/reader to initiate integration immediately once the given relatum has been read in. If model construction starts in general by placing the relatum first in the model, in order to then place the referent relative to it, one would expect the initial mental model to be easier to construct from a topicalized P1 in which the relatum is mentioned first. The opposite was observed—namely, initial model construction was easier with a canonical P1 than with a topicalized P1. The benefit of a preposed relatum thus is restricted to premise integration—that is, to extending an initial model of a layout.

We have offered a common explanation of the findings by De Vooght and Vandierendonck (1998) and Baguley and Payne (2000). This, however, does not rule out that De Vooght and Vandierendonck are right in claiming that focusing in the initial model from P1 contributes to ease of premise integration. In order to enhance the probability of detecting a possible focusing effect on premise integration, we have examined pronominal anaphors in addition to nominal anaphors, since pronouns are expected to be more sensitive to focusing effects. P2 comprehension times, however, did not reveal an influence of the antecedent on the ease of premise integration. P2 comprehension times differed neither as a function of the position of the antecedent in P1, nor as a function of its grammatical role. The position of the antecedent did affect accuracy, however, in a different way for nouns and pronouns. With pronominal anaphors, participants made fewer errors if the anaphor was assigned to the first element of P1, while with nominal anaphors, they made fewer errors if the anaphor was assigned to the second element of P1. This pattern is consistent with the idea that the first element of P1 is likely to be its topic and that P2 might either continue P1's topic or perform a topic shift. A central claim of centering theory (Gordon, Grosz, & Gilliom, 1993; Grosz, Joshi, & Weinstein, 1995) roughly states that topic continuity is best realized by a pronoun, whereas a noun might support topic shift. This explanation would, in turn, suggest that our results are in accordance with Gernsbacher's (1989; Gernsbacher & Hargreaves, 1988) advantage of first mention—namely, that the element mentioned first in P1 is indeed more accessible than the second one. On this account, it would be more suitable to access the less accessible second element by means of a more explicit linguistic device such as a nominal anaphor. In order to pursue such an interpretation, however, it would be more convincing if P2 comprehension times had exhibited an analogous pattern, which was not the case.

In a previous experiment (Oberauer et al., in press) with conclusions in verbal form, we had found a *C–A* advantage—that is, verbalized conclusions could be verified faster if the end term *C* of P2 was mentioned before the end term *A* of P1. Such a *C–A* advantage was not observed for picture verification in the present experiment. Verification latencies were the same, regardless of whether the picture denoting the end term *C* of P2 was presented 1,000 msec before the picture denoting the end term *A* of P1 or the other way around. Since the interval between the onsets of the two pictures was not varied, it is possible that the chosen interval of 1,000 msec was not appropriate to detect a *C–A* advantage in this task.

To conclude, it has been fruitful to examine reasoning processes in the spatial domain, of which premise integration is a crucial task, from the perspective of language comprehension. We have obtained convincing evidence in favor of two linguistically motivated principles that are crucial for premise integration in spatial reasoning: relatum = given and given–new. Our results are consistent with mental model theory, which was intended as a theoretical framework of both language comprehension and reasoning (cf. Garnham, 1996). We hope that our work contributes to provoking new insights by integrating given knowledge in both research areas.

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NOTES

1. In this article, we will consider only determinate descriptions that permit the inference of an unstated relation.

2. Chafe's (1970, p. 218) given–new analysis of the single canonical sentence *The box is under the table* is especially pertinent in the present context, according to which the grammatical subject is given and the prepositional phrase conveys new information.

3. Whereas the middle term *B* forms part of both premises, end terms are mentioned only in one of the premises, P1 (nonantecedent *A*) or P2 (new element *C*).

4. Subject determiners are *der* (masc./nom.), *die* (fem./nom.), and *das* (neut./nom.), object determiners are *dem* (masc./dat. or neut./dat.) and *der* (fem./dat.). Subject pronouns are *er* (masc./nom.), *sie* (fem./nom.), and *es* (neut./nom.), object pronouns are *ihm* (masc./dat. or neut./dat.) and *ihr* (fem./dat.). There is a peculiarity concerning the German preposition *von* (*of*), which is—as in English—part of the construction with *links* (*left*) and *rechts* (*right*), but not with *über* (*above*) and *unter* (*below*). The preposition *von* and the masc./neut. determiner *dem* usually collapse into the single form *vom*, the form that we used in our material.

5. The pictures used as stimulus material in the picture verification task were taken from a commercial sampler of drawings (Grüneisl & Zacharias, 1981). These black-and-white drawings were scanned and transformed to a 120 × 120-pixels PCX format.

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